CONSERVATION AND ADAPTATION IN BRITISH COLUMBIA: STRATEGIC OPPORTUNITIES IN A CLIMATE CHANGING WORLD

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EXECUTIVE SUMMARY

British Columbia is touted to the world as being 'super natural'.

But is this true everywhere in the province?

Where and what are the options to maintain B.C.'s incredible natural history for the future?

How will climate change affect what we value today?

Where are the risks and opportunities?

This report aims to examine some of the largest questions facing the natural environment in B.C. We examine how the ecological values of this province vary and at how the current human footprint overlays across ecological values. We also look at potential climate change futures, and how climate may alter the ecosystems that exist here today. Finally, we look at carbon conservation, undertaking the first steps to understand the great stores of carbon we have in B.C..

Each of these pieces provide insight into possible options for the province moving forward. Understanding patterns of development today, in combination with future pressures, provide key information to guide conservation and land management decision making, and to help identify opportunities for B.C. to contribute to global mitigation of climate change through carbon management. This project both creates a solid foundation for setting strategic direction for land management, and identifies where additional work is needed to support tactical decisions regarding conservation needs for British Columbia.

APPROACH

In order to examine these patterns, we create four thematic map layers of information for the province:

- Ecological Proxy: a coarse assessment of the ecological values present in B.C.;
- Human Footprint: a coarse assessment of past and current footprint development patterns;
- Climate Change and Ecosystems: describes one potential climate future for B.C.;
- Biological Carbon: a preliminary look at where carbon is stored in B.C. ecosystems today.

The first two maps – ecological proxy and human footprint – are to be considered together. As single layers, they provide only part of the story of the values and condition of B.C.'s ecosystems. Together, they provide a picture of natural and human caused patterns across huge landscapes – identifying where broad ecological values remain, and the potential risks associated with existing patterns of cumulative industrial development.

Together these maps show that there are significant areas of B.C. where the human footprint is low, and the ecological values remain intact and functional. The north and northwest, the major coastal and interior mountain ranges, and the mainland coast are key areas that are largely in good condition. Conversely, there are significant areas with an intensive and/or extensive human footprint that has already significantly affected the ecological values present; these areas include the whole central and southern interior of the province, the southern coast and Vancouver Island, the north east of the province, and more localized areas within the mountain ranges such as the Rocky Mountain Trench. Within these two general patterns there is significant local variability – key areas that remain of high value in otherwise degraded landscapes, and conversely, new and increasing human modification in largely pristine landscapes. Opportunities, risk and urgency for conservation and adaptation actions vary in these different locales.

The third series of maps examines one of many possible future scenarios associated with climate change. This example of what a single future scenario[1] may mean for the climates associated with different ecosystems in B.C. gives us an overview of the scope and scale of the types of ecosystem changes that may well be heading our way. The scenario presented in this report is relatively conservative about future greenhouse gas emissions (globally we are currently exceeding the assumptions embedded in that scenario), however the extent of projected changes to B.C.'s ecosystems is sobering.

Perhaps the most dramatic prediction in this scenario is the huge (95,000 km^2) in both absolute and relative terms projected increase of areas with climate more suited to grow grasses and shrubs (grassland 'climate envelopes) rather than the forests that grow there now. Nowhere in the province is predicted to lose grassland or coastal dry low elevation climate envelopes: these systems are projected only to increase. Conversely, boreal systems aren't created anywhere in this scenario, but are almost completely lost from their existing locations. All the other climate envelopes are both lost from existing locations and gained elsewhere, with a significant increase in the driest ecosystems and a tendency for a reduction of the wetter systems.

The analysis presented in this report reflects the climate 'envelopes' – (such as combinations of moisture and temperature)-- that support B.C.'s ecosystems currently. But species and ecosystems will not just shift positions. In fact, it is not expected that individual species will be capable of 'migrating' fast enough to keep apace of the rate of climate change, and it is clear that individual species will be highly variable in terms of their ability to adapt (Hamann and Aitkin 2013). Unfortunately the species most likely to move or adapt quickly are weedy species. For example, the grasslands projected to 'move' up through the centre of the province are will likely be low in native grassland diversity and dominated by invasive species such as knapweeds. We therefore expect that existing ecosystems will disassemble and reassemble in significantly different forms, depending upon the responses of the individual species. For example, increasing rates of individual tree mortality have been observed globally and locally (Allen et al. 2010; Van Mantgem 2009; Utzig and Holt 2011); a trend expected to increase as the effects of climate change are increasingly felt. Individual tree mortality combined with natural disturbances will be the key mechanisms for changes in local ecosystems.

Although exact details about the future are unknown, the one certainty is that the future will not be similar to the past in terms of climate. Since ecosystems respond directly to climate, we can be sure that ecosystems themselves will also change. Information on climate change has the capacity to corroborate or change the current wisdom on where and what conservation actions are needed.

The fourth series of maps examines the subject of static carbon in B.C.'s ecosystems: that is, the carbon currently held both in the above-ground and below-ground biomass. Carbon management is becoming a key economic feature in B.C. and around the world, and is likely to become only more important as the true effects of climate change are felt worldwide. Surprisingly, a carbon map of B.C. did not appear to exist prior to this project, and in these maps we examine what data are readily available and what actions are needed to feed important information on carbon into decision-making in the future.

IN SUMMARY

[1] Predictions of future climates vary with a) the specific models used and b) the specific 'scenario' about what future greenhouse gas release will be.

The results from each map are discussed in the report at the provincial scale, but in addition, each ecoprovince is discussed individually (see main report). Here are a number of key learnings arising from those summaries:

Large areas with high ecological proxy values and low human footprint are globally rare, and support globally rare ecological values in B.C.. They also present relatively low cost opportunities for conservation action today;

- Within each ecoprovince, larger areas with high remaining ecological proxy scores may be particularly important to maintain into the future. More local scale work is needed to identify such important remaining area of habitat, and undertake conservation adaptation planning, but this report identifies the distribution of potential starting places for investigation, with potential identification of core areas;
- Areas with overall low average footprint are often interspersed with relatively focused moderate or high human footprint. Although small in area, these are often critical geographic locations, including low elevation valleys on the coast, significant physical corridors between or through mountain ranges, confluences of river systems, and so forth. Here, small areas of highly functional habitat can be compromised by a relatively focused footprint. Identifying key areas to both mitigate existing impacts and to plan ahead to avoid future impacts to functionally critical areas for adaptation should be a priority across B.C., but particularly in areas with rapid development footprints.
- Overall, regions with relatively low footprints represent opportunities for relatively low cost conservation / adaptation opportunities to maintain significant ecological values into the future.
- These maps consider only the existing footprint, and in parts of the province (e.g. the northwest) the rate of increase in industrial footprint is dramatic. In areas with a high rate of change, areas with the highest ecological values, as well as critical areas for habitat and movement, must be maintained as new development projects are planned.

Conversely, significant areas of the province have a moderate or high footprint today. These are primarily areas on Vancouver Island, in the north east of the province, and large parts of the Central Interior and Southern Interior. Within these areas:

- Areas with higher remaining ecological proxy values are likely of particular significance for protection today in order to maintain existing ecological values.
- Areas with low ecological proxy values have likely already been impacted, and restoration of key areas should be paramount. In both the south/central and north east of the province, consideration of future climate change trajectories will be particularly key to determining appropriate restoration strategies.
- Such large areas with extensive cumulative footprint point to the urgent need for developing effective cumulative impact assessment and management in determining resource development policies.
- Areas with concentrated high footprint represent a significant threat to functional ecosystems overall in the region. Urgent development of policies to mitigate these threats should be undertaken.

	ECOLOGICAL PROXY LOW	ECOLOGICAL PROXY MEDIUM	ECOLOGICAL PROXY HIGH
FOOTPRINT LOW	**Risk / Urgency** – lower **Opportunity** – high **Priority** – cumulative effects management needed now.	**Risk / Urgency**– lower **Opportunity** – high **Priority** – cumulative effects management needed now.	**Risk / Urgency**– moderate **Opportunity** – high **Priority** – planning and action needed to maintain options. Local analysis required.
FOOTPRINT MEDIUM			**Risk / Urgency**– high **Opportunity** – more limited **Priority** – planning and action to mitigate / to maintain options
FOOTPRINT HIGH	**Risk / Urgency**– high **Opportunity** – limited **Priority** – action to mitigate / to maintain options	**Risk / Urgency**– high **Opportunity** – limited **Priority** – urgent action to mitigate / to maintain options	**Risk / Urgency**– highest **Opportunity** – limited **Priority** – urgent action to restore and limited maintain options

EFFECTIVE ACTIONS?

The results from this report can be used as a decision-support tool to understand the nature of the state of BC. But what types of actions are feasible moving forward? The next section summarises what we know about effective conservation actions.

Our knowledge on how to engage in robust long-term land management is deep and wide. However, our application of the principles can sometimes be weak or inefficient. In order to have a good chance of maintaining ecological integrity into the future, key principles include:

Effective Protected Areas: To be effective, protected areas, or areas managed primarily for conservation, should be of sufficient size, well placed, and representative of the range of ecosystem types. Around 15% of B.C.'s land base is protected in parks and reserves, with a high variability by ecoprovince and by biogeoclimatic zone. Recent conservation advice suggests that around 50% of the landscape should be in large well placed areas managed primarily for conservation in order to provide sufficient core area to maintain most species and functions across the landscape (Noss et al. 2012; Environment Canada 2013). Typically, politically-driven conservation targets and outcomes are much lower than this level (Svancara 2005).

Create or Maintain Viable Linkage Corridors Between Protected Core Areas: Allowing species to move between core habitat areas has been considered key to maintain genetic diversity and functional systems for many years. Even without climate change, it has been recognized that protected areas on their own are generally insufficient to maintain robust populations of most species.

Maintain or Restore Critical Habitat: At smaller scales than protected core areas, rare habitat types and habitats critical to maintaining populations in the long term should be maintained and/or restored. These act as critical habitat for non-mobile species and stepping-stones for mobile ones.

Maintain Functions Everywhere Else: Manage the remaining land base to ensure critical habitat elements and key functions are maintained at all scales, (i.e. across landscapes and stands). This includes maintaining adequate levels of habitat to result in low risk to ecological integrity, maintaining natural hydrologic patterns, and maintaining landscape connectivity for the wide range of species large and small.

Plan Ahead Without Blinders on: Ensure that individual human activities do not exacerbate one another and together impact critical habitats and functions. Cumulative effects analysis must be used to ensure adequate planning in advance of development.

Climate change brings with it some of the most fundamental changes possible for ecosystems. At the most basic level, changes in seasonal temperatures and moisture levels will fundamentally change the species that can and will inhabit individual places in the province, resulting in cascades of further change. Dynamics between species will change. At the local scale, some populations will increase and others will decrease. The natural disturbance regimes that maintain and change systems will also change, in some areas significantly. For example, fires may be more frequent and severe as temperatures increase. Resetting an existing system to a new ecosystem may involve moving through a period of intense disturbance while fuel levels and fire regimes re-align with one another. The building blocks of good conservation planning as outlined above remain unchanged, but climate change adds urgency to:

Review Goals: Adjust land management goals to focus on maintaining ecosystem services over the long term. The landscape level overview, combined with information about climate change, causes us to change how we consider planning and management. Adopting a broad goal that prioritizes maintaining ecosystems and ecosystem services will provide the most likely opportunity for natural systems to adapt (Seppala et al. 2009).

Modify and Increase the Area of Protected Areas: As ecosystems disassemble and reassemble, having sufficient area that is largely free from the stresses of the human footprint and representative of the fundamental building blocks of ecosystems (termed 'enduring features or land facets' (for example Anderson et al. 2010; Beier et al.2010) is important. This type of analysis has occurred in limited areas of the province to date (Y2Y 2012) and should be expanded. The area management for conservation should also be increased in line with levels likely to be effective, something on the order of 50% of the landscape (Noss et al. 2012).

Consider the Future State of Ecosystems: Examine the trajectories for future ecosystems, under a range of models and scenarios (Millar et al. 2007; Chapin et al. 2009; www.resiliencealliance.org). Based on the predictions of what may occur in the future, and their level of certainty, assess whether the goal of management for a given ecosystem is to:

a) **Manage for resistance** that involves maintaining the current structure and function; an example of this may be important old growth that moderates its own climate and has a reliable water source into the future;

b) **Manage for resilience** such as reducing fire risk in a forested ecosystem where fuel loadings are high, but also 'bet hedge' by maintaining appropriate species and structure throughout the zone; or

c) **Manage for transition** in areas with high agreement that significant and potentially catastrophic disturbance and change is likely, such as from forested to open forest or grassland; here appropriate species can be introduced, fuel loadings can be significantly reduced etc.

Connect Landscapes: Understand that climate change isn't a simple 'moving north' story. The changes are complex, and will occur in all directions and at multiple scales – moving up mountains, through valleys, through mountain ranges, across plateaus, and so on. Very large areas with little gradient will be particularly difficult to manage for conservation (e.g. across the south and central interior), and this difficulty will be further exacerbated by the human footprint. There is an urgent need to get strategies in place today to prevent existing connectivity from being eroded, and to restore connectivity where it is already curtailed.

In Summary: B.C. has a huge global responsibility for a wide diversity of biodiversity values, and we know these values are under threat globally. B.C. also have a lot to gain in planning ahead, including finding new ways to extract economic value from our forests and natural wealth in a way that strengthens our provincial economic base and business opportunities for the future.

MOVING FORWARD

Seize Existing Opportunities: B.C. has a significant opportunity to become a leader in climate change adaptation. Regional analysis should be undertaken to ensure that opportunities to retain ecological integrity are identified. The strategic level analysis provided here can kick start this process – but local data should be used to identify a) easy wins where values remain and opportunity costs are low, b) areas where careful cumulative effects planning is needed to avoid reducing adaptation potential and c) critical areas where protection or restoration is needed urgently.

Understanding the Trade-offs: It is widely acknowledged that maintaining fully functioning systems is the most effective approach to managing for the long-term, yet land management policies tend to shy away from this goal. Climate change brings new dimension and urgency to this short-term trade-off. Embracing management strategies that prioritize maintenance of ecological integrity are most likely to be efficient in maintaining the full range of goods and services in the long-term.

