Research Report

BC Journal of Ecosystems and Management

A vulnerability-based strategy to incorporate climate change in regional conservation planning: Framework and case study for the British Columbia Central Interior

Timothy G.F. Kittel[1], Sara G. Howard[2], Hannah Horn[3], Gwen M. Kittel[4], Matthew Fairbarns[5], and Pierre Iachetti[6]

Abstract

High uncertainty in the future of regional climates and ecosystems presents a challenge to the conservation of biodiversity and landscapes. We present a framework to handle uncertainty in the incorporation of climate change in regional conservation planning. The framework uses expert opinion to: (1) formulate qualitative scenarios of climatic and ecological change based on expected as well as less probable but plausible futures not tied to specific model projections; (2) synthesize established knowledge of the climate vulnerability of species and ecosystems of concern; and (3) specify no-regrets climate adaptation strategies to reduce these vulnerabilities in conservation site selection. This framework was implemented in an ecoregional assessment of the British Columbia Central Interior selecting terrestrial and freshwater high-priority conservation sites. Including climate vulnerability-based adaptation strategies in the regional site-selection process had a substantial effect on both freshwater and terrestrial assessments. Selection of high-priority sites based on these strategies generally increased the number, size, buffering, and connectivity of selected sites; included and expanded on sites selected based on standard (non-climate change specified) criteria alone; and drew more from moderately favourable sites. Although limited by our understanding of species and ecosystem vulnerability, the integration of vulnerability assessment, moderate to severe change scenarios, and a no-regrets approach generated regional conservation strategies for climate change adaptation in the face of uncertainty in the future of climates, landscapes, and species.

KEYWORDS: *British Columbia; Central Interior Ecoregional Assessment; climate change; conservation planning; freshwater ecosystem change; Marxan analysis; no-regrets strategies; protected area selection; scenario planning; species vulnerability to climate; terrestrial ecosystem change; vulnerability assessment.*

Contact Information

1 Institute of Arctic and Alpine Research, University of Colorado, Boulder, CO 80309-0450, USA. Email: kittel@colorado.edu

2 Aquatic Ecologist (Formerly with The Nature Conservancy of Canada, 200–825 Broughton Street, Victoria, BC V8W 1E5). Email: sarahoward@yahoo.com

3 Graduate Student, University of Alberta, Department of Biological Sciences, PO Box 8399 Station Central, Victoria, BC V8W 3S1. Email: hlhorn2@telus.net

4 Vegetation Ecologist, NatureServe, 4001 Discovery Drive, Suite 2110, Boulder, CO 80303, USA. Email: gwen_kittel@natureserve.org

5 Aruncus Consulting, 2130 Kings Road, Victoria, BC V8R 2P9. Email: aruncus_consulting@yahoo.ca

6 Conservation Director, ForestEthics (Formerly Director of Conservation Science and Planning with the Nature Conservancy of Canada). Email: Pierre@forestethics.org

Kittel, T.G.F., S.G. Howard, H. Horn, G.M. Kittel, M. Fairbarns, and P. Iachetti. 2011. A vulnerability-based strategy to incorporate climate change in regional conservation planning: Framework and case study for the British Columbia Central Interior. *BC Journal of Ecosystems and Management* 12(1):7–35. ***http://jem.forrex.org/index.php/jem/article/view/89/66***

Introduction

The Nature Conservancy of Canada undertook an ecoregional conservation assessment for the Central Interior of British Columbia that incorporated climate change as a threat (Iachetti and Howard 2011; Loos 2011). In this article, we present the framework implemented to develop climate adaptation strategies for selection of priority conservation sites in the context of high climatic uncertainty. Elsewhere in this special issue, Howard and Carver (2011), Horn (2011), and Kittel et al. (2011) lay out the details of how this was put into practice for different components of the regional assessment. We provide an overview of implemented climate adaptation strategies and analyze the effect they had on site selection for the ecoregion. This is followed by additional strategies for handling climatic uncertainty in regional planning and local conservation site design. We conclude with a synopsis of the framework and its implementation.

In this article, we present the framework implemented to develop climate adaptation strategies for selection of priority conservation sites in the context of high climatic uncertainty.

The climate change threat

Long-term, on-going anthropogenic changes to the Earth system are multifaceted, involving altered atmospheric composition, disrupted global biogeochemical cycles, converted landscapes, and overused natural resources (Millennium Ecosystem Assessment 2005; Parry et al. [editors] 2007; Solomon et al. [editors] 2007). The physical consequences of these system changes include complex alterations to climate across a range of variables and spatial and temporal scales. For continental lands and waters, observed and anticipated changes entail altered averages, extremes, seasonality, and interannual variability of surface climate and hydrology (Meehl et al. 2007; Allison et al. 2009; Serreze 2010; Fung et al. 2011). Sustained altered forcing may, with time, additionally result in regional climates crossing critical thresholds, producing abrupt climate shifts, or lead to the development of "novel" climates characterized by combinations of conditions with no current analogue (Williams et al. 2007; Lenton et al. 2008; Schellnhuber 2009).

These changes jeopardize the persistence of species, structure of biological communities and food webs, and ecosystem function (Fischlin et al. 2007; Kundzewicz et al. 2007). Ecological transitions may also be non-monotonic, abrupt, and give rise to novel ecosystems (Williams and Jackson 2007; Scheffer et al. 2009). Such environmental changes additionally pose a threat to provisioning of ecosystem services and hence to our socio-economic stability (Fischlin et al. 2007; Rounsevell et al. 2010). The challenge for land management as a whole, and in particular for biological conservation practice, is how to anticipate and plan for such system-altering impacts, including how to develop ecoregional plans that account for climate change in the selection of conservation sites (Hannah et al. 2002b; Mawdsley et al. 2009).

Conservation planning and climate uncertainty

Climate model experiments convey a vital lesson—climate system sensitivity to anthropogenic forcing is of a magnitude and rate to cause substantial ecological impacts that will have consequences for the conservation of biodiversity and ecosystems (Lovejoy and Hannah 2005). The cascade of environmental impacts is often explored through ecological model projections of species, community, and ecosystem dynamics driven by climate model projections (e.g., Kittel et al. 2000; Hannah et al. 2002a). Such climatic and ecological projections are naturally of interest to land management planners, who wish to know with some confidence the rate and direction of climate change for an ecoregion or protected area and the nature of future climates at different planning horizons.

However, a problem in incorporating climate change in conservation planning is the high magnitude of uncertainty in model-generated future climate and ecological projections (Botkin et al. 2007; Conroy et al. 2011). By "high," we mean that uncertainty is as large or larger than system sensitivity (e.g., Tebaldi et al. 2004). Uncertainty in climate projections arises from multiple sources including

- underlying complexity of the climate system and other practical constraints limiting our ability to model climates (Rial et al. 2004; Randall et al. 2007; Knutti 2008; Schellnhuber 2009);

- uncertainty in forthcoming human forcing (e.g., emissions and land use change) determined by future socio-economic policy and global economic growth (reflected in part by the breadth of emission scenarios in, for example, Forster et al. 2007 and Anderson and Bows 2011); and
- insufficient consideration of the spectrum of important human forcings in most climate model experiments (Pielke et al. 2009).

High levels of uncertainty also apply to ecological projections because of inherent ecosystem complexity and because key biotic processes are often poorly considered in ecological model experiments (Botkin et al. 2007; Purves and Pacala 2008; Wiens et al. 2009).

Studies quantifying sources of climate projection uncertainties show them to be high, especially at the regional level (e.g., Tebaldi et al. 2004; Christensen et al. 2007). Progress in both climate and ecological modelling addressing uncertainty issues will advance our understanding of system behaviour. However, many uncertainties are inherently hard to constrain (e.g., stemming from socio-economic, climate, and ecological system complexity), while significant reduction in others is likely to be long in coming (e.g., model representation of system dynamics) (Knutti 2008; Watson 2008; Conroy et al. 2011).

The multiple sources and magnitude of uncertainty mean we do not, and likely will not, have climate and ecological projections that are definitive enough in their geography and temporal progression to rely on for planning. This is not to say that such projections be disregarded altogether; this is for two reasons. First, as noted earlier, model projections tell us that climatic and ecological dynamics are substantially sensitive to ongoing human forcing. Second, the dispersion of projections (e.g., for a range of emission scenarios and models) tells us that we should place wide confidence intervals on projection-based outlooks on the future. In addition, the multiple sources and magnitude of uncertainty mean that while any suite of projections occupies an extensive portion of future environmental space, these projections may not sufficiently capture a broader domain of outcomes arising from unknown, or known but poorly represented, system dynamics.

Limitations in applying projections

Conservation plans have increasingly acknowledged climate change as a threat, but in many cases the strategy has been (1) to decide that the uncertainty is so large there is no reasonable way to handle it in a conservation plan or (2) to focus the effort on an ensemble of climate projections selected to capture responses of different models to a range of emission scenarios as a way of accounting for uncertainty (e.g., Hamann and Wang 2006). Neither approach is satisfactory. The first leads to plan failure by not providing for a critical threat to biodiversity and ecosystem integrity over coming decades. The second is attractive because it gives us maps and numbers to work with, but it is risky because projection-driven planning often proceeds as if working with real possible outcomes, giving a false sense of certainty (regardless of upfront caveats saying otherwise). This approach, even in the case of using ensembles, overlooks or underrepresents sources of uncertainty. In this way, a focus on projections constrains our outlook on possible futures because they do not represent the full domain of possible future climates.

Projections also constrain our thinking because they do not tell us enough (or are used in ways that do not tell us enough) about how future climates will be manifested relevant to the ecology of species and landscapes. Projections are often used in a simple manner relative to climatic controls over processes of interest, only evaluating change in a few variables (commonly temperature and precipitation, whereas wind and solar radiation regimes may be critical to survivorship, for example) and also at limited time scales (such as monthly, rather than additionally considering submonthly events and interannual variability). Such application of projections ignores the complexity with which climate directly and indirectly affects species and landscape processes (Hallet et al. 2004; Kittel et al. 2010). This is partly related to problems of spatial and temporal scale in climate model outputs. Some climate dynamics that drive ecological dynamics and surface hydrology are not adequately portrayed by climate models, such as daily precipitation event structure in global climate models (Randall et al. 2007; Ashfaq et al. 2010). The coarse spatial resolution of global climate model outputs (e.g., 1–4° latitude/longitude grid intervals) further limits the utility of models at ecoregional and landscape levels where these outputs would be most valuable for conservation planning. Downscaling techniques can map projections locally and give additional insights to planners, but these techniques are still subject to underlying global model limitations and come with their own drawbacks (Fowler et al. 2007; Wiens and Bachelet 2010).

Vulnerability approach

An alternative approach to projection-driven assessments is more "bottom up," looking at how vulnerable species or ecosystems are to climate change (Turner et al. 2003; Pielke and Guenni 2004; Young et al. 2010; Dawson et al. 2011; Glick et al. [editors] 2011). Objectives of such a vulnerability approach are to gain insights into resistance (to changing state) and resilience (ability to recover) of conservation elements to a changing climate and, based on this, to devise strategies to reduce or cope with this risk (Hansen et al. 2003, 2010; Game et al. 2010).