Carbon – the dollar of the future: managing carbon will become paramount in our lifetimes. Yet most economies have only just started to graze the surface of what this might mean. With its good start, B.C. has significant opportunity to reduce carbon emissions through land use policy. Building on existing work to more fully understand the stocks and dynamics of carbon in different ecosystems is needed to bring opportunities to realization.

Consider Species – and not just trees: individual species will vary significantly with respect to their vulnerability to climate change. Significant efforts are needed to attempt to understand this variable vulnerability, and to identify foundation and keystone species that warrant particular focus. This will vary regionally in this vast province, but is a key step needed in prioritizing conservation actions.

Comprehensive Cumulative Effects Management: Development occurs faster than conservation. Effective planning that focuses on cumulative effects management is crucial if B.C. is to have any hope of maintaining its existing biodiversity values and opportunities. Climate change is also outpacing conservation actions, further increasing the urgent need for active management of B.C.'s landscapes to ensure effective adaptation.

INTRODUCTION

The need for conservation management of global biodiversity has never been greater. The human footprint has become more extensive and diversified at an ever-expanding rate, with direct impacts on nature. Climate change adds a new twist to the land management story – species will need to “adapt” to climate change if they are to survive, and there is also an urgent need to manage carbon directly in order to “mitigate”, the effects of climate change. Land managers must now consider how management strategies can be most effective to promote both adaptation and mitigation in order to maintain as much biodiversity as is feasible – the most effective way to maintain ecosystem goods and services into the future.

British Columbia’s vast extent, relatively small human population, and seemingly endless green valleys might give the impression that we don’t need to worry about these issues, and the land will adapt and take care of itself. The work in this report takes a step back and examines these assumptions.

- Where are human activities creating the greatest pressures on British Columbia’s ecosystems?
- Are there areas of the province with a relatively greater need for conservation?
- What may climate change bring to this vast landscape?
- Where are the opportunities and the risks moving forward?

This report takes a ‘big picture’ approach and looks at the entire 95 million hectares of B.C., a vast area three times the size of Germany. We don’t look at specific locations but aim instead to examine province-wide patterns of change on the landscape. Understanding patterns helps to set conservation and management priorities. This project both creates a solid foundation for setting strategic direction for management, and identifies where additional work is needed to support tactical decisions regarding conservation needs for British Columbia.

This public summary of results is supported by a technical background document (Appendix 1) that provides detailed information on map layers, data, interpretation, and cautions.

WHAT DID WE LOOK AT?

We created four thematic map layers of information for the province:

- Ecological Proxy: a coarse assessment of the ecological values present in B.C.;
- Human Footprint: a coarse assessment of past and current development patterns;
- Climate Change and Ecosystems: describes one potential climate future for B.C.;
- Biological Carbon: a preliminary look at where carbon is stored in B.C. ecosystems today.

The first two maps – ecological proxy and human footprint – are to be considered together. As single layers, they provide only part of the story of the values and condition of B.C.’s ecosystems. Together, they provide a picture of natural and human caused patterns across huge landscapes – identifying where broad ecological values remain, and identifying the potential risks associated with existing patterns of cumulative industrial development. Together the two maps give us some insight into what has already happened to ecosystem values as a result of the human footprint, and also identify how priorities for conservation actions may differ as a result of the current industrial footprint.

The third series of maps examines one of many possible future scenarios associated with climate change. The field of climate change research, monitoring and understanding is fast moving, full of dense information and details.

This example of what a single "future scenario[2]" may mean for the climates associated with different ecosystems in B.C. gives us an overview of the scope and scale of the types of changes that may well be heading our way. Although exact details about the future are unknown, the one piece of information that is certain is that the future will not be similar to the past in terms of climate. Since ecosystems respond directly to climate, we can be sure that ecosystems themselves will also change. Information on climate change has the capacity to corroborate or change the current wisdom on where and what conservation actions are needed. We will discuss how currently available information may be used to assess the efficacy of conservation actions today.

The fourth series of maps examines the subject of static carbon in B.C.'s ecosystems: that is, the carbon currently held both in the above-ground and below-ground biomass. Carbon management is becoming a key economic feature in B.C. and around the world, and is likely to become only more important as the true effects of climate change are felt worldwide. Surprisingly, a carbon map of B.C. did not appear to exist prior to this project, and in this new map we examine what data are readily available and what needs to happen to use this type of information to feed into decision-making in the future.

Because B.C. is so large, we present the results from this work at two levels. First, we take a provincial perspective, looking at broad patterns and trends. Second, we briefly summarize each of B.C.'s nine ecoprovinces in isolation. Ecoprovinces are a useful way of looking at areas with different natural characteristics and features and help us look more closely at some of the patterns seen for B.C..

WHAT DID WE LEARN?

ECOLOGICAL VALUES

B.C. has extremely high natural biodiversity – from mountains to grasslands, and salmon stocks to ancient forest ecosystems. We did not attempt to map this incredible array of values – data availability and the inherent complexity of biodiversity itself precludes that. However, we did want to look for patterns in terms of where existing biological values may have some bearing on key areas in relation to conservation opportunities or climate adaptation into the future. We are limited by data availability but our Ecological Proxy map illustrates broad patterns across the province in terms of the general diversity of key ecological values present. In some areas it also reflects the current condition of those values.

The Ecological Proxy map is aimed at representing 'coarse filter' or 'special' ecological values, with a focus on those values that may be particularly important in terms of climate change adaptation. To that end, the map includes a range of types of information: terrestrial ecosystems (older forests, grasslands); hydrologic/aquatic habitats and linkages (rivers/lakes/wetlands); mapped 'very rich' areas (Important Bird Areas, estuaries), and locations of rare ecosystems and species (in an attempt to reflect 'at risk' genetic diversity in the province). This is not a biodiversity, or "hot-spots" map, and it is not intended to identify specific areas for conservation actions. On its own, the theme is useful to understand where there are more or fewer of the values that may reflect broad ecological values. In particular it may be useful when looking at opportunities to maintain core habitat and also in identifying areas that promote resilience to the diversity of external stressors caused by the human footprint. Each individual hectare of the province is given a score based on presence of any of these listed values, with higher scores given for single higher value components or multiple lower value components. Looking at the province as a whole, large areas with higher/multiple scores have a different type of biodiversity compared to areas with patchy or fragmented higher scores, and are different again from areas with generally occurring lower scores.

[2] Defined by a prediction of what the future level of CO2 in the atmosphere will be.

The name of this map – Ecological Proxy – reminds the reader that the map does not attempt to reflect all aspects of biodiversity or ecological value for each and every hectare of B.C.. Data are sparse and variable, and a true biological diversity map would be very hard to construct. Instead the values included in this map largely represent habitat types that have particularly high value as the 'coarse filter', since they tend to contain high value ecosystem components. For example, old-growth forests and grasslands that are in a reasonable condition indicate high diversity and also tend to be the components of terrestrial ecosystems that are at risk from development. Major rivers, lakes (>5ha), and wetlands are the foundation of aquatic ecosystems, linking systems together and providing habitat for aquatic and terrestrial species. They are also the foundation for water, nutrient and energy movement – the lifeblood for all biological systems. No mapping is available to allow us to highlight those rivers, lakes and wetlands in best condition today, so we included them all in this layer. Intact predator/prey systems are globally rare and reflect functioning ecosystems. Estuaries and Important Bird Areas are localized but extremely high value habitats, often occurring at the interface between many different ecosystems, and responsible for maintaining large abundances and also numbers of populations, and facilitating species movement. Finally, locations of rare and endangered species and ecosystems provide generalized point source information on areas of concern with respect to maintaining this aspect of the genetic diversity of B.C.'s species. In total, the values on this map reflect areas likely to be important as core habitats today, and these building blocks of functional ecosystems are also likely to be of critical importance in climate change adaptation, since maintaining functioning systems, processes and promoting natural adaptation is likely the most effective strategy moving forward.

The map of ecological proxy reflects a cumulative series of values and provides a lens to look at different values in different parts of the province, but cannot automatically be used to compare different areas of the province in terms of their ecological importance. For example, some areas are naturally more diverse than others, but can have equal inherent ecological value. The mapping can be used primarily to understand the variety of ecological features present in a broad region, and to focus in within ecologically similar regions to understand where ecological complexity or condition may be higher within an otherwise relatively homogeneous ecological region.

Looking at the province as a whole, three areas stand out as showing larger contiguous areas with the highest scores for the ecological proxy measure.

- The areas within the mainland temperate coastal rainforest and in areas of the leeward side of the mountains in the Central Interior have extensive areas of mature and old-growth forests, wetlands, large and small river systems, Important Bird Areas and estuaries.
- The Boreal and Taiga Plains are completely different ecosystems to those on the coast but also have extensive areas of wetland complexes set amongst older, often small-statured forest ecosystems.
- The Rocky Mountains in the Southern Interior Mountains ecoprovince is a landscape of moderate scores for ecological proxy, but contains smaller areas that received the highest score province-wide.
- Conversely, the middle of the province, between the major mountain ranges, tends to have lower scores for ecological proxy: in the north the ecology is much simpler and the diversity of habitat types is more limited than elsewhere in the province, and in the south the former extent of habitats has been altered by human footprint.

Although the data used is generally province-wide, there are a few notable exceptions: for example, for Tree Farm Licenses where data on forest cover are not publicly available. This is particularly evident in areas such as Haida Gwaii and for the Clayoquot Sound region of Vancouver Island.

Map 1. Ecological Proxy map of British Columbia See legend for details. Note the lack of data for Haida Gwaii and parts of Vancouver Island, giving the impression of lower values.

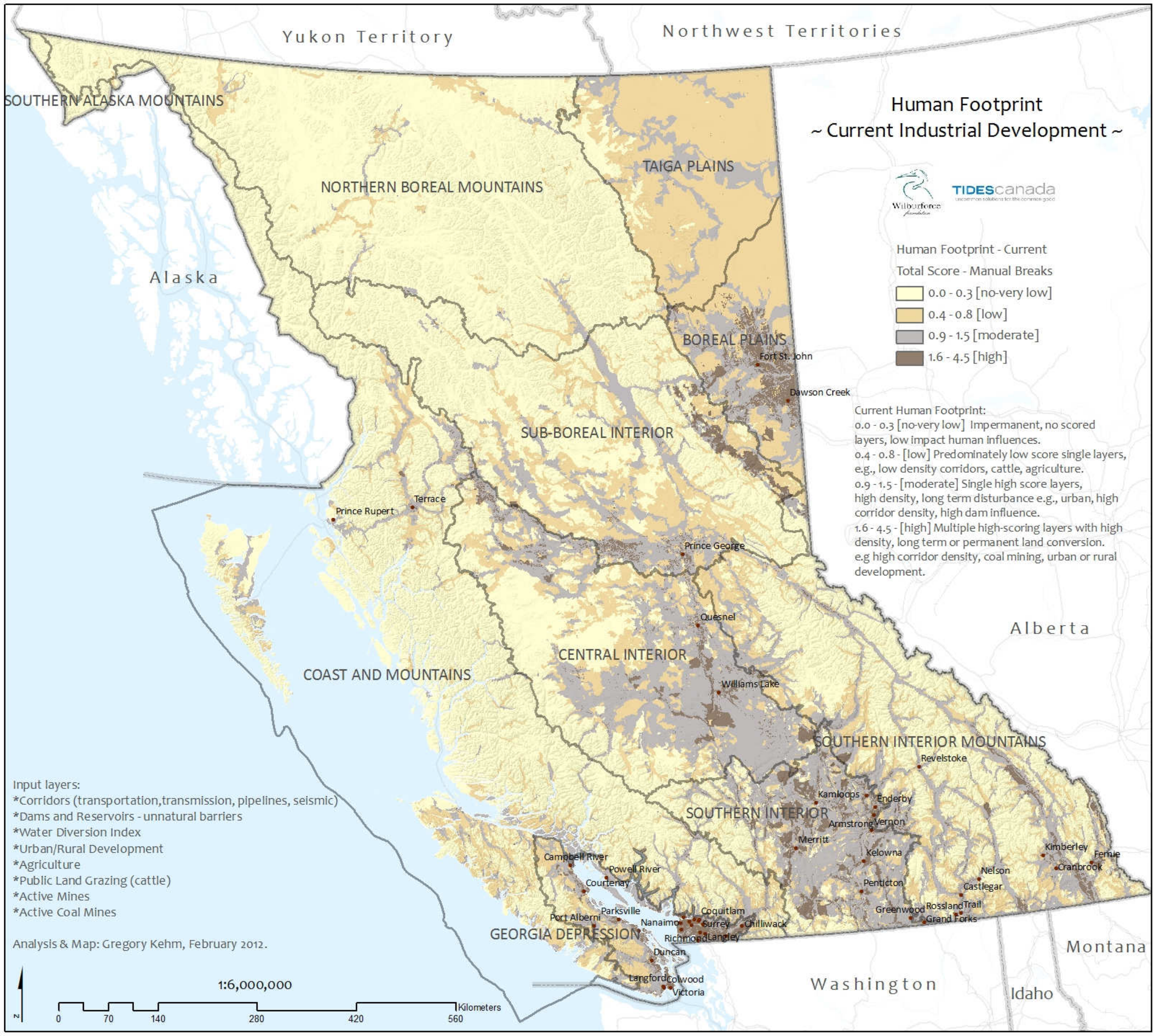
THE INDUSTRUAL HUMAN FOOTPRINT

Map 2 shows the cumulative human footprint for the province. Key activities known to affect functioning of ecosystems are included in the map (see Map 2 legend, and Appendix for full details), and includes roads and corridors, land use change (agriculture, urban / rural development), mines and water diversion. Provincially the patterns of existing development are highly variable, with particular types of footprint occurring in different areas, with differing intensities and focused on different ecosystems.