Species or ecosystem resistance and resilience are relative to the magnitude of the threat. One technique is to assess vulnerability under a set of "change scenarios" that reflects a breadth of probable as well as less probable but still possible futures (Peterson et al. 2003). The objective, however, is not to evaluate vulnerability across a large, extensive set of scenarios but to limit ourselves to a well-selected, manageable set specifically including scenarios that challenge our thinking about dynamics under future states beyond those experienced or expected (Peterson et al. 2003; Turner et al. 2003). Change scenarios can be general (qualitative) or specific (quantitative) statements of contrasting future states and can be developed from established knowledge of system behaviour, observed trends, system sensitivity from model projections, and "imaginative speculation" (Peterson et al. 2003). These form alternative reference frames for discussing species and ecosystem vulnerabilities. For scenarios developed from projections, it is natural to select a consensus or average of projections as seeming most probable, but exploring outliers can be more in keeping with challenging our expectations of the future.

An important element of the vulnerability approach is that climate risk can be considered in a comprehensive context of other threats, with the goal of devising strategies that enhance the adaptive capacity of a conservation element across the suite of threats. Ideally, these strategies are "no regrets" actions having benefits related to other threats, regardless of what climate future is realized (e.g., Howard et al. 2010; Wilby and Vaughan 2010). (Although commonly referred to as "no regrets," these strategies may more likely be "low" or "least regrets," because increases or some shifting in conservation priorities in consideration of climate change, while having broad benefits, may incur implementation or opportunity costs [Wilby and Vaughan 2010].)

So, in contrast to projection-based approaches, the vulnerability approach helps us deal with climatic uncertainty by focussing on what we know about organisms and ecosystems, on what is expected and unexpected but plausible climate and ecological change, and on no-regrets action. Vulnerability analysis brings with it its own uncertainties, not least of which are gaps in understanding direct and indirect climatic controls over population, community, and ecosystem dynamics as well as in understanding interactions with other stressors—limitations shared with projection-based approaches.

In the next section, we lay out a vulnerability-based framework for considering climate change as a threat in regional conservation planning. In a case study, we then present an implementation of this framework in an ecoregional assessment for the British Columbia Central Interior.

Climate vulnerability framework for regional conservation planning

Treating climate change as a threat

If we consider climate change to be a threat and approach it as other threats, we can devise an integrated strategy (framework) that allows us to plan in face of its uncertainty. With threats such as human-driven habitat fragmentation, flow regime alteration, invasive species, or disturbance regime change (e.g., fire, infestation, sediment loading), certain elements of these threats are unpredictable and have consequences both foreseen and unforeseen. We may not know, for example, the timing, duration, intensity, location, or other biologically critical impacts of a threat, yet we face these uncertainties and devise plans that incorporate these threats. With such threats, we use expert knowledge to assess the vulnerabilities of species and ecosystems to these threats and to recommend strategies to enhance their resistance and resilience (Groves 2003:268*ff*). We can follow the same approach for climate change.

Framework

Our goal was to create a climatic vulnerability framework for ecoregional assessments that:

- is rapid and easily implemented;
- is based on best understanding; and
- produces straightforward, no-regrets strategies for climate adaptation.

The framework has three stages. First, build qualitative change scenarios of alternative future conditions.

Second, assess in what way and to what degree species and ecosystems of concern are vulnerable under these change scenarios. Third, devise climate adaptation strategies to reduce such vulnerabilities. These are strategies to modify conservation targets (species and ecosystems) and corresponding goals (quantity and quality of sites for conservation of these targets), which together make up ecoregional assessment site-selection criteria (Loos 2011). In implementation, the three stages may be woven together and proceed iteratively until well-defined strategies emerge.

Expert team synthesis

The climate vulnerability assessment can be accomplished by multidisciplinary expert teams as are routinely assembled for ecoregional assessments, drawn from non-governmental organizations, agencies, consultants, and academia (Groves 2003:43*ff*)—but with expertise expanded to explore climate sensitivities. The expert teams are charged with synthesizing established knowledge of climate vulnerabilities and potential remedies (adaptive measures) for target organisms and ecosystems, while recognizing the limitations of this task (gaps in data and conceptual understanding). Such synthesis draws climatological, hydrological, and ecological lessons from the field, historical analyses, and model experiments. Model experiments include (but are not limited to) projections under different forcings and are undertaken, in part, to guide change scenarios and gauge climatic and ecological sensitivity. Rigour in team syntheses can be enhanced as time and resources permit through external review or formalized "expert elicitation" protocols (MacMillan and Marshall 2006; Runge et al. 2011).

Because population and ecosystem dynamics depend on biotic and abiotic factors in addition to climatic controls, climate vulnerability also needs to be evaluated in terms of linkages among ecosystem elements. Such functional links contribute to indirect and nonlinear effects of climate and include landscape (e.g., linking terrestrial and freshwater habitats) and trophic connections (e.g., predator–prey dynamics).

In addition, climate change needs to be examined in the context of other threats. Inclusion of these threats in team deliberations is important because of strong synergisms between climate change and other threats, as well as cumulative effects (Sala et al. 2000; Carroll et al. 2006; Brook et al. 2008), and because one way for climate adaptation strategies to meet the no-regrets goal is if these strategies also reduce vulnerabilities to other threats. By bringing a broader threat context into a climate vulnerability analysis, we should also recognize that projecting the future state of other threats comes with its own uncertainties (Sala et al. 2000; Lee and Jetz 2008).