Some ecoprovinces reflect a generally low human footprint development pattern, in particular the Coast and Mountains, the Northern Boreal Mountains, and parts of the Southern Interior Mountains. On the Pacific coast however there is significant variability. The Lower Mainland has significant urban development with little functional ecosystem remaining in the urbanized core. Similarly, the few major valleys through the southern Coast Mountains (e.g. around Whistler) and also on Vancouver Island have significant areas of both urban and rural development and industrial forestry activity. Much of the remainder of the coastal temperate rainforest has a localized footprint consisting primarily of forest management roads and harvesting primarily in lower elevation valleys and areas with lower relief, leaving many higher elevation or very remote areas with little or no industrial footprint. The Northern Boreal Mountains and parts of the Southern Interior Mountains also have a low and relatively impermanent human footprint today.

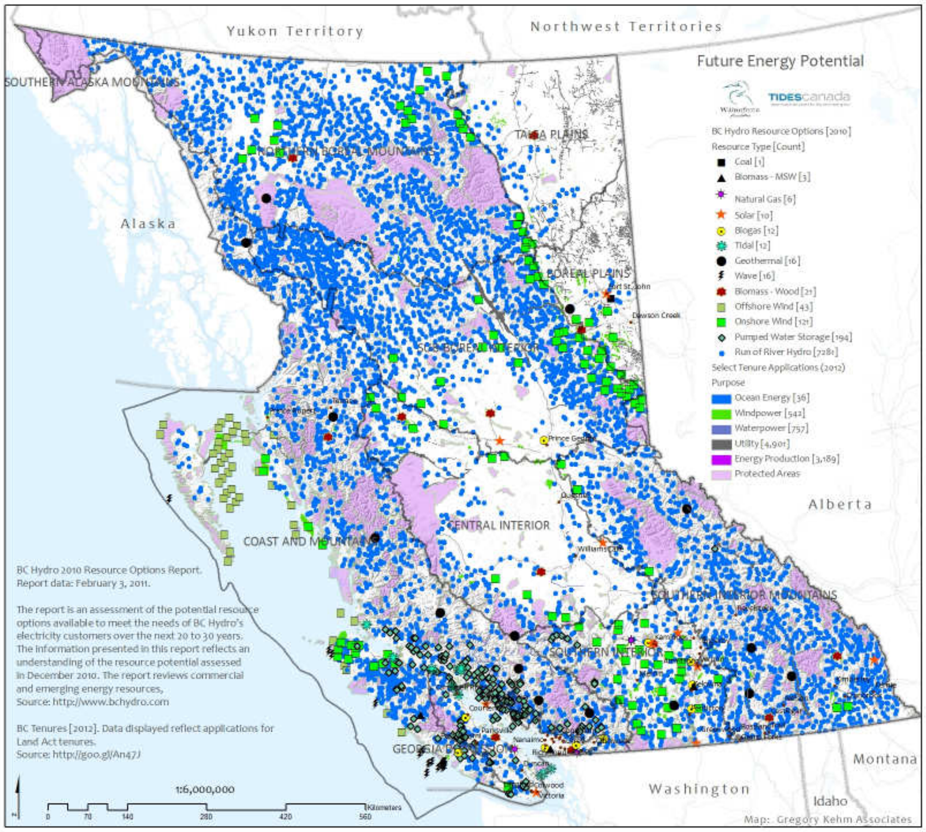
Other areas of the Province have significant human footprint today. In particular, the whole of the Central Interior and Southern Interior has a significant cumulative footprint, though the source of the pressure changes from primarily roads and forest management in the Central Interior to more urban and agricultural development in the Southern Interior. Cumulatively, this central band in the province has a significant number and extent of pressures. The northeast of the province – the Boreal Plains and Taiga Plains ecoprovinces -- also has an extensive human footprint. Some is less permanent than that in the southern Okanagan (e.g. seismic lines in particular), but in other regions in the north east there is also significant cumulative and permanent footprint.

The ecological influence of development varies. Some human activities are relatively localized but extremely intensive: coal mines for example. Others are extensive and potentially relatively impermanent, such as seismic lines resulting from oil and gas exploration, or cattle grazing in some ecosystems. The local and landscape effects of this type of footprint are highly dependent on the density and timeframe over which they occur, the sensitivity of the ecological values present, and on the policies in place to reduce negative impacts (e.g. protection of water courses from cattle). Other types of extensive development, such as roads and corridors, affect relatively limited total area, but are known to have significant ecological impacts. These impacts include disturbance of populations of sensitive species, declining habitat values (from siltation to rivers), and direct mortality of animals on roads, or associated with hunting. Forest management – which isn't mapped directly here, but inferred from road density -- can have variable ecological impacts, dependent on the sensitivity of the ecosystem and the land management policies in place. Forest management tends to maintain parts of the natural ecosystem, at least in comparison to other land use changes, but does alter the distribution of age classes of forest, with older forests often reduced significantly compared to what would occur naturally. Important natural processes such as hydrology or landscape connectivity can also be affected, especially where development is of high intensity. The patterns shown in Map 2 reflect both the extent of the area developed and the intensity and/or permanency of the development, since we attributed higher weighting to more permanent or intensive activities. Some activities fall in the middle of this range, for example seismic lines are pervasive across parts of the Boreal and Taiga Plains, but they are relatively impermanent, at least in comparison to coal mines or highway corridors.



Map 2. The Human Footprint of British Columbia See legend for details.

Note that only a limited subset of existing activities are included in Map 2 so many other current and planned developments (e.g. independent power projects, power lines, mines, recent forest harvest roads, etc.) are not shown. Some sense of the scale of such potential developments is shown on Map 3.



Map 3. These potential future energy projects are amongst a range of current planned developments that are **not included** in the Human Footprint map. Data sources: B.C. Hydro Resource Options Report, 2010; Province of British Columbia, 2012.

In summary, although people tend to think of "Super Natural British Columbia" as being wild and largely untouched by human development there are in fact significant patterns of development, with high variability in the extent, intensiveness and permanence of that development. Areas of the province with the highest human footprint scores tend to have either multiple cumulative developments (e.g. the combined effect of roads, grazing, seismic lines), or single fewer developments with more permanent or intensive effect (e.g. coal mines, or conversion to urban or agricultural land) on the ecological values present.

CLIMATE CHANGE

Climate change is considered by many to be the most significant 'human footprint' the world has witnessed to date. Ecosystems are dependent on the climate in which they are situated, so they will clearly shift as aspects of climate continue to change. Maps 4 and 5 show one example of how climate change may result in changes in ecosystems across British Columbia.

A relatively simple way to consider how climate changes may affect ecosystems is to undertake “bioclimate envelope modeling”. This approach takes the climate ‘envelope’ – that is the range of climate variables (temperature/ precipitation etc.) projected to occur for Location A at some time in the future - and attempts to match them to a climate envelope that occurs somewhere today (Location B). The model then describes Location A in the future in terms of the ecosystem that is currently found associated in Location B today. E.g. a location in southern B.C. may have a future climate envelope that currently exists in northern California – considering the types of species and ecosystems present today in northern California provides the reader **a sense** of the types of ecosystems that are currently associated with particular types of climate, but it does not predict that the particular ecosystem will actually occur at that location in the future.

The modeling links only to climate, not all the other factors that will affect whether individual species will occur somewhere – for example, whether the soil is suitable for an individual plant species, or whether the species has any chance of moving to that location. The utility of this methodology lies in translating complex climate data that mean very little to most people, into a general ecosystem type that can be visualized.

Previous bioclimate analyses for B.C. have limited themselves to the potential climate/ecosystem associations already found in B.C. (e.g. Hamann and Wang 2006) which is a significant limitation if we expect novel climates currently not found here. The bioclimate envelope modeling presented here utilizes data from the whole of Western North America, looking to match future predicted climate envelopes in B.C. to those currently found anywhere in this range.

A key factor affecting projected future climates is the scenario used. In this case, a single ecosystem envelope projection was examined, based on output from a single climate model – the Canadian General Circulation Model (CGCM3) -- and one emission scenario (A2). The A2 scenario assumes slow regionalized economic growth, continued use of fossil fuels and moderate, but continuously increasing CO_2 emissions. Humans are presently emitting CO_2 at a rate higher than this scenario.

Results:

From this single future scenario, the climate envelopes -- and therefore the projected ecosystems associated with the climate -- are predicted to shift significantly across B.C., with the extent and the significance of change differing quite widely by ecoprovince.

The same basic data are shown in Table 1 and Figure 1. Table 1 shows the area (in square kilometers) and percent change projected for each broad ecosystem type in the province. Note that these summary numbers don’t reflect the location of future ecosystems – for example, all of a particular type could be lost from one area, but be predicted to show up in another area, and this would not be apparent in this simple summary of area of each broad ecosystem type. This pattern is reflected for many systems, as ecosystems are projected to move northwards (though this is a simplification of the actual trends), and often up in elevation. Table 1 therefore shows the change in area of those that increase and those that decrease, plus the total area change for each type.

Table 1. Summary of predicted change for current broad ecosystems of B.C.. Table shows area of increase and area of decrease separately, the total net change, the total absolute change, and the percent change from the original area today. All numbers are in km^2. Table sorted by percent change from original area.

Broad Ecosystems	Area of Increase Km^2	Area of Decrease Km^2	Net Change Km^2	Total Change Km^2	% Change from original area
Grassland/ steppe	95,242	0	95,242	95,242	3705%
Coastal – dry – low elevation	14,720	0	14,720	14,720	673%
Coastal – transition	112,289	-14,475	97,814	126,764	424%
Interior - dry – high elevation	39,879	-5,871	34,008	45,750	210%
Interior – dry – low elevation	66,506	-9,618	56,888	76,124	155%
Montane / sub-boreal spruce – wet	40,963	-69,560	-28,598	110,523	152%
Interior – moist – low elevation	24,858	-16,845	8,013	41,703	142%
Alpine – transition	30,471	-30,183	288	60,654	142%
Interior – wet – low elevation	10,704	-21,151	-10,447	31,855	139%
Boreal systems – high elevation	0	-79,748	-79,748	79,748	100%
Interior – wet – high elevation	3	-99,367	-99,364	99,371	100%
Coastal – high elevation	326	-33,263	-32,938	33,589	94%
Montane / sub-boreal spruce – dry	49,245	-25,697	23,548	74,942	92%
Boreal systems – Low elevation	43	-119,481	-119,438	119,524	76%
Coastal - wet - low elevation	51,913	-4,733	47,180	56,646	64%
Alpine	31,634	-38,801	-7,168	70,435	53%

Many of the projected changes are dramatic. Perhaps the most significant is the predicted huge increase of 95,000 km^2 (in absolute and relative terms) of grassland/steppe ecosystems: all in areas of the province where trees currently grow, providing habitat and goods and services. Nowhere in the province is predicted to lose grassland or coastal dry low elevation systems; these ecosystems are projected only to increase. Conversely, boreal system envelopes aren't created anywhere, but are almost completely lost from their existing locations. All the other types are both lost from existing locations and 'gained' somewhere else, with a significant increase in the driest ecosystems and a tendency for a reduction in area in the wetter ecosystems.

Remember that these numbers ***reflect the climate envelopes that currently influence these ecosystems.*** It is not expected that individual species will actually be capable of 'migrating' fast enough to keep pace with the rate of climate change (Jump 2005; Wilson and Hebda 2008). The survival options open to individual species in a changing world are to 'get used to their new environment', adapt (evolve) new strategies over time, or move/migrate to more suitable locations. The influence of climate change on individual species has been discussed in detail elsewhere (Pojar 2010); and it is clear that individual species will be highly variable in terms of their adaptive abilities. Unfortunately the species most likely to move or adapt quickly are weedy species. For example, the grasslands projected to 'move' up through the centre of the province will likely be low in native grassland diversity and dominated by invasive species such as knapweeds and orange hawkweed. We therefore expect that existing ecosystems rather than migrating in their current assemblages will instead disassemble and reassemble in different forms, depending upon the responses of the individual species.

This scenario shows just one potential of a large array of potential futures, and it does not illustrate the range of options, nor the uncertainties associated with climate models. The scenario used is quite conservative in its modeling of the CO2 output into the future, and current levels of CO2 in the atmosphere are higher than those assumed to be present today in this scenario. There is also little indication that the human response to the emissions will match the reduction in future that is assumed in this scenario – at least to date.

These results do provide some sense of the potential scope of change that may be expected – and the types of results being shown here are generally consistent with the types of changes being projected by more detailed and localized studies on climate change. For example, these methods have been used to project detailed ecosystem and social vulnerabilities for areas in British Columbia[3]. There are many discussions of how such climate changes will affect ecosystems directly (e.g. WorldBank 2012; Pojar 2012), and natural disturbance regimes directly and indirectly. For example, as temperatures increase and summer precipitation declines (as is predicted by many models in various parts of the province) the frequency and severity of fires may radically alter (e.g. see an example for the West Kootenays – Utzig et al. 2011). This single mechanism for change will have significant implications for humans, both directly in terms of fire risks, and indirectly for goods and services in many areas of the province.

[3] For example, in the Kootenays (www.kootenayresilience.org), in the Kamloops region (www.k2kamloopstsa.com), in the Smithers region (www.bvcentre.ca/research/project/a_multi-scale_trans-disciplinary_vulnerability_assessment).