Change scenarios and planning horizons

Teams can evaluate climate vulnerability for different time horizons with corresponding change scenarios. Under the expectation that the climate change threat will increase over the coming decades, vulnerability analyses can be considered for short- and long-term planning horizons. The nearer-term horizon can be considered in terms of climate change scenarios sufficient to alter survivorship and other ecological processes but under which species and ecosystems are still capable of local adaptation, such as over the next 20 years (this represents a "moderate disruption" change scenario). For species, this might be through phenotypic or genotypic adjustment or redistribution within local landscape units. Over the longer term (i.e., towards the end of the 21st century), we can consider the possibility that climatic conditions will have changed so much we have little expectation ecosystems will be the same or any species of concern will be retained on the local landscape (Bachelet et al. 2001; Araújo et al. 2004). Under such a "severe disruption" change scenario, we must consider substantially different adaptation strategies and conservation goals. These two planning horizons have parallels elsewhere in conservation assessment, such as 10- and 100-year time frames applied in evaluating population reduction and extinction risk for species of concern for the International Union for Conservation of Nature's Red List (International Union for Conservation of Nature 2010).

Each team's goal is a manageable number of qualitative change scenarios considered relevant to species and ecosystems of concern at time frames important to planning. Through the process of laying out these scenarios, ecologists and conservation practitioners are able to:

- understand the uncertainties in climate change and limitations underlying climate projections;
- train themselves to use projections to visualize alternative futures and species responses, rather than to tie their thinking closely to details of projections; and
- think beyond projections to develop less expected, more imaginative yet plausible scenarios of climatic and ecological change.

Case study

Ecoregional assessment for the British Columbia Central Interior

The Nature Conservancy of Canada explicitly considered climate as a threat in an ecoregional assessment for the Central Interior of British Columbia (Iachetti and Howard 2011). We give some background on the assessment process in this section; in the following section, we describe how the climate vulnerability approach was implemented for this domain.

The goal of an ecoregional assessment is to select a portfolio of high-priority conservation sites across a region (Groves et al. 2000, 2002). This regional portfolio then guides and provides broad context to finer-scale conservation site design and management plans. Sites are selected to best capture occurrences of conservation targets (species, communities, and ecosystems of high conservation value) (Groves 2003:81*ff*). Initially, selection is based on expert teams identifying these targets and setting corresponding conservation goals (e.g., as a percent of a species's occurrences or of an ecosystem's distribution). These goals are then optimized against site suitability based on current integrity (e.g., protected status, unimpounded watershed) and level of threat from human activities (e.g., distance from roads, road/stream crossings) (see Maps 13 and 14 from Nature Conservancy of Canada, 2010b). The process also favours lowering the total area covered by sites in the portfolio (to minimize area-related conservation costs). This optimization is iteratively accomplished using Marxan site-selection software (Ball et al. 2009; University of Queensland 2011); Marxan implementation for this ecoregional assessment is described by Loos in this issue (2011:88–97), with mapped results presented online (see Nature Conservancy of Canada 2010b). Marxan runs are readily modified to reflect different conservation strategies by altering species and ecosystem targets and corresponding goals (Loos 2011).

For the Central Interior, ecoregional assessments were undertaken for freshwater (Howard and Carver 2011) and terrestrial (Horn 2011; Kittel et al. 2011) realms. These two assessments were separately generated but were co-ordinated to link goals where, for example, species rely on both environments. Expert team members and supporting advisors were selected from scientists and conservation practitioners knowledgeable on the ecology and protection management of species and ecosystems of the region. One expert team evaluated the region's freshwater ecological systems and species, and three teams evaluated terrestrial ecological systems, plant species, and vertebrate animal species, respectively; these evaluations were integrated through discussions among teams and in the Marxan site-selection process. To give an idea of team sizes, the freshwater team had 4 members and 11 advisors, whereas the terrestrial animal species team had 11 members and 29 advisors.

The terrestrial assessment domain encompassed the Central Interior and Sub-Boreal Interior ecoprovinces (see Map 1 from Nature Conservancy of Canada, 2010b). The freshwater domain consisted of the nine major drainages (ecological drainage units) that have a majority of their area within the terrestrial domain (see Map 2 from Nature Conservancy of Canada, 2010b). Conservation planning units evaluated by Marxan were 500-ha hexagons for terrestrial runs and watersheds for freshwater runs (Loos 2011). Because watersheds vary in area, our analysis of freshwater results considered both number of watersheds and total area; terrestrial analyses evaluated number of planning units (hexagons).

Implementation of the climate vulnerability framework

Overview

The ecoregional assessment applied the climate vulnerability framework for both freshwater and terrestrial realms. The teams readily accomplished the development of change scenarios, target vulnerabilities, and adaptation strategies during two workshops over a 3-month period. For each realm, the expert teams prepared two sets of conservation targets and corresponding goals for Marxan runs:

1. a set without climate issues in mind ("standard runs"), and
2. an additional set that incorporated their climate adaptation strategies ("climate runs").

By comparing the results from the two Marxan runs, we evaluated the effect of climate adaptation strategies on site selection in the ecoregional assessment.

Teams applied neither a fixed approach nor predetermined strategies. Each team decided on the most appropriate approach for devising climate adaptation strategies depending on the depth and breadth of their expertise, an exploration of the nature of plausible climate change threats (change scenarios) to organisms and ecosystems in their realm, and an assessment of corresponding climate vulnerabilities. Teams identified areas of overlap (e.g., between freshwater and terrestrial realms, between terrestrial ecosystems and species targets), worked together to integrate their climate adaptation strategies (e.g., freshwater strategies for waterfowl were matched to those devised by the terrestrial animal team), and examined functional interactions among their targets.

In the next sections, we summarize the strategies identified by the teams and subsequently incorporated into Marxan climate runs. Teams also recommended climate adaptation strategies to further modify site selection through regional site-selection criteria that cannot be accommodated in Marxan algorithms and through local conservation site design (see the "Next Steps" section).

Freshwater climate adaptation strategies: Species

In light of a climate change threat, the freshwater team re-evaluated freshwater species targets already identified for the standard assessment (Howard and Carver 2011). Taxonomic groups covered were herptiles, fish, waterfowl, aquatic insects, and mollusks. Species evaluated were species of concern whose life histories in some way depend on continental waters and for which sufficient geographic data existed.

Hydrologic and thermal regime change scenarios by riverine, lacustrine, and wetland ecosystem type were drawn from the literature (Schindler 2001; Tyedmers and Ward 2001; Chu et al. 2003, 2005; Carver and Kangasniemi 2006; Peart et al. 2007; Rodenhuis et al. 2007; Pike et al. 2008a, 2008b). Thermal changes were considered generally; that is, usually not in terms of an explicit range of temperature change. Hydrologic scenarios encompassed either an increase or decrease in precipitation, earlier snowmelt, and the possibility of an increase in storm events. For river environments, scenarios included increased water temperatures, altered seasonal hydrograph (e.g., higher peak flows and longer periods with low summer flow), increased flooding damage, shorter river-ice period, changes in channel structure, and increased sedimentation (Table 1). For lake habitats, change scenarios considered included warmer water temperatures, shorter ice-covered period, altered vertical thermal structure (e.g., thermocline depth and gradient), and shifted shoreline environments. For wetlands, scenarios included reduced wetland size and depth and loss of seasonal wetland habitat.

The freshwater team assessed the vulnerability of species relative to these moderate-disruption scenarios based on knowledge of species life histories (Table 1; Howard and Carver 2011). Where vulnerability was judged to be greatest, species goals were elevated (e.g., for 5 out of 27 vertebrate species), unless the standard-run goal was already set high (Table 1). The evaluation process also allowed for a species to be considered as potentially benefiting from climate change, with the option of lowering conservation goals (one case: Chiselmouth; see Table 1).

Freshwater climate adaptation strategies: Ecological systems

The freshwater team also evaluated ecological system conservation targets; however, for programmatic reasons the goals for these systems were not changed as part of the ecoregional assessment's climate adaptation strategy. In future assessments, goals could incorporate climate adaptation strategies based on hydrologic and thermal regimes (Howard and Carver 2011). Freshwater system types identified by the team as particularly vulnerable were:

- rivers with snowpack-dominated hydrographs;
- small-volume lakes and wetlands (more subject to warming and evaporation);
- hydrologically isolated lakes and wetlands (more subject to local changes vs. those with large watersheds and high-mountain source regions); and
- cold-water regime aquatic environments (such as glacial-melt lakes and streams, and tundra wetlands).

These ecosystems would warrant the assignment of greater conservation goals.

Terrestrial climate adaptation strategies: Ecological systems

In the terrestrial systems assessment, conservation targets corresponded to the "ecological system" in the International Vegetation Classification (NatureServe 2009). An ecological system, as used here and defined by NatureServe (Comer et al. 2003; Kittel et al. 2011), is a dynamic assemblage of plant communities that occurs together on the landscape, is tied together by similar ecological processes (such as underlying abiotic environmental factors or gradients), forms a readily identifiable unit at intermediate geographic scales (tens to thousands of hectares), and generally persists for 50 or more years (and so includes seral stages). The dynamic nature and defined spatial and temporal scales are important attributes of ecological systems relevant to the evaluation of climate change vulnerabilities and development of adaptive strategies.

For assessments of ecological systems, a standard strategy is to set conservation target goals to select a substantial portion (e.g., 30%) of each system where it is found in good condition (e.g., lack of and distance from roads and other human impacts) (Kittel et al. 2011).

TABLE 1. Climate vulnerability rating, habitat, vulnerability under change scenarios, and conservation goals for selected freshwater species of concern (adapted from Freshwater Analysis Appendix, Table 7, Nature Conservancy of Canada, 2010a, and Howard and Carver 2011). Species are selected from most, moderately, and least vulnerable species. For some species, specific populations are indicated (in parentheses). Climate vulnerability rating ranged from 0 to 5, with 5 being most vulnerable ("–2" indicates a species that may benefit from climate change). Impacts for selected change scenarios are given in *italics*. Goals for standard and climate runs are represented as a percent of species occurrences. A standard or climate goal is **bolded** if greater than the other goal. For species with the highest vulnerability ratings (4 or 5), the climate adaptation strategy was to increase the goal from 30% to 50% unless already high (50% or 100%).

Taxonomic group	Species (population)	Climate vulnerability (5=high)	Habitat	Change scenario and *impacts*	Conservation goal (% occurrences) Standard	Climate
MOST VULNERABLE						
Amphibian	Coastal tailed frog *Ascaphus truei*	5	Highly specialized habitat requirements: cool, swift, permanently flowing streams with cobble and anchored boulders	Loss of water and higher water temperatures; small permanent streams may become ephemeral: *Habitat reduction*	30	**50**
Amphibian	Western toad *Bufo boreas*	5	Breed in shallow, littoral zones of lakes, temporary and permanent pools and wetlands, bogs and fens; tadpoles associated with benthic habitats; populations in northern British Columbia depend on areas of high snow accumulation lacking permafrost to survive through winter	Loss of water with reduced precipitation and increased temperatures: *Habitat reduction* Northern British Columbia – reduced winter snowpack: *Reduced winter survival*	30	**50**
Fish	Bull trout *Salvelinus confluentus*	5	Depend on cold clear water (< 17°C); spawning and rearing in small streams	Increased stream temperatures (> 17°C): *Favouring replacement by rainbow trout*	50	50
Fish	Arctic grayling *Thymallus arcticus* (Williston Watershed)	4	Spawn in spring in smaller tributaries shortly after ice-out	Earlier ice-out: *Potential emergence before prey available*; also affected by increased temperatures in tributaries	30	**50**
Fish	Lake trout *Salvelinus namaycush*	4	Lakes	Hypolimnetic volumes in small lakes are expected to warm and shrink with climate change: *Habitat reduction*; warmer water temperatures: *Delayed spawning*	30	**50**
MODERATELY VULNERABLE						
Fish	Sockeye salmon *Oncorhynchus nerka* (x-Fraser)	3	Typically use thermocline in lakes as a cold water refuge	Key temperature issue is warming in streams: *Mostly affecting migration routes*	50	50
Dragonfly	Olive clubtail *Stylurus olivaceus*	3	Ponds and marshes rich in aquatic vegetation	Sedimentation, prolonged low flows, and altered stream structure: *Populations sensitive to alteration of habitats*	30	30