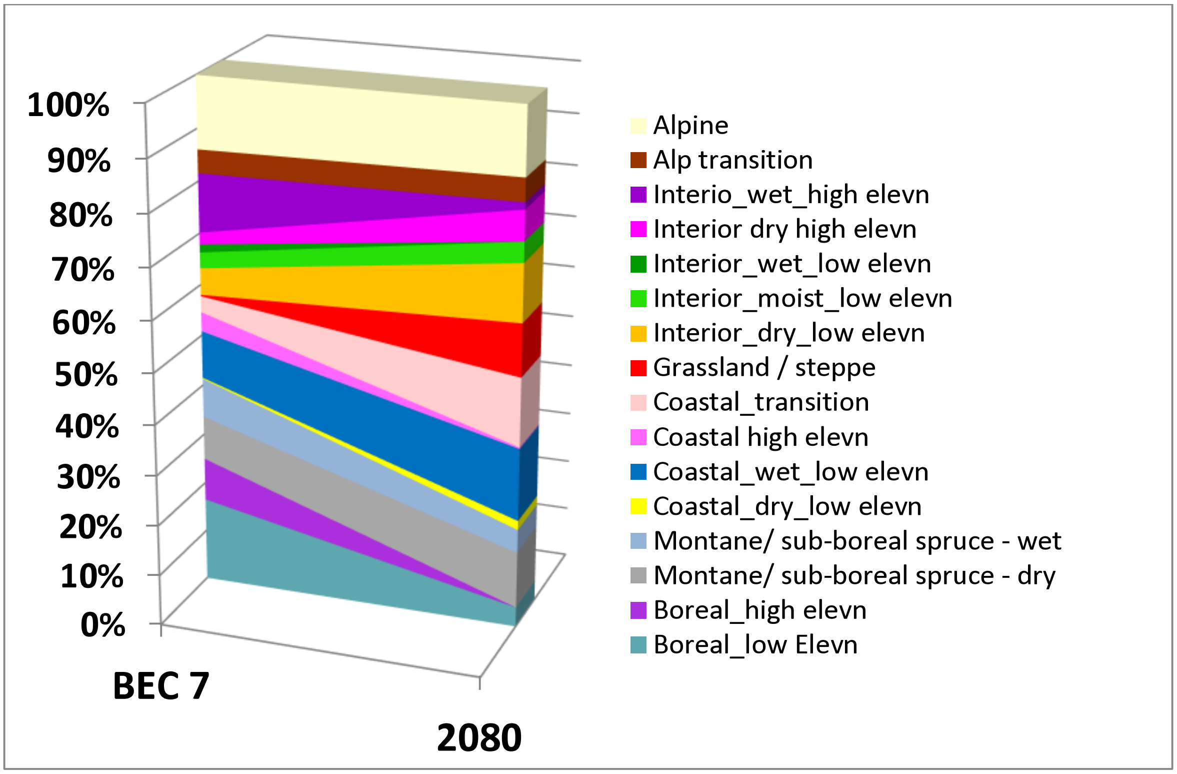


Fig. 1. The percent change for broad ecosystem units – from "current mapping" to 2080.

Climate change is also likely to interact with the effects of land use: The ability of species to respond to climate change by moving to some new location will be significantly influenced by the life history of the species - combined with the permeability of the landscape itself. The human footprint is known to significantly affect the extent to which species can safely move through landscapes, even if sufficient habitat exists for them (Jetz, et al. 2007; Proctor et al. 2012). As seen earlier in this report, the landscape of B.C. is variable in terms of its human footprint – but in many areas the industrial footprint is both deep and wide, significantly reducing the potential at least for some species, to respond to a changing climate (Noss et al. 2012). Changes in land use are identified as the largest direct factor globally affecting the ecosystem services available from the land – including biodiversity and freshwater supplies (Nelson 2005).

As is shown in the maps below (Maps 4 and 5), the types of changes vary by ecoprovince. Each is described simply in the ecoprovincial summaries below. The take home message is not to 'believe' this single future scenario will come to pass – but to understand that the implications of climate change will be significant and will profoundly affect many natural values and many of the goods and services that humans rely upon, including those most basic values such as a safe space to live in and having sufficient available water to drink.

The best hope for nature to adapt to climate change is to reduce the compounding degradation effects caused by human land use on natural systems (Pojar 2010).

Clearly, climate change details need to be front and center of any conservation planning, or in fact, any land or resource decision-making. This will require significant work throughout the province, but should be incorporated in 'daily business' in all land management decisions moving forward.

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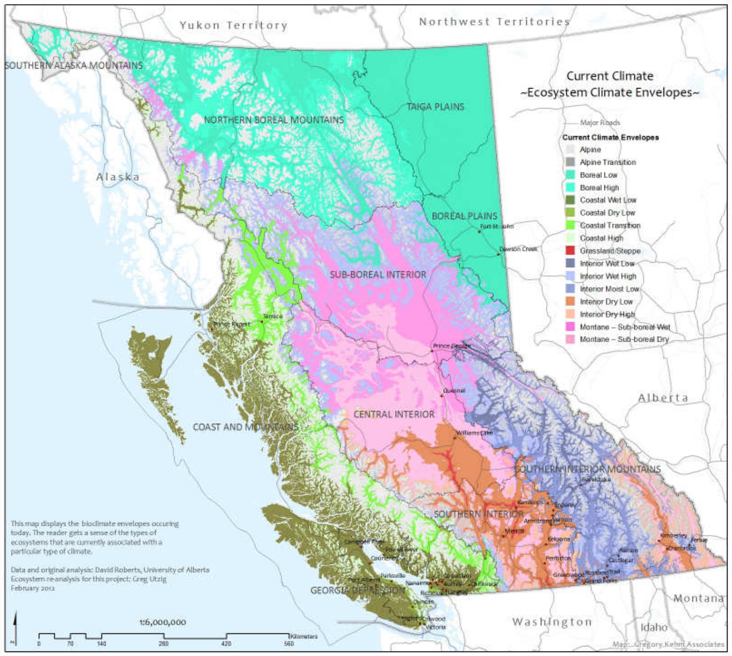
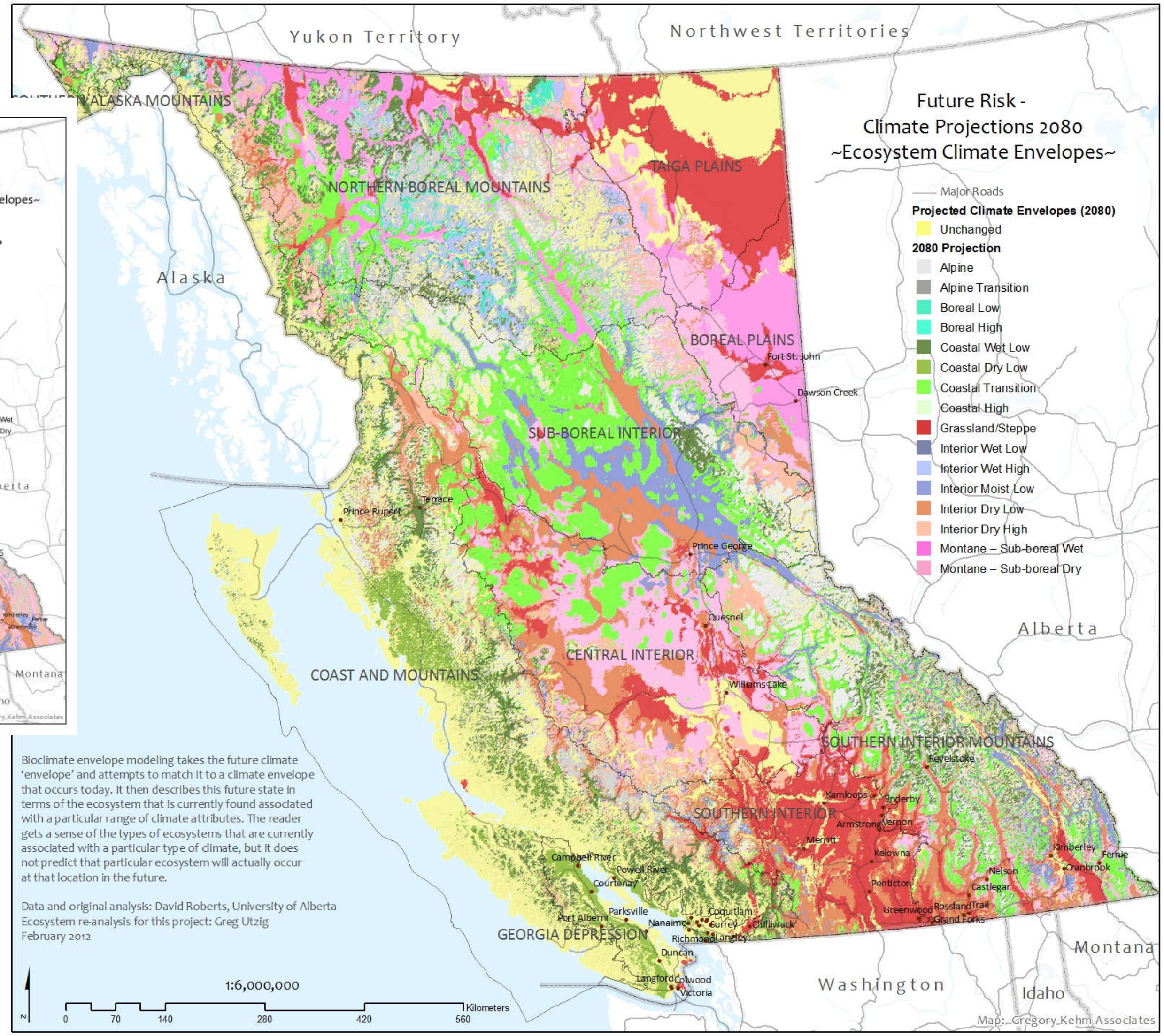




Map 4 and 5. Bioclimate envelopes current (inset map) and projected future (right map), under a conservative CO2 scenario (A2).
Significant shifts in climate envelopes are predicted. See legend and text for details and cautions.

B.C.'S ECOSYSTEMS AND CARBON

The science is already clear that adaptation to climate change is an option only if the rate and extent of the changes are significantly reduced from their current trajectories (Seppala et al. 2009).

"The resilience of many ecosystems is likely to be exceeded this century by an unprecedented combination of climate change, associated disturbances (e.g., flooding, drought, wildfire, insects, ocean acidification), and other drivers of global change (e.g., land-use change, pollution, overexploitation of resources)" (Parry et al. 2007).

Mitigation of climate change should therefore be the primary goal worldwide. Mitigation is a matter of carbon management (both release and uptake) of which ecosystems have a primary role to play. Understanding patterns of natural carbon in landscapes is therefore an essential starting place. Astonishingly, until very recently no such maps existed for B.C..

Carbon is a building block of life. Carbon is 'fixed' from the air by living plants then cycled, stored, and released by living and dead plants and animals, and by decomposing organic material, and by organic matter in the soil. Ecosystems store a diversity of carbon as: above-ground biomass (stems, branches, leaves, bryophytes and lichens); below-ground biomass; dead biomass (litter, woody debris), and organic carbon in the soil. The security of that storage is dependent on many factors, with a primary one being the rate of natural disturbance for the ecosystem.

The new era of climate change has greatly elevated the need to understand, manage, and reduce the carbon that is released into the atmosphere. Carbon management has become one of the fastest growing and profoundly important areas of new knowledge worldwide.

Yet – we have a poor understanding of where and how carbon is stored and released from the different ecosystems of British Columbia. In this project we have developed two maps that provide preliminary estimates of the amounts and distributions of carbon stored in ecosystems. Map 6 estimates the amount of static carbon stored in living vegetation - above and below ground - for the different ecosystems of B.C.. The map is based on forest inventory data from the province of B.C., and as such is limited by its accuracy. However, since 95% of B.C. is crown land, this coverage is extensive, and is limited primarily where tree farm licenses exist. Map 7 shows the broad patterns and estimated amount of static organic carbon stored in the soil systems of B.C. These data are taken from the Harmonized World Soils database and include a range of descriptive soil attributes used to model the distribution and estimated amounts of top and sub soil organic carbon. While the map contains known errors, it is perhaps the first soil carbon map for the province and an important starting place to understand the data gaps and future needs to understand and manage the carbon landscape.

Others have explored general concepts of carbon in B.C. (see Pojar 2010, Hebda and Wilson 2008), and the descriptions here are intended to aid in highlighting the general differences between B.C.'s ecosystems and in identifying how such differences are relevant to determining management actions moving forward. Some general patterns shown on the maps include:

Low Disturbance Ecosystems: the coastal and inland temperate rainforests (Coast and Mountains and Southern Interior Mountain ecoprovinces) tend to have the highest stores of carbon today both in biomass and in soils. B.C. retains a high proportion of the world's intact temperate and inland rainforests and the faster-growing and larger trees of these forests sequester and store some of the highest densities of carbon per hectare anywhere in the world. This is partly a result of being dominated by only rare stand-replacing disturbances, and moving into the future although these old growth forests are predicted to change with climate change, many are likely to maintain in a similar low frequency disturbance regime for some time – they therefore are likely to remain as net carbon sinks of very high carbon value into the future.

Forest harvesting is major source of carbon emissions in the province. Although forest management is potentially 'carbon neutral' carbon emissions cannot be easily offset ***in a timeframe relevant for climate change mitigation*** by afforestation or reforestation because it takes such a long time for forests to grow and mature. In addition, traditional industrial forests require extensive roads and landing areas resulting in loss of significant areas of growing space.

The conversion of mature or old forests to young forests, whether through logging or natural stand-replacing disturbances, results in a pulse of carbon release immediately and for several years thereafter. After harvesting much of the carbon stored in the system is lost immediately - there is disturbance to the soil and the original vegetation, and sometimes warming of the site, resulting in an increased rate of decomposition of coarse woody debris, litter, and soil organic matter. Losses of $CO2$ due to respiration exceed the amount fixed through photosynthesis by the regenerating forest. Typical commercial rotations also reduce total carbon stored by harvesting trees at their maximal growth rate, not at their largest size. Thus, avoiding the destruction and degradation of these forests, particularly long-term stable old-growth forests, is an important strategy for present and future carbon storage.

Higher Disturbance Ecosystems: The sub-boreal spruce zone forests, especially those surrounding numerous wetlands (e.g., the Nechako River near Prince George) of the Sub Boreal Interior Ecoprovince show as moderately high carbon stores on Map 6. This ecoprovince is typified by a sub-continental climate, cold winters, warm summers, and equal amounts of precipitation in summer and winter. Dense coniferous forest dominates from valley bottom to timberline, with increased shrub and tree cover on the scattered wetlands. The potential climax of white (hybrid) spruce and subalpine fir covers the greatest portion of the ecoprovince. The soils associated with Sub-alpine forests of the Taiga Plains, Boreal Plains, and parts of the Sub-boreal Interior show on the soils map as significant carbon stores. There is a band of such soils following the trench north of and following Williston Lake, the Nechako Plateau and down the Nechako River valley to south of Prince George. There are two other concentrations of sub-alpine forests showing up as carbon sinks to the east of the Columbia Mountains: one primarily in the Taiga zone and a second to the South of Fort St. John Dawson Creek and the Peace River (including tributaries of the Peace River). Further south, across the Central Interior, stores of carbon in the forests are relatively low due to the high natural disturbance rates.