TABLE 1. (Continued)

Taxonomic group	Species (population)	Climate vulnerability (5=high)	Habitat	Change scenario and *impacts*	Conservation goal (% occurrences)	
					Standard	Climate
LEAST VULNERABLE						
Bird	Canvasback *Aythya valisineria*	2	Depend on deep lakes	Deep lakes more stable through changing climate; though for increasing temperatures: *Could affect food sources*	30	30
Fish	White sturgeon *Acipenser transmontanus* (Middle and Upper Fraser River)	1	Large rivers; usually begin spawning after peak spring discharge; eggs and larvae mostly in side channels	Large rivers relatively insensitive; peak flows: *Might help spawning*; though for lower low flows in summer: *Could affect habitat in side channels*	100	100
Fish	Chiselmouth *Acrocheilus alutaceus*	–2	Spawn early summer, egg development temperature-sensitive; adults prefer deeper, higher velocity runs and glides; juveniles prefer side channels with low velocities and dense vegetation	For warmer temperatures: *Potential for increased habitat* (currently limited by lack of warm water habitats)	**50**	30

An additional criterion in target site selection is to represent the variety of the target's physiographic environments. This is accomplished by setting goals for topographically designated "ecological land units" (based on discrete elevation ranges, slopes, and aspects) (Kittel et al. 2011). Together, these criteria select target sites across the horizontal breadth of an ecological system's distribution and by the variety of its topographic settings—a strategy that aims to capture the target's ecological and genetic variability over major environmental gradients (Kittel et al. 2011).

The terrestrial team re-evaluated this approach in light of climate change concerns. Their strategy was to set conservation goals for the near-term scenario to preserve currently intact ecosystems by their ecological land units (the standard approach) and to use the same criteria for the long-term scenario (70–100 years on), when the magnitude of climate changes could severely disrupt these ecosystems (Kittel et al. 2011). The basis for this strategy is that landscapes selected for current physical integrity and to capture the domain's physiographic diversity (i.e., ecological land unit diversity) may offer the best prospect for intact ecological and evolutionary processes and for future development of new, functioning ecosystems (Cowling et al. 1999; Beier and Brost 2010). As "enduring landscapes," these physical landscapes are largely defined by their topographic character and so are not sensitive to climate change (unless significant changes in their geomorphology result from changes in climate). Capturing the variety of ecological land units present as a way of providing opportunities for future habitats under a changing climate was also employed in an ecoregional assessment conducted by Neely et al. (2001).

Under this strategy, standard goals to capture physiographic diversity were maintained when considering climate change but their relevance rephrased. Goals were set to select both areas with high heterogeneity and those with low heterogeneity. As a climate adaptation strategy, selecting heterogeneous terrain offers the opportunity for local species movement within drainages and with elevation as microclimates change, whereas more homogeneous areas may ease lateral movement following regional shifts in climate (e.g., flat terrain of the Fraser Plateau may facilitate native grassland colonization from the south under a warming scenario) (Kittel et al. 2011).

For future assessments, the terrestrial systems team proposed the following:

- to increase target goals above those of the standard approach (30% of mapped area) as a stronger strategy under the severe-disruption change scenario;
- to include a minimum size criterion in target site selection to allow for spatial processes such as disturbance (i.e., the "minimum dynamic area," Pryce et al. 2006; Leroux et al. 2007) and to increase these size criteria in Marxan climate runs (e.g., because of the likelihood of increased fire frequency under a warming, drying scenario; Johnson and Larsen 1991) (Kittel et al. 2011); and
- to favour selection of populations at the northern limits of key species where these limits are well within the ecoregional assessment domain (e.g., for ponderosa pine and Douglas-fir) in consideration of ecological change scenarios with poleward shifts of, for example, forest tree species under a warming scenario (e.g., Hamann and Wang 2006) (Kittel et al. 2011).

Terrestrial climate adaptation strategies: Vertebrate species

The terrestrial animal species team re-evaluated target vertebrate species (herptiles, birds, and mammals of concern) and goals with respect to a climate change threat. Climatological, hydrological, and ecological change scenarios (Table 2) were guided by observational and modelling studies (Koteen 2002; Chan-McLeod and Bunnell 2003; Root et al. 2003; Bunnell et al. 2004; Bunnell and Squires 2005; Hamann and Wang 2006; Murdock et al. 2007; Moritz et al. 2008; Pike et al. 2008a, 2008b; Seip 2008; Spittlehouse 2008).[1] The team developed climate adaptation strategies for moderate-disruption change scenarios for both target species and habitats ("focal ecosystems") (Horn 2011). Implemented strategies include

- adding climate vulnerability of species or habitats as a rationale for including a species as a conservation target (e.g., Great Basin spadefoot, American pika) or, in a few cases, eliminating from consideration species evaluated as likely to benefit from climate change (e.g., Lazuli Bunting);
- for species considered vulnerable to climate, increasing their goals or goals of their corresponding focal ecosystems (decreasing goals if less vulnerable, provided the species is not of concern due to other causes); and
- placing an emphasis on higher elevation and more northern target goals (under a generalized change scenario of rising temperatures) (Horn 2011).