These forests are commercially logged and have been massively impacted by the last decade of mountain pine beetle outbreaks that have killed most of the trees on around 15 million hectares. Although naturally these forests are dominated by more frequent natural disturbance events than wetter forests elsewhere, they do still store significant amounts of carbon. Because of the large "beetle-kill" areas a bioenergy industry from dead wood has been suggested as economically viable. However, carbon emissions as a result of cutting the wood, soil disturbance and wood burning are not yet known. As with coastal and wet interior forests, harvesting and removing wood from these forests decreases carbon stocks and releases carbon through soil disturbance and changes in soil processes, and can also result in the forest being a carbon source for about a decade after logging (Freeden et al. 2006).

Natural disturbances such as insect outbreaks and fire are suggested to have less impact per hectare on carbon emissions from forests than conventional forest management. Fire and insects leave most of the forest biomass allowing decay and slow carbon release whereas logging removes 50 to 80 percent of total above-ground biomass

- only some of which is then stored as wood products for some period. A “beetle-killed” forest is still a functional forest: the soil is undisturbed, and the standing dead trees release carbon slowly in these colder climates. Detailed analysis should be undertaken to understand the implications for carbon along with the interplay between human and natural disturbances in these systems.

For all systems, detailed full-cost carbon accounting is needed to ensure land management decisions are fully taking into account the larger picture, and that opportunities for reducing the release of carbon into the atmosphere are being identified and included in decision-making.

Peatlands / Bogs / Wetlands: The peatlands / bogs and wetlands of the Taiga and Boreal Plains Ecoprovince are indicated as significant carbon sinks by the soil map, with the Fort Nelson Lowland bogs and wetlands a dominant feature of the landscape. Peatlands are carbon-rich - with a greater soil carbon density per square metre than any other terrestrial ecosystem. B.C.’s peatlands cover about 6 percent of the province and are estimated to store 6.8 billion tonnes of carbon and to sequester about 1.5 million tonnes of carbon per year (Wilson and Hebda 2008). Cool temperatures and cool, wet, acidic and oxygen-poor soils result in slower decomposition of materials and a slow release of carbon from bogs naturally. North-eastern B.C. is currently undergoing rapid resource development including logging, and oil and gas exploration – activities that severely disturb the surface and release greenhouse gases. Peatlands are severely affected by surface disturbance and are also very sensitive to drought, a decrease in the water table, and melting permafrost – all predicted outcomes of climate change in this area. As a result the future effectiveness of these ecosystems as a carbon sink is in jeopardy.

A few areas of permafrost can be found in the Fort Nelson Lowland, on the southern edge of permafrost range and may disappear relatively soon due to warming, although retaining forest and peatland cover may slow this loss for some time. Loss of the permafrost could result from any disturbance of the vegetation cover – including the logging, fire, roads, railroads, seismic lines or pipelines currently active in the area. Significant southern wetlands and bogs exist in B.C. that don’t appear at the scale of either map, including Burns Bog in Delta, the Creston Valley Wetlands and the Upper Columbia Valley Wetlands. These and many other smaller scale features are significant for their biodiversity, linkage function and carbon storage and sequestering abilities.

Grasslands: Grasslands do not show up as significant carbon sinks on either the forest or soil carbon sink maps, but grasslands do sequester large amounts of carbon in grassland soils[4]. Stored carbon is released upon cultivation or development, while overgrazing promotes invasion by exotics which simplifies and reduces grassland sequestration abilities, biodiversity values, and adaptation capacity. Grasslands today cover a small part of the province and their contribution to the carbon economy is also relatively small, but moving forward with climate change, grasslands are predicted to expand and planning to promote carbon store and maintain biodiversity will become increasingly important.

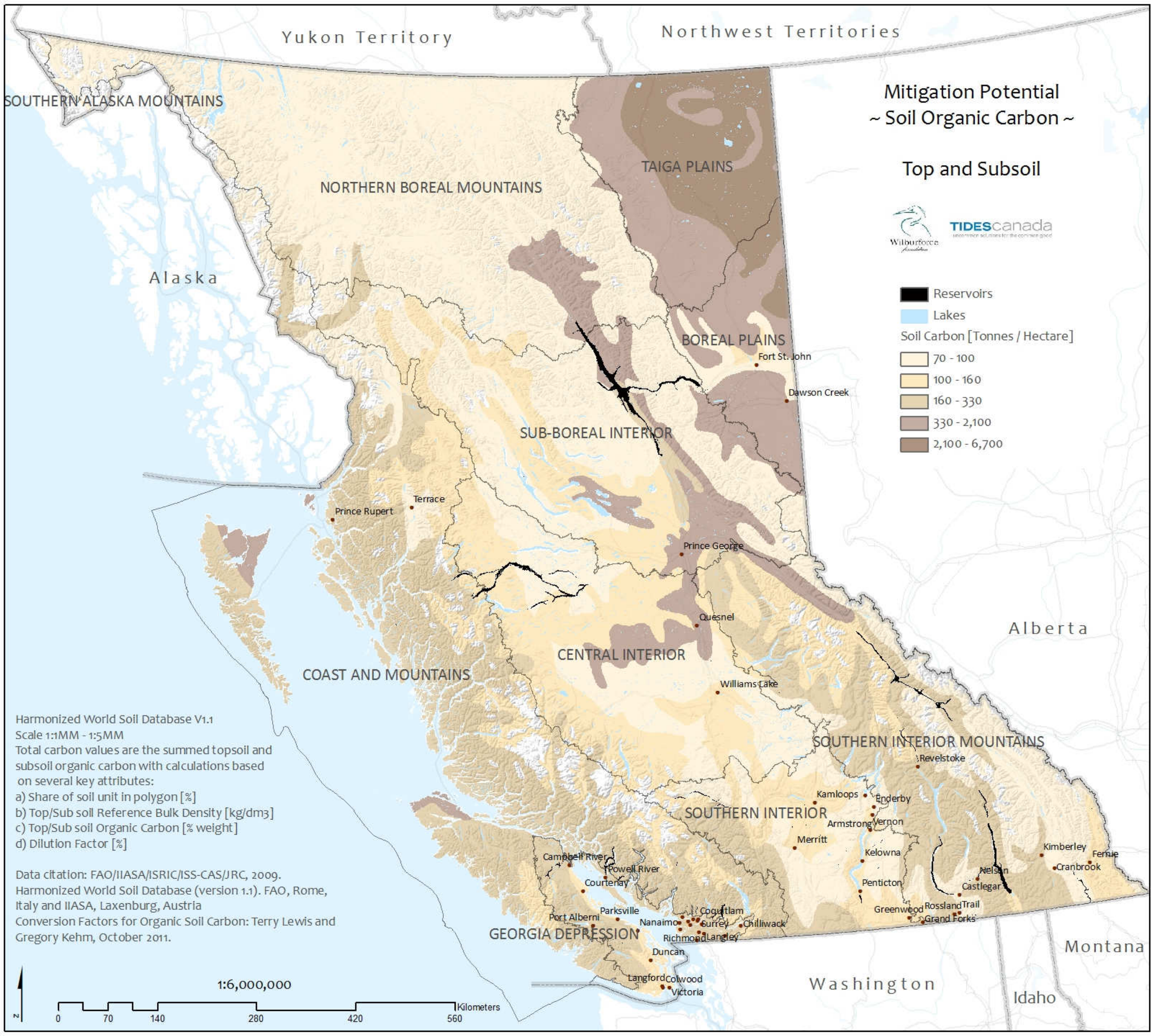
High Elevation and Cold Ecosystems: Alpine areas and associated permafrost areas are also not shown as significant carbon sinks on either map, but the thawing of the permafrost in these systems will result in release of carbon as $C0_2$ and CH_4. The release of this carbon is a significant potential positive feedback from terrestrial ecosystems to the atmosphere and to a warming climate. Permafrost in the northern mountains and high plateaus may be less susceptible to thawing but the melting of some high elevation permafrost may have resulted in significant terrain instabilities in future. Permafrost is susceptible to disturbance by mining, development and by road-building for proposed wind-power projects.

[4] The scale of the data used, and the dispersed nature of grasslands result in their relatively minor presence on the carbon maps. Additional local work is needed to understand overall storage and dynamics in grassland and other ecosystems of B.C..

Map 6. Mitigation Potential – Forest Carbon. See legend for details.

Both the static terrestrial biomass carbon map and the soil organic carbon map are draft and have received informal review by a limited number of scientists. While they are some of the first carbon maps to be produced of the whole of B.C., and are based on best available information important assumptions were made, specifically the available data and attribute information, and specific conversion values for forest carbon in British Columbia[5].

[5] we used a biomass to carbon conversion factor published in an article on Pacific Northwest forests, specifically Washington State. see the technical methods appendix for information on methods used and the assumptions made.



Map 7. Mitigation Potential - Estimated soil organic carbon. See legend for details.

The maps demonstrate how below and above-ground carbon varies significantly for different ecosystems. For example, the immense wetland / organic soil complexes in the Naikoon Provincial Park, Haida Gwaii and the Taiga Plains highlight the highest soil carbon areas in the province. Further work is needed to understand how the stability of that carbon is affected by both natural disturbance regimes, and direct management activities. Significant efforts should be made to incorporate the results of such work into the decision-making for individual ecosystems provincially, and around the globe. The maps presented in this report are preliminary and look only at 'static' carbon, but they provide a starting place for pulling together an understanding of total terrestrial carbon density (soil and terrestrial biomass carbon) and for taking carbon mitigation considerations within land management decision-making seriously.

In Summary: In order to mitigate and manage for carbon we require more information. Forests ecosystems are relatively well-studied in B.C. but there is still a lack of comprehensive information upon which to make decisions about land management. For example, a lack of full cycle data on the dynamics of carbon from forest to mill to market, and the difference in sequestration rates between young versus older forests and which types of forests are sources and which are sinks, over what time periods. We also need to know how much carbon is stored in soils, and dead wood in order to quantify carbon-forest-atmosphere dynamics and the ebb and flow of carbon stocks. Creating a total picture of all carbon pools including better information on soils, carbon uptake, and differential rates of tree mortality for different ecoregions, will also improve carbon accounting.

Carbon management is critical to the future state of nature on this planet. To date, there has been relatively poor data, or patchy data on the existing stores of carbon for the province. This situation is starting to change, and there is a growing interest in the stored carbon and how management decisions affect the length and stability of that storage. This is one area where significant additional work needs to occur. As the realities of climate change start to be brought into everyday policy development and decision-making, people will need to understand how all management decisions affect carbon outputs, and a carbon driven management framework may emerge. Before these steps can occur, much more understanding of existing total carbon patterns and how they are influenced by human actions and natural events is needed. This carbon map provides the first example of such a map for B.C., and as such provides a starting place for this important conversation.

ADAPTATION: LOOKING FOR RISKS AND OPPORTUNITIES

A starting place to determine what opportunities and risks exist for biodiversity values and climate change adaptation is to combine the ecological proxy and human footprint maps. Regions of the province differ ecologically so profoundly that regions should be assessed individually and not traded-off against one another. Map 8 overlays these two layers of information and highlights how the range of human footprint overlaps with the range of ecological values; conservation needs and opportunities therefore differ across the province.

Conservation action occurs at the site level, and actual conservation measures also require local and more detailed information than that presented here. The ecological proxy layer is just that – a broad proxy for the phenomenal biodiversity in the province – and provides a regional perspective to help contextualize local conservation action and adaptation needs. These maps of British Columbia as a whole can provide an overview of the types of patterns occurring in B.C., which can be used to highlight strategic level opportunities to maintain biodiversity values, identify options for linkage networks, and highlight the areas of greatest risk.

Looking at this combined map, it is important to remember that some of the ecoprovinces naturally have low values for the ecological proxy values being measured here. For example, the Northern Boreal Mountains is not very diverse, except for some transitional vegetation from coastal to boreal. The distinctive feature of the ecoprovince is the extensive high subalpine and alpine habitats. (Demarchi, 2010)

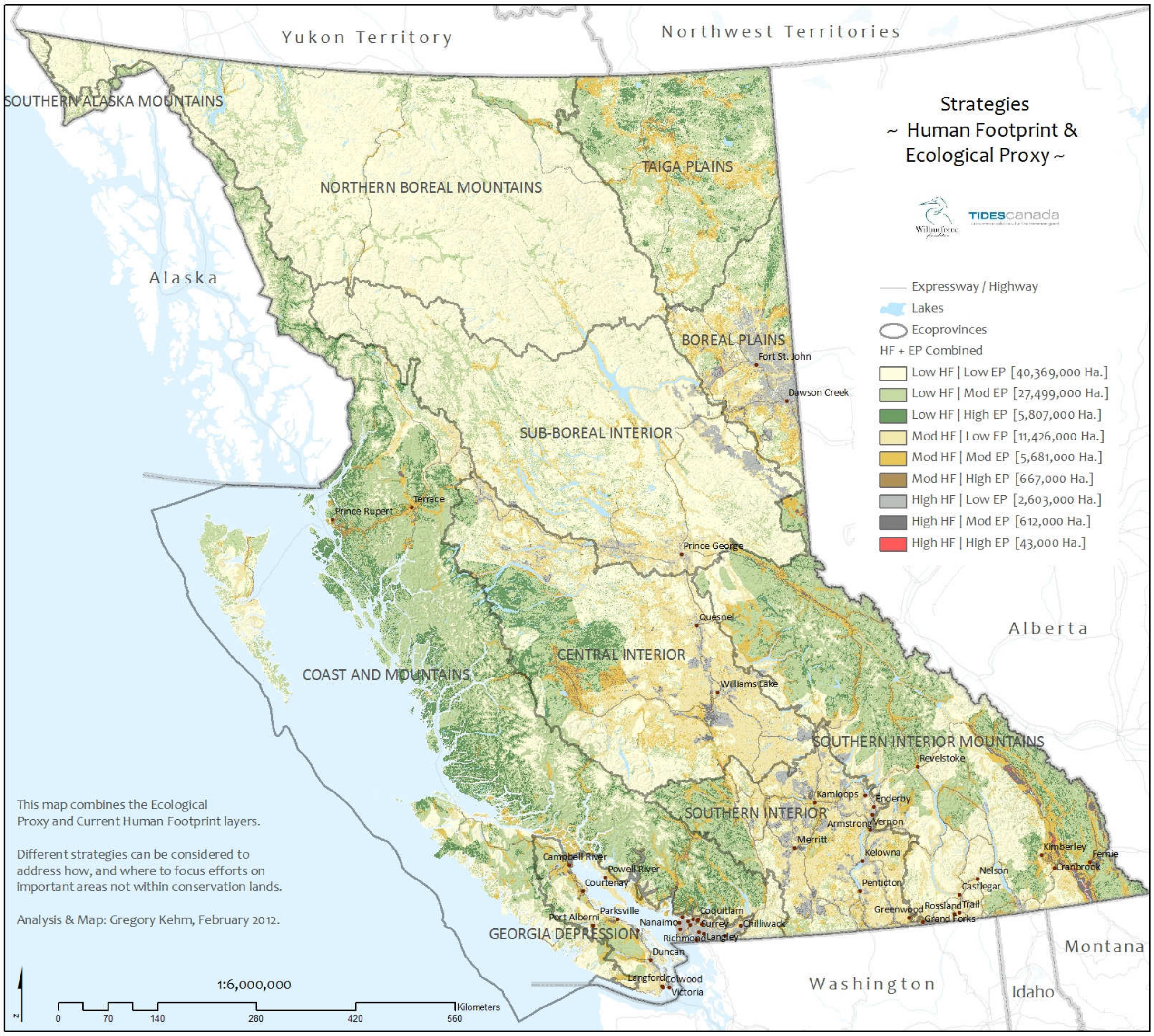
Other regions historically had higher values but have been impacted by the human footprint. It can be misleading to compare across different regions with respect to the ecological proxy values: for example, there is no suggestion that the Taiga Plains have higher inherent ecological values compared with the Northern Boreal Mountains. Any areas that are highlighted as having high combinations of values are likely to be locally and regionally significant into the future, especially if located in an otherwise relatively low value matrix. This includes many areas on the mainland coast, on Vancouver Island, and throughout the Southern Interior Mountains. With the exception of climate change effects, the existing industrial footprint pressures are relatively low in these regions.