Table 2 presents vertebrate species climate vulnerabilities and corresponding adaptation strategies for selected change scenarios.

Terrestrial climate adaptation strategies: Plant species

The plant species team considered many species of concern to be highly vulnerable to climate change because of current restricted ranges and potentially limited dispersal capabilities. However, because so little is known about physiological and habitat requirements of rare species and because of climatic uncertainties (especially with respect to precipitation), the team concluded it would be difficult to devise species-specific strategies to reduce their vulnerability. Instead, the team implemented more generic strategies to reduce rare plant vulnerability to climate change. These strategies were to conserve populations *in situ* to the extent underlying habitat conditions will allow and to maintain a diversity of sites (e.g., ecological land units) within each ecosystem to provide as broad a mix of future potential habitat conditions as possible. The first was accomplished by selecting all current element occurrences (sites with documented populations), the same as their standard goal. The second strategy relied on the breadth of sites selected by terrestrial ecological system and vertebrate habitat goals as the best opportunity for plant species populations to persist *in situ* for some duration or to disperse to new environments over the longer term (under a scenario of major geographic shifts in habitats).

Effect of climate adaptation strategies: Comparison of Marxan outputs

To evaluate the effect that considering climate change as a threat had on site selection, we compared Marxan output statistics from multiple standard and climate runs. A single Marxan run iteratively produces an optimal set of sites, or a "solution," to meet target goals. However, because a random component to the selection of planning units exists in any one solution, single solutions for different sets of targets and goals are not necessarily comparable. Instead, we tracked how often a planning unit was selected in 500 runs.

[1] Additional source: Morgan, D.G., R. Walton, and D. Fraser. 2009. Assessment of the impact of climate change on terrestrial wildlife in British Columbia. Future Forest Ecosystem Initiative, B.C. Ministry of Forest and Range, and B.C. Ministry of Environment, Victoria, B.C. Unpublished draft.

TABLE 2. Climate vulnerabilities and corresponding strategies for terrestrial vertebrates (adapted from Horn 2011, Table 5). Change scenarios include direct and indirect climatic impacts on species (see text and Horn 2011 for supporting references). Climate adaptation strategies included increasing Marxan site-selection goals for species and associated habitats ("focal ecosystems") and providing for corridors and buffers in conservation site design (see sections on "Terrestrial climate adaptation strategies: Vertebrate species" and, on p. 27, "Landscape- and site-level climate adaptation strategies"; Horn 2011).

Change scenarios	Example impact	Vulnerable species	Climate adaptation strategies
Loss of habitat structure at stand and landscape scales	Old forest structure altered by beetle kill and associated salvage logging	Species dependent on old/mature forests (e.g., mule deer, pine marten, fisher, bats)	Target goals increased for vulnerable species and focal ecosystems
Change in composition of ecological communities	Reduced forage, particularly for specialist species	Clark's Nutcrackers and grizzly bears vulnerable to loss of whitebark pine	Target goals increased for vulnerable focal ecosystems to buffer against change
		Red squirrels and Red Crossbills vulnerable to reduced cone supply due to loss of mature/old pine forests	Target goals increased for focal ecosystems that provide alternative food sources
	Increases in species that thrive under climate change may be detrimental to other species	Caribou vulnerable to increased number and proximity of deer and moose and associated increases in wolves	Target goals decreased for species likely to be "winners" under climate change, or these species not included as targets
Change in hydrology due to change in precipitation, evapotranspiration, and snow accumulation and melt times	Variability in peak and low flows; impacts on water levels of wetlands, lakes, streams	Wetland-dependent species such as amphibians, Eared Grebe, Sandhill Crane, Black Tern, and Long-billed Curlew	Target goals increased for species strongly associated with wetlands and riparian areas and for focal ecosystems such as small forested wetlands
Change in timing of life stage events and habitat use	Early emergence from winter habitats; change in timing of winter range use	Sandhill Cranes and Common Loons arriving earlier and departing later from summer nesting areas	Target goals increased for vulnerable species
Shifts in climatic envelopes of habitats (altitudinal and latitudinal)	Ecosystem latitudinal shifts in response to warming temperatures; warming of high-elevation habitats	Alpine species (hoary marmot, American pika, White-tailed Ptarmigan)	Ensure connectivity at different spatial scales during conservation site design
	Loss of important habitat "hotspots"	Species aggregations (e.g., "Important Bird Areas")	Buffer biodiversity hotspots through increased target goals and conservation site design

This metric, reported as the percentage of runs, is referred to as the "summed solution" (Loos 2011) (Figures 1a–1d; see Maps 18, 21, 27, and 29 from Nature Conservancy of Canada 2010b).

To evaluate the response of sites with greatest conservation value and suitability, we focussed on planning units selected at least 60% of the time—we refer to these as "most frequently selected" sites. In addition, currently protected areas were set to always be selected in Marxan runs because such areas would be included as a matter of course in an ecoregional conservation plan (Loos 2011). Consequently, our analysis further focusses on non-protected, frequently selected sites where changes in targets and goals can have an impact. Given their value and unprotected status, these sites are conservation priorities—we refer to these as "high-priority" sites.