Analysis of area-specific carbon dynamics is key to identifying management strategies. Further work on the dynamics of carbon in each system should be prioritized, in order to look for synergistic opportunities that work both for the capacity of systems/people to change (adaptation) and opportunities to not release carbon (mitigation).

Large areas with high ecological proxy values and low human footprint are globally rare, and support globally rare ecological values in B.C. (Austin 2009). They also present relatively low cost opportunities for conservation action, something needed especially in this time of climate change. In B.C., this includes the wide expanses of the Northern Boreal Mountains and northern part of the Sub-Boreal Interior, where globally significant populations of large mammals roam the landscape. Much of the Coast and Mountains, and Southern Interior Mountains similarly have a generally low-to-moderate human footprint, but have more diversity in ecological proxy values, and more localized areas of high human footprint. Conservation opportunities are potentially more plentiful today in these regions, though rapid on-going development in key areas (major valley systems) is rapidly foreclosing existing options.

The incursion of the human footprint into relatively intact systems is observed most clearly in the diversity of combinations found in areas such as the Taiga and Boreal Plains, where the significant footprint is embedded within a landscape of variable remaining ecological values. This to some degree reflects the recent effects of the incredible pace of development in these regions, and highlights the need for action and management of the cumulative footprint immediately, before all opportunities to do so are lost.

Regions with generally high values for ecological proxy interspersed with areas of low values today may be a result of human pressures, a pattern that shines a spotlight on what may happen in the future if development continues. An example is the condition of certain areas of Vancouver Island -- the most heavily impacted area of the coastal temperate rainforest in B.C. -- where significant values have been altered due to cumulative development from a range of pressures. There is an urgent need for action today to increase resilience in these important ecosystems. In addition, coastal and inland temperate rainforests have some of the highest stores of carbon per hectare in the world, and can also be some of the most stable carbon stores through time due to low natural disturbance regimes. Opportunities to find synergies between biodiversity adaptation and carbon management have some foothold in parts of the Great Bear Rainforest (north and mid mainland coast), but opportunities across B.C. should be sought.



Map 8. A step towards developing strategies – looking for opportunities and costs.

THE RESULTS: A CLOSER LOOK AT ECOPROVINCES

From the overview, we see that patterns and trends vary significantly in across the province - the underlying ecological factors are quite different across the different regions, as is the history and intensity of industrial development. The interaction between climate and existing ecosystems also differs so widely in these different areas, so climate change can also be expected to have significantly different effects in different areas.

In the following section, we summarize the patterns for each series of values by individual ecoprovinces. Ecoprovinces still represent very large areas, but are at a more manageable scale to think about conservation actions and planning activities.

NORTHERN BOREAL MOUNTAINS

The ecosystems of the Northern Boreal Mountains are relatively simple, and don't contain the diversity of 'ecological proxy' values found in other regions of the province; yet these massive and wild landscapes are home to exceptional biodiversity values. The large populations of ungulates and predators still found here are extirpated from the vast majority of their ranges further south in North America. For example, the huge and wild Muskwa-Kechika (including Northern Rocky Mountains Provincial Park) in this area still retains healthy populations of ungulates and predators. The exceptional ecological values aren't highlighted by the ecological proxy map because of the vastness of the landscape, and the relative simplicity of the ecosystems. The massive scale of the entire, wild landscape of the Northern Boreal Mountains Region that makes this region so ecologically unique. Grizzly bears, for example, rely on the salmon, and vegetation along the rivers for food. But these large predators travel in and rely on most of the entire landscape. They hibernate in high elevation dens, rely on early spring food on avalanche slopes and wander the landscape in search of ungulates and other game. In addition, many of the major rivers, for example, the Muskwa, Liard, Frog and Finlay river systems, stand out on the map of ecological proxy values because of their localized diversity:

Ecological State	Human Footprint	Climate Change	Carbon	Strategies
Relatively simple ecosystems but globally important ecological values Good condition today.	Low throughout the region. (Increasing in some areas)	Increasing complexity predicted, but species need to move here. Simple ecosystems may lack resilience. Prone to collapse?	Relatively low carbon stores compared to other areas of the province. Unknown effect of CC on these stores?	Moderate urgency. Must plan to maintain linkages in all directions, and locally within region.

Northern Boreal Mountains
Opportunity for natural adaptation good. Plan to maintain existing values, and ensure any development continues to facilitate movement and natural adaptation to CC.

The industrial human footprint in the Northern Boreal Mountains is very low throughout the whole region, with the exception of the rippling effect from the Williston Reservoir. The Williston Reservoir project dammed the Peace River to the south, significantly affecting the hydrology of the region. Currently the Northern Boreal Mountains region has very low levels of influence from human development, but this analysis doesn't include some of the more recent planned industrial expansions in the region.

Our climate projection for this region suggests there will be some significant changes in the future: the prolonged cold temperatures that currently prevail determine the nature of these simple ecosystems today. As the climate shifts, the climate envelopes of this region are projected to become much more complex. This suggests that the predicted climate changes will be ecologically significant and may cross many ecological thresholds resulting in a large number of ecological changes. The bioclimate envelopes predicted here in 2080 are currently associated with ecosystems not present in this zone at all today; climate combinations currently associated with grasslands, wet coastal ecosystems, and interior dry low elevation systems are all predicted here in future, while the alpine is predicted to be much reduced. These predictions don't suggest that all these ecosystems will be 'moving' to this region – however such diverse predicted changes in climate envelopes suggest types of changes that will have a wide diversity of effects on the existing ecosystems and species. The current climate limits many species there today. These climatic thresholds may be crossed and new species and ecosystems may become viable in this northern zone. The number and diversity of these predicted changes increases the uncertainty of predicting how this region will look in the future. This very uncertainty and inability to accurately predict the changes increases the need to allow free and consistent movement of species from distant areas to the Northern Boreal Mountains region – now and in the future.

Strategies: The overlap of ecological proxy and footprint (Map 8), shows that there are still many opportunities for relatively 'low cost' conservation in this zone. However, there are many existing and proposed developments not included in our footprint layer. These developments include: transmission corridors, mining claims, hydro development etc. All of these developments point to a need for **urgent planning** action to ensure that key areas are maintained and that ecosystem connectivity - to all directions on the compass - is not constrained by the increasing rate of development in key areas. It is important to retain the current values of the Northern Boreal Mountains region to facilitate the retention and movement of organisms during the predicted climate changes.

SUB-BOREAL INTERIOR

The Sub-Boreal Interior Ecoprovince is comprised of the plateau country of the Nechako plateau, the Nechako lowlands, and the northern Rocky Mountain Trench. The ecoprovince is surrounded by mountain ranges that include the Skeena, Omineca and Hart Ranges. Prince George is located on the southern edge of the region, Smithers near the western border and the Williston Reservoir in the north east. It is a landscape of wetlands, lakes and streams and mountains, with large areas of alpine tundra in the mountainous regions, and dense forests of spruce, fir and deciduous species throughout. The ecological proxy values for this ecoprovince (Map 1) are relatively low and evenly distributed across the landscape, though a number of watersheds stand out in the northwest portion of the area, including the Skeena River. Babine, Takia and Stewart Lakes and the Damdochax and Sustat. These river systems contain very diverse older forest ecosystems and many lakes and wetland systems. In contrast, the more southern areas of the Sub-Boreal Interior are dominated by relatively simple plateau forest ecosystems.

Ecological State	Human Footprint	Climate Change	Carbon	Strategies
Relatively simple ecosystems in moderate condition (though variable)	Low in North, moderate to localized high in South. High footprint in some critical valleys.	Increasing complexity predicted, but requires extensive movement of species?	Some opportunity for carbon storage in more stable systems. Potential release of carbon due to increasing fire in south?	Urgency to maintain core areas and connectivity in all directions. Urgency to manage cumulative developments.

Sub-Boreal Interior
Opportunity for natural adaptation relatively high in most areas with lower footprint. Focus on key river corridors and movements areas through mountain ranges. Intentional planning required to prevent key areas being impacted.

The Sub-Boreal Interior, overall, has a relatively low industrial human footprint with forestry, mining, and the associated roads account for most of the human impact. The human footprint increases in intensity in the southern portion of the region due primarily to the major transportation corridors associated with major valley systems such as the Rocky Mountain Trench. The areas affected by the major transportation routes are also the areas of naturally higher ecological diversity and as such are important areas for maintaining a diversity of habitats and movement corridors for species.

Predictions of climate change suggest that there may be a shift from climates that support the current boreal ecosystems and montane / sub-boreal spruce ecosystems to climates that support the current interior moist and dry low elevation ecosystems. These changes may result in less alpine and more of a 'coastal transition' type of climate. As with the more northerly Northern Boreal Mountains zone, this increase in apparent diversity of climates into the future may reflect how these relatively climate-limited systems may cross existing climate thresholds, potentially allowing significant changes in species distributions in this ecoprovince. Management that allows species movement will be key to maintaining opportunities moving forward.

Strategies: Map 8 shows how the generally low human footprint leaves significant opportunity for relatively low cost conservation and adaptation planning at this time. As with the Northern Boreal Mountains, however, human development in this region is increasing at ever faster rates. **Immediate, and effective management of cumulative effects and conservation planning is required to ensure that critical opportunities are not lost.**

TAIGA AND BOREAL PLAINS

The Taiga and Boreal plains are in the north east of the province, to the east of the Rocky Mountains. The Taiga Plains is sub-arctic in climate, and is a large lowland dissected by the Liard River and its tributaries. The Boreal Plains is slightly warmer in climate, and consists of plains, prairies, lowlands, incised by a number of major river systems such as the Peace, Pine and others. The Ecological Proxy values of the Taiga Plains are relatively high. due to combinations of the extensive distribution and diversity of mature and older forest and wetlands, lakes and river ecosystems. The Boreal Plains shows two distinct areas: the north- eastern section has greater topographic relief, similar to the Taiga Plains, and exhibits a similar diversity of Ecological Proxy Values. The Ecological Proxy values are lower in the region around Dawson Creek and Fort St John.

Development pressures in the Boreal Plains are pervasive and include agriculture, roads, seismic development, transportation corridors, cattle grazing, and water diversion. The cumulative overlay of these different types of development are apparent in the extensive and high pressure human footprint (Map 2).

Ecology	Human Footprint	Climate Change	Carbon	Strategies
Relatively simple systems. Moderate condition today.	Boreal: - High footprint – primarily extensive, but cumulative impacts. Taiga: Mostly low intensive , but impacts to species and functions likely.	Increasingly complex ecosystems? Requires massive species movements. Potential for collapse?	Likely release of carbon through warming. Management strategies to reduce human-induced losses ?	Urgent to prioritise core areas with low footprint, to act as source zones and to identify corridors through this high impact landscape.

Boreal / Taiga Plains
Opportunity for natural adaptation significantly curtailed by existing and ongoing human footprint.
Urgent planning and action required to facilitate natural processes and species movements into future.

The Taiga Plains have also seen extensive development, much of which has relatively low permanence. Many areas are affected by cattle grazing, agriculture, and particularly seismic lines and roads. The extensive nature of this footprint results in effects on sensitive species in particular, and to ecological processes such as hydrologic effects and movement through the region.

The current high and low elevation systems of the Boreal and taiga Plains are predicted to significantly shift with climate change; the relatively simple boreal systems are predicted to largely disappear from both zones, to be replaced primarily by grassland type climates in the Taiga Plains and by montane / sub-boreal spruce type climates in the Boreal Plains. Our climate scenario predicts that boreal systems will largely disappear (to 24% of their former area) across the province and it is in these two ecoprovinces that this prediction is expressed most clearly. Rapid and whole-sale shift of climate envelopes will have any predictable and many less predictable effects on species, ecosystems and ecosystem services.

Strategies: the overlay Map (8), shows that much of these two areas need urgent conservation management in relation to climate change and the current high human footprint which already limits opportunities for action across much of these two large areas. However, there are also some key areas of opportunity highlighted in this map that currently exhibit a relatively low footprint, and still have ecological values today. These areas may be key 'low cost' opportunities around which to focus conservation management and adaptation actions in these areas. Local planning is urgently required to **ensure critical areas** – using best available information – **are identified and protected**. **Urgent cumulative effects management is needed across the whole zone to lessen the manageable impacts and allow for natural adaptation to climate change.**

COAST AND MOUNTAINS AND GEORGIA DEPRESSION

The coastal temperate rainforest region of British Columbia is still primarily dominated by old growth forests, wetlands, rivers and lakes. Ecological diversity is high and there are many estuaries, Important Bird Areas, and habitat for endangered species and ecosystems. For example, the Coast and Mountains Ecoprovince and the Georgia Depression Ecoprovince account for 80% and 90% respectively of all birds that occur and 60% of those that nest in the province. The ecological values mapped here are generally evenly distributed across the whole coastal mountain region, though some lower elevation areas in the mainland midcoast, and on the Sunshine Coast, and the lower elevations throughout the region stand out as areas of higher ecological values. Note that there are apparent white 'squares' on the map because some areas lack significant data (i.e., tree farm licenses on Haida Gwaii and Vancouver Island plus private land areas, where forest data aren't publicly available).

Ecology	Human Footprint	Climate Change	Carbon	Strategies
Very high values and highly diverse.	Low footprint in mid and north coast. High in South, on Vancouver Island, and in key corridors in the mid and north.	Predicted to be similar to current, but warmer and wetter than anywhere currently in Western N. America.	High stores above and below ground. Stable ecosystems. Opportunity high.	Ecosystem based management reduces pressure on 'Great Bear' region. High urgency elsewhere.

Coast and Mountains

Opportunities to manage for important ecological values remain, particularly in areas with relatively low footprint. High urgency elsewhere on coast to manage cumulative effects. Effects of climate change unknown and could be significant - monitoring necessary. Significant opportunities to prioritize carbon management.

There is a low human footprint throughout much of the mainland coast. However, a number of key corridors have high footprint in the northern part of the region, with localized intensive footprint in the Skeena and Bulkley systems between Prince Rupert and Terrace in the north; and more pervasively in the south in the coast region and on Vancouver Island. A significant history of forestry and road development has resulted in an extensive footprint on the outer south coast of the mainland. On Vancouver Island the human footprint is both intensive and extensive. There have been multiple cumulative impacts that have affected significant areas of the Island, particularly on the drier east side. Regions around Victoria, Vancouver and the lower mainland exhibit a significant and permanent human footprint.

The predicted climate envelope shifts on the coast appear, at first glance, to be relatively low in comparison with other areas of the province. The most obvious predicted shifts are an extension of the climate envelope currently associated with the dry low elevation coastal Douglas fir system, which is shown to shift further up the mainland coast and into the Hecate lowland region. A more detailed look at the modeling results shows however, that of all the predictions for B.C. ecosystems, the coastal predictions have significant uncertainty. The model "looked for" climate envelopes to "match" current envelopes and could not find a good fit for coastal regions anywhere in Western North America. This leaves significant uncertainty in our knowledge around potential predictions for these globally important ecosystems.

Strategies: Map 8 shows that the coastal region is typified by extensive areas of both relatively low human footprint and high ecological proxy values. The implementation of ecosystem-based management for the mid and north coast will promote a lower risk management strategy for this area. Such a strategy will help to maintain these unique values. Careful management will be required however, to deal with the upcoming climate change challenges for these systems, as will the management of the increasing numbers of new industrial developments (e.g. power project developments and mining), including those occurring in some of the more northern watersheds in this region (e.g. the Iskut).There is, in contrast, a significant human footprint which limits potential conservation opportunities on Vancouver Island and the southern part of the coast. Vancouver Island and the lower Fraser Valley currently have a significantly different forest management regime and a greater human footprint from other activities, particularly on the east side of the Island than the 'ecosystem-based management' areas further north. Important opportunities remain to identify critical movement corridors and habitat areas within this zone, but urgent action is needed due existing and growing development, combined with the largely unknown effects of climate change on these forest ecosystems.

CENTRAL INTERIOR AND SOUTHERN INTERIOR

The south-central portion of B.C. is significant due to its historic ecological diversity. The massif of the Coast Mountains creates areas of steep rugged terrain on the west side. This rugged terrain has high wilderness values, mature and old forest, many lakes, rivers and wetlands and shrub-grassland habitat. For example the area contains the Tweedsmuir Park area, the large and obviously outstanding intact area around the Stein Valley, connecting the interior to the coast.

Ecology	Human Footprint	Climate Change	Carbon	Strategies
Localised high value areas – at multiple scales. Extensive areas with lower values remaining.	Extensive areas of very high cumulative footprint, with key exceptions in mountain areas.	Significant shifts, with large increases in grassland envelopes, and predicted loss of drier forest.	Fire and CC likely to result in significant release. Management strategies need to prioritize to reduce losses.	Opportunity low- but urgent to protect remaining core areas, and to allow species movement. Urgent to manage for restoration and resilience.

Southern Interior and Central Interior
High footprint in many areas increases pressures, and reduces opportunities for natural adaptation to climate change. Puts increasing pressure on the need to protect and connect the isolated remaining areas of habitat in these regions. Restoration and cumulative effects management urgent.

Historically, open forests, grasslands, wetlands and growth inland temperate rainforest were prevalent in the Southern Interior. Today, however, the Central and Southern interior regions generally have low ecological proxy values due to the high and extensive human footprint. Only relatively small patches of old growth forest and grassland remain, and wetlands and riparian areas have seen extensive losses. The plateau country of the Central Interior has relatively little mature and older forest remaining due mostly to a significant die-off following the mountain pine beetle epidemic and extensive and intensive forest harvesting and salvage in this zone.

It is worth noting that this region not only has one of the highest natural species diversities in the province but also contains the last remaining habitat of many rare and endangered species. Overall, the historically high ecological values have been significantly impacted leaving only small areas intact, and so tend not to be seen on this scale of map.

Fig. 2. Landscape level effects of forest harvesting east of Prince George in the Central Interior Mountains.

The human footprint map for this region reflects the pervasive levels of cumulative development throughout the Central and Southern Interior. The type of footprint and its ecological influence differs throughout these zones. An extensive road network associated with forestry (Figure 2) and human settlement is central to the footprint throughout both regions. The footprint also reflects the extensive mining, power lines, agriculture and grazing. This large area has a significant, pervasive and largely permanent footprint in comparison with the rest of B.C.. The pace of development in major valleys is currently continuing largely unabated and with little if any planning or cumulative effects management.

Climate change predictions for these regions suggest significant changes. The key prediction is a reduction in area of low and high elevation dry and moist forest types, and a significant increase in the amount of the grassland climate envelope. In this particular climate scenario, there is an additional 150,000ha forecast from the current 30,000ha of grasslands. The extent of this change is ecologically significant: a change to a climate envelope that in other areas does not support tree growth, and will also represent a significant ecosystem goods and services shift. The area of higher elevation parkland or alpine systems is also forecast to be reduced significantly in this scenario.

Strategies: high value ecological areas are limited in this landscape, so remaining old growth, wetlands, riparian areas and functional grasslands warrant immediate conservation action. For climate change adaptation, this area if key to allowing movement of species into new ecosystems, yet options have or are rapidly being foreclosed by intense development in many key valleys (e.g. the Okanagan). Managing for connectivity in the few remaining intact systems, and maintaining or restoring ‘stepping stones’ in development areas is critical. **This high diversity area warrants immediate conservation actions and planning and management of cumulative effects.**

SOUTHERN INTERIOR MOUNTAINS

The Southern Interior Mountains Ecoprovince containing the Rocky, Selkirk and Purcell Mountains have somewhat similar ecological diversity and values to the coastal regions. Historically, old growth forests, grasslands, a diversity of lakes, rivers and wetlands, and the more localized habitat for endangered species and ecosystems are responsible for the highest values in the area. High elevation glacier systems that don't have the coarse filter ecological attributes mapped here, and the large amount of privately managed land (where data are missing) are responsible for some of the areas on the map that score lower ecological values within this region. In addition, some areas (primarily in the Rockies) are mapped as not having "an intact predator prey system", which makes them stand out from neighboring areas where similar intact systems have been mapped by the Ministry of Environment. However, the whole area still retains populations of large carnivores such as cougar, grizzly and black bears and recovering populations of Kokanee Salmon, unlike the neighbouring Southern Interior where significant populations of large mammals are already lost. .

Ecology	Human Footprint	Climate Change	Carbon	Strategies
Areas with high ecological proxy especially in mountain areas	Generally low footprint overall, but high cumulative footprint in major valley systems. Massive expansion in existing backcountry not shown.	Warmer / wetter at higher elevations, with increased grassland and dry forest at low elevations.	Opportunity to maintain carbon stores, and reduce losses through management	Urgent protection/ restoration of remaining habitat. Consider ecosystem trajectory. Connectivity management key due to footprint.

Southern Interior Mountains
Generally low footprint in mountains has resulted in this area retaining BC's southern-most populations of predators such as grizzly bears. But intensive footprint in key natural corridors (major north /south valleys and through mountains) create barriers to CC adaptation. CC itself will intensify this with shifts in type of ecosystems present in these zones, increasing need to restore and protect areas to promote species movement.

The overall footprint for this region is low, but the areas of cumulative development are distributed within and around the majority of the major valley systems. Examples include the Rocky Mountain Trench, the Elk Valley, the Kootenay Lake and Arrow corridors, and the various travel ways through the major mountain systems in this region. Some of these areas have significant cumulative types of development pressures from forestry, reservoir and dam development, transportation and mining. These activities reduce habitat quality and make the movement of species in otherwise obvious travel corridors difficult. Humans have inhabited and developed the valley bottoms which also provide critical wildlife habitat and movement corridors. The climate change scenario examined here suggests a complex series of changes whose ecological significance are hard to determine without finer scale examination. In the big picture however, the current low and high elevation moist and wet types may tend to become more coastal in climate, becoming wetter and warmer. The current dry, low elevation areas are predicted to shift to drier lowland forest, or grassland envelopes in across a wide area. The extent of this predicted change to drier forest, or grassland is much less than in the adjacent Southern Interior, but is still significant. These are the areas where people currently live and work, and such a shift will change fire regimes and the goods and services available in these areas. Parkland habitats will decrease, and there is an increase in alpine climate envelopes predicted in these zones.

Strategies: like the adjacent Southern Interior, identifying key areas of existing low elevation habitat will be key to promoting biological diversity here. The expanding human footprint in sectors such as mining requires cumulative effects management to ensure key values are not lost. Climate adaptation will require planning to ensure movement of species in this topographically challenging area.

SUMMARY

Large areas with high ecological proxy values and low human footprint are globally rare, and support globally rare ecological values in B.C.. They also present relatively low cost opportunities for conservation action today;

- Within each ecoprovince, larger areas with high remaining ecological proxy scores may be particularly important to maintain into the future. More local scale work is needed to identify such important remaining area of habitat, and undertake conservation adaptation planning, but this report identifies the distribution of potential starting places for investigation, with potential identification of core areas;
- Areas with overall low average footprint are often interspersed with relatively focused moderate or high human footprint. Although small in area, these are often critical geographic locations, including low elevation valleys on the coast, significant physical corridors between or through mountain ranges, confluences of river systems, and so forth. Here, small areas of highly functional habitat can be compromised by a relatively focused footprint. Identifying key areas to both mitigate existing impacts and to plan ahead to avoid future impacts to functionally critical areas for adaptation should be a priority across B.C., but particularly in areas with rapid development footprints.
- Overall, regions with relatively low footprints represent opportunities for relatively low cost conservation / adaptation opportunities to maintain significant ecological values into the future.
- These maps consider only the existing footprint, and in parts of the province (e.g. the northwest) the rate of increase in industrial footprint is dramatic. In areas with a high rate of change, areas with the highest ecological values, as well as critical areas for habitat and movement, must be maintained as new development projects are planned.

Conversely, significant areas of the province have a moderate or high footprint today. These are primarily areas on Vancouver Island, in the north east of the province, and large parts of the Central Interior and Southern Interior. Within these areas:

- Areas with higher remaining ecological proxy values are likely of particular significance for protection today in order to maintain existing ecological values.
- Areas with low ecological proxy values have likely already been impacted, and restoration of key areas should be paramount. In both the south/central and north east of the province, consideration of future climate change trajectories will be particularly key to determining appropriate restoration strategies.
- Such large areas with extensive cumulative footprint point to the urgent need for developing effective cumulative impact assessment and management in determining resource development policies.
- Areas with concentrated high footprint represent a significant threat to functional ecosystems overall in the region. Urgent development of policies to mitigate these threats should be undertaken.

	ECOLOGICAL PROXY LOW	ECOLOGICAL PROXY MEDIUM	ECOLOGICAL PROXY HIGH
FOOTPRINT LOW	**Risk / Urgency** – lower **Opportunity** – high **Priority** – cumulative effects management needed now.	**Risk / Urgency**– lower **Opportunity** – high **Priority** – cumulative effects management needed now.	**Risk / Urgency**– moderate **Opportunity** – high **Priority** – planning and action needed to maintain options. Local analysis required.
FOOTPRINT MEDIUM			**Risk / Urgency**– high **Opportunity** – more limited **Priority** – planning and action to mitigate / to maintain options
FOOTPRINT HIGH	**Risk / Urgency**– high **Opportunity** – limited **Priority** – action to mitigate / to maintain options	**Risk / Urgency**– high **Opportunity** – limited **Priority** – urgent action to mitigate / to maintain options	**Risk / Urgency**– highest **Opportunity** – limited **Priority** – urgent action to restore and limited maintain options

STRATEGIES FOR ACTION

CONSERVATION AND ADAPTATION OPTIONS

Simultaneous with required immediate mitigation actions, conservation and adaptation strategies are essential if we are to maintain functional biodiversity and reliable ecosystem services into the future. The true value of 'ecosystem goods and services' – that is, the supports to human life that are provided by nature are often only appreciated as they get lost. When "bits and pieces" of nature's complexity disappear, people are typically surprised by the implications to human populations. Having robust conservation and management goals also reflects the growing need for humility in the field of policy development; good policy makers have realized that 'commanding and controlling' nature generally has not been successful. The loss of the Atlantic cod stocks, 15 million hectares of dead pine in the interior of B.C., increasing mortality of cedar trees across southern B.C., and large fires occurring earlier in the fire season are all examples where humans have recently been 'surprised' by nature when apparently well thought-through management strategies have failed.

Good land management – and therefore good conservation planning contains the following elements:

Effective Protected Areas: To be effective, protected areas must be sufficient in size, well placed, and representative of the range of ecosystem types. While the maps in this show existing protected areas, we do not analyze their quality or distribution. Around 15% of B.C.'s land base is protected in parks and reserves, with a high variability by ecoprovince and by biogeoclimatic zone. Mountain tops are more protected than productive valleys; northern regions and the coast have more protection than other areas. Some ecosystems have extremely low levels of protection, such as the coastal Douglas fir, grasslands and dry forests in B.C. – all areas with the highest densities of rare and endangered species and ecosystems (Austen 2009). Most protected areas are not linked together or managed for their particular roles in maintaining landscape connectivity. Recent conservation advice suggests around 50% of the landscape should be in large well placed areas managed for conservation (parks or other designations) in order to provide sufficient core area to maintain most species and functions across the landscape (Noss et al. 2012; Environment Canada 2013). Yet still, most politically-driven conservation targets and outcomes are much lower than this level (Svancara 2005).

Maintain or Restore Critical Habitat: At smaller scales than protected core areas, rare habitat types and habitats critical to maintaining populations in the long term should be maintain or restored. These act as critical habitat for non-mobile species and stepping-stones for mobile ones.

Maintain Functions Everywhere Else: Manage the remaining land base to ensure critical habitat elements and key functions are maintained at all scales, (i.e. across landscapes and stands). This includes maintaining adequate levels of habitat to result in low risk to ecological integrity, maintaining natural hydrologic patterns, and maintaining landscape connectivity for the wide range of species large and small.

Plan Ahead Without Blinders on: Ensure that individual human activities do not exacerbate one another and together impact critical habitats and functions. Cumulative effects analysis must be used to ensure adequate planning in advance of development. This process is in its infancy in B.C. and will require significant political buy-in if it is to become effective.

Create or maintain Viable Linkage Corridors Between Protected Core Areas: allowing species to move between protected areas has been core habitat areas has been considered key to maintain genetic diversity and functional systems for many years. However, even without climate change, it has been recognized that protected areas are generally insufficient to maintain robust populations of most species.

HOW DOES CLIMATE CHANGE AFFECT CONSERVATION PLANNING?

Climate change brings with it some of the most fundamental changes possible for ecosystems and species – including humans. At the most basic level, changes in seasonal temperatures and moisture levels will fundamentally change the species that can and will inhabit individual places in the province, resulting in a cascade of further change. Dynamics between species will change. At the local scale, some populations will increase and others will decrease. At the broader scale, the natural disturbance regimes that maintain and change systems will alter, in some areas significantly (for example, fires may become more frequent and severe as temperatures increase). Resetting an existing system to a new ecosystem may involve moving through a period of intense disturbance while fuel levels and fire regimes re-align with one another.

For example - areas with frequent fires tend to have low fuel loadings as excess fuel is burned frequently. As a system moves from a historic low frequency fire regime to one with a higher likelihood of fires, there will be a period where high fuel loads are present – leading to the potential for massive and catastrophic fires, in the period of adjustment.

The building blocks of good planning as outlined above remain unchanged, but climate change adds urgency to:

Review Goals: Adjust land management goals to focus on maintaining ecosystem services over the long term. The landscape level overview, combined with information about climate change, causes us to change how we consider planning and management. Adopting a broad goal that prioritizes maintaining ecosystems and ecosystem services will provide the most likely opportunity for natural systems to adapt (Seppala et al. 2009).

Modify and Increase the Area of Protected Areas: As ecosystems disassemble and reassemble, having sufficient area that is largely free from the stresses of the human footprint and representative of the fundamental building blocks of ecosystems (termed 'enduring features' or ' land facets' e.g. Anderson 2010; Beier 2010). This type of analysis has occurred in limited areas of the province to date (Pojar/Kehm) and should be expanded. The area protected should also be increased in line with levels likely to be effective, something on the order of 50% of the landscape (Noss et al. 2012; Environment Canada 2013).

Consider the Future State of Ecosystems: Examine the trajectories for future ecosystems, under a range of models and scenarios (Millar et al. 2007; Chapin et al. 2009; www.resiliencealliance.org). Based on the predictions of what may occur in the future, and their level of certainty, assess whether the goal of management for a given ecosystem is to:

a) **Manage for resistance** which involves maintaining the current structure and function; an example of this is to maintain important old growth which moderates its own climate and provides a reliable water source into the future;

b) **Manage for resilience** such as reducing fire risk in a forested ecosystem where fuel loadings are high, but to also 'bet hedge' by maintaining appropriate species and structure throughout the zone;

c) **Manage for transition** in areas with high agreement that significant and potentially catastrophic disturbance and change is likely, such as from forested to open forest or grassland; here appropriate species can be introduced, fuel loadings can be significantly reduced etc.

Connect Landscapes: Understand that climate change isn't a simple 'moving north' story. The changes are complex, and will occur in all directions and at multiple scales – moving up mountains, through valleys, through mountain ranges, across plateaus, and so on. Very large areas with little gradient will be particularly difficult to manage for conservation (e.g. across the south and central interior), and will be further exacerbated by the human footprint. There is an urgent need to get strategies in place today.

This brief summary points to a change in mindset that climate change requires, but in many cases options are relatively limited. Classic conservation strategies are needed as much as ever, while climate change primarily increases their urgency. In addition, climate change adds a new dimension: we must actively consider what may be coming, and figure out how to reduce vulnerabilities and maintain resilience into the future (Chapin et al. 2009).

CONCLUSIONS AND NEXT STEPS

British Columbia is one of few places remaining in the world where healthy populations of the full complement of species still roam wild in many areas, and globally rare ecosystems such as inland and coastal temperate rainforests still exist in large tracts. **This vision lulls people into a false sense of security.** B.C. is the last vestige of a 'once wild' North America (Laliberte and Ripple 2004), but the pressures on ecosystems here are significant and increasing.

This report highlights the areas of B.C. with the highest and most extensive levels of human footprint. The scale of the mapping highlights regional and provincial patterns. Very localized developments, which can also have significant negative impacts, are important to track, but were outside the scope of this project

Given B.C.'s high global responsibility for biodiversity values, all areas with the highest ecological proxy values are of significance. This diversity of coarse ecosystems – connected hydrologic systems, older forests and important local habitats – will all be key to adaptation planning for the future. Any highest value proxy areas existing among areas of higher footprint are likely of significant importance, and are likely at high functional risk today. However, at the scale of the province, many important values are not visible on this map. Next steps must include regional level analysis and planning to identify locally relevant critical areas, including viable species corridors between regional core areas using the best data available, and the development of conservation strategies to maintain these areas into the future.

Surprisingly to many, and contrary to the idea of a green B.C., there are large areas of the province with significant extensive and cumulative human footprint. Large areas with the highest footprint today are also the same areas with the highest densities of rare and endangered species and habitats. Immediate measures are needed to prevent further losses, and to begin to restore the functioning of ecosystems and processes in these areas.

Areas where the human footprint remains low today are significant since they provide opportunities to maintain options for natural adaptation; such opportunities are increasingly rare both within B.C. and globally. There is also variation in the ecological values present in the low footprint areas. Areas with high ecological proxy values, especially those found within areas of generally lower diversity, may be particularly important to identify and maintain into the future. This analysis provides a starting point for identifying these areas, and more regional planning is needed to verify critical areas of interest.

Areas with a moderate level of footprint today are at risk from the impacts of cumulative development. Within these general zones, areas with highest ecological proxy values should be identified and their functions protected. Policies should be developed that manage the effects of cumulative development, especially to areas with higher ecological proxy values. Restoration of ecosystem functions and habitat will be required in some areas.

This provincial-scale project has focused on broad patterns of ecosystems, however individual species, and therefore their ecosystems, will vary significantly with respect to their vulnerability to climate change (Pojar 2010; Dawson et al. 2011). Significant efforts are needed to attempt to understand this variable vulnerability, and to identify foundation and keystone species that warrant particular focus. This will vary regionally in this vast province, but is a key step needed in prioritizing conservation actions.

Development occurs faster than conservation and Map 3 makes it clear that much development is ongoing in B.C.. Effective planning that focuses on cumulative effects management is crucial to ensuring B.C. maintains its existing biodiversity values and opportunities. Climate change is also outpacing conservation actions, further increasing the urgent need for active management of B.C.'s landscapes to ensure effective adaptation.

Mitigation of climate change will become a primary human endeavor. Looking for synergies between adaptation planning and carbon storage should be a key element of land management decisions. B.C. has an opportunity to show global leadership in this regard by thoroughly investigating the stocks and dynamics of carbon in its ecosystems and understanding what opportunities exist to promote both mitigation and adaptation of nature together.

Nothing in our human experience to date suggests that less effort will be needed, or the path straightforward. Yet if our goal is to strive for diverse, functional, and stable ecosystems in the future – the types that humans can rely on for goods and services, economic growth and stability -- then maximizing the ability of systems to adapt naturally to the oncoming changes will be key.

REFERENCES

Anderson MG, Ferree CE (2010) Conserving the Stage: Climate Change and the Geo-physical Underpinnings of Species Diversity. PLoS ONE 5: e11554.

Allen, C.D. et al. (multiple authors). 2010. A Global Overview of Drought and Heat-induced Tree Mortality Reveals Emerging Climate Change Risks for Forests. Forest Ecology and Management 259 (4): 660–684,

Beier P, Brost B (2010) Use of Land Facets to Plan for Climate Change: Conserving the Arenas, Not the Actors. Conservation Biology 24: 701-710.

Chapin F. S. III, G. P. Kofinas, and C. Folke (eds) 2009. Principles of Ecosystem Stewardship. Resilience-Based Natural Resource Management in a Changing World. Springer.

Dawson T. P. et al. 2011. Beyond Predictions: Biodiversity Conservation in a Changing Climate. Science 332: 53

Environment Canada. 2013. How much habitat is enough? Third Edition, Environment Canada, Toronto. http://www.ec.gc.ca/nature/E33B007C-5C69-4980-8F7B-3AD02B030D8C/894_How_much_habitat_is_enough_E_WEB_05.pdf

Fredeen, A.L. 2006. How is Forest Management Influencing Carbon Storage in Sub-boreal Forests? Natural Resources and Environmental Studies Institute, Research Extension Note #06.01. University of Northern British Columbia, Prince George, British Columbia, Canada. http://web.un B.C..ca/~fredeena/Fredeen REN 2006.pdf

Hamann, A. and Aitken, S.N. 2013. Conservation planning under climate change: accounting for adaptive potential and migration capacity in species distribution models *Diversity and Distributions* **19**: 268–280.

Jetz, W., D. S. Wilcove, and A. P. Dobson. 2007. Projected Impacts of Climate and Land-use Change on the Global Diversity of Birds. Plos Biology DOI:10.1371/journal.pbio0050157.

Jump, A. S. and J. Penuelas. 2005. Running to Stand Still: Adaptation and the Response of Plants to Rapid Climate Change. Ecology Letters 8: 1010-1020.

LaLiberte, A.S., and W. J. Ripple. 2004. Range Contractions of North American Carnivores and Ungulates. Bioscience 54 (2).

Millar, C. I., N. L. Stephanson, and S. L. Stephans. 2007. Climate Change and Forests of the Future: Managing in the Face of Uncertainty. Ecological Applications 17(8): 2145–2151.

Nelson, G.C. Undated. Drivers of Ecosystem Change. Chapter 3 Millennium Ecosystem Assessment. Available at: www.unep.org/maweb/documents/document.272.aspx.pdf.

Parmesan, C. 2006. Ecological and Evolutionary Responses to Recent Climate Change. Annual Review of Ecology and Systematics 37: 637-669.

Pojar, J. 2010. A New Climate for Conservation. Nature, Carbon and Climate Change in British Columbia. www.davidsuzuki.org/publications/downloads/2010/newclimate_report_DSF.pdf

Proctor, M., et al. 2012. Population Fragmentation and Inter-Ecosystem Movements of Grizzly Bears in Western Canada and the Northern United States. Wildlife Monographs 180: 1–46

Noss, R.F., et al. 2012. Bolder Thinking for Conservation. Conservation Biology 26 (1): 1–4.

Seppälä, R. A. Buck and P. Katila. (eds.). 2009. Adaptation of Forests and People to Climate Change. A Global Assessment Report. IUFRO World Series Volume 22. Helsinki. 224 pp.

Steffen W., J. Grivevald, P. Crutzen and J. McNeill. 2011. The Anthropocene: Conceptual and Historical Perspectives**.** Phil. Trans. R. Soc. A 369: 842–867.

Svancara L.O.K., et al. 2005. Policy-driven Versus Evidence-based Conservation: a Review of Political Targets and Biological Needs. Bioscience 55: 1-7.

Utzig, G., J. Boulanger and R. F. Holt. 2011. Climate Change and Area Burned: Projections for the West Kootenays. Report #4 the West Kootenay Climate Vulnerability and Resilience Project. www.kootenayresilience.org

Utzig, G. and R.F. Holt. 2012. An ecosystem vulnerability and resilience assessment for West Kootenay Ecosystems. Report # 7 from the West Kootenay Climate Vulnerability and Resilience Project. Available at www.kootenayresilience.org

Van Mantgem, P. J., et al. 2009. Widespread Increase of Tree Mortality Rates in the Western United States. Science: 323: 521–524.

Wilson, S.J. and R.J. Hebda. 2008. Mitigating and Adapting to Climate Change through the Conservation of Nature. The Land Trust Alliance of British Columbia, Saltspring Island, B.C. 58 pp.

WorldBank 2012. Turn down the heat. Why a 4^0 warmer world must be avoided. Available at: http://.climatechange.worldbank.org/sites/default/files/Turn_Down_the_heat_Why_a_4_degree_centrigrade_warmer_world_must_be_avoided.pdf

Yellowstone to Yukon Conservation Initiative (2012) Muskwa-Kechika Management Area: Biodiversity Conservation and Climate Change Assessment. Y2Y, Canmore, AB, Canada.