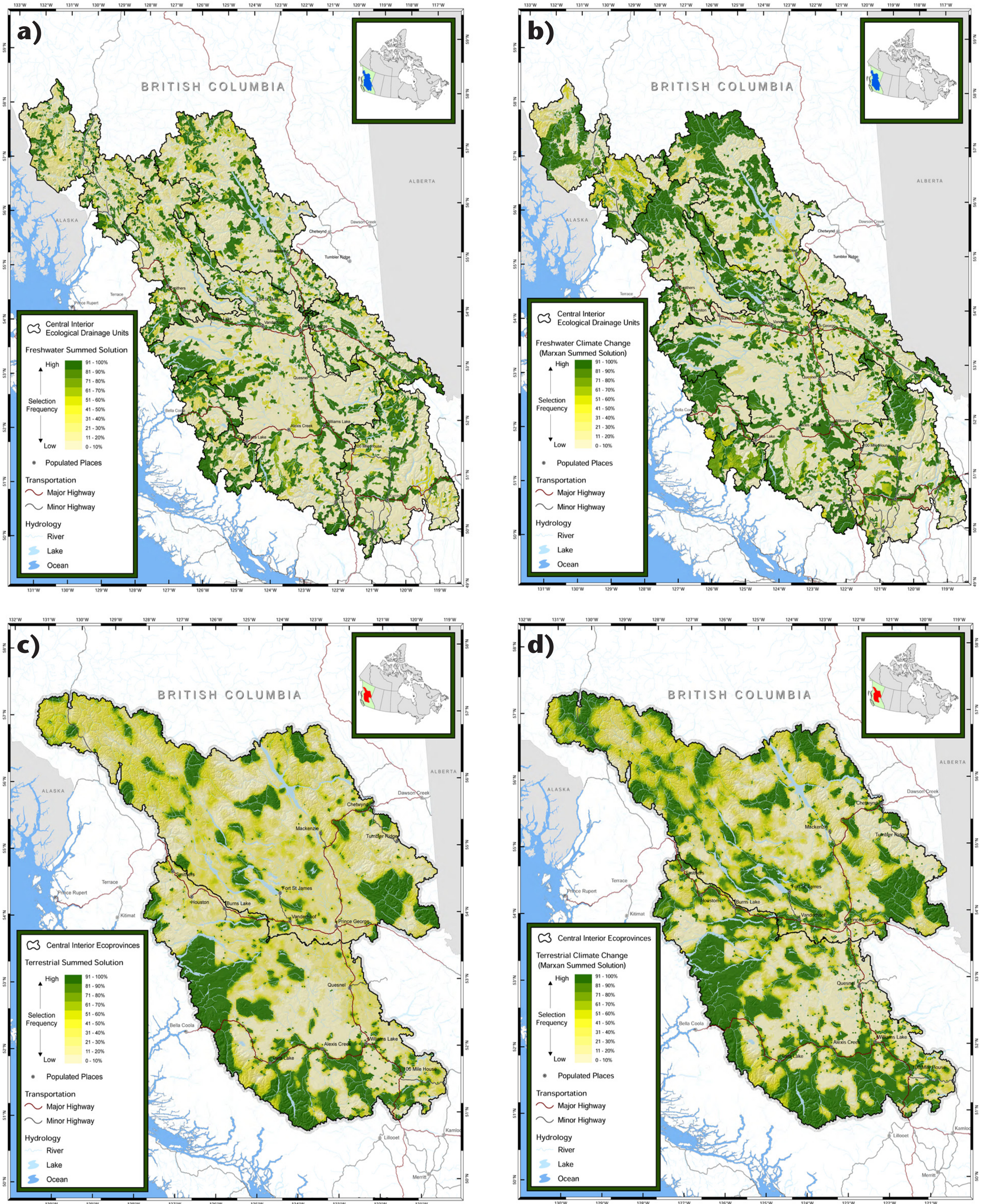

FIGURE 1. Summed solutions for: freshwater (a) standard and (b) climate runs; and terrestrial (c) standard and (d) climate runs. Legend is by deciles of percent selection frequency, with darker shading indicating greater selection frequency. Inset maps show the location of the British Columbia Central Interior Ecoregional Assessment's freshwater (in a, b) and terrestrial domains (in c, d) relative to the rest of Canada. For full-resolution versions of these maps, see Maps 21 (a), 29 (b), 18 (c), and 27 (d) from Nature Conservancy of Canada, 2010b.

Results

Impact of considering climate on the number of selected planning units

In both standard and climate summed solutions, a large portion of freshwater and terrestrial planning units was selected either most of the time (> 90% frequency) or rarely (≤ 20% of the time) (Figures 2a, 2b). Freshwater and terrestrial summed solutions had similar responses to the inclusion of climate adaptation strategies. Compared to standard runs, climate-adaptation criteria shifted these distributions to the higher end—with more sites being selected more frequently. Strong increases were evident in the number of most frequently selected freshwater and terrestrial planning units (selected ≥ 60% of the time) (Figure 3), dominated by increases in sites selected 91–100% of the time (Figures 2a, 2b). For both freshwater and terrestrial solutions, the result was that roughly one-third of all planning units were selected 91–100% of the time in the climate run, up from one-fifth in the standard run.

Character of priority sites

These shifts occurred primarily through an expansion of the standard solution's most frequently selected sites (Figure 1a vs. 1b, 1c vs. 1d, Figures 4a, 4b)—often enlarging areas around species element occurrences and currently protected areas (e.g., Figures 4c, 4d). This expansion drew from sites that were less favoured in the standard solution, shown by decreases in the number of units in 11–40% selection frequencies (Figures 2a, 2b). In contrast, little change occurred in the number of planning units in the lowest selection frequencies (0–10%) for both freshwater and terrestrial climate runs (Figures 2a, 2b) as these were areas with the lowest suitability (see Maps 13 and 14 from Nature Conservancy of Canada, 2010b). In general, then, the climate runs picked less favoured sites to meet higher target goals but continued to avoid the least desirable (most impacted) locations. For both freshwater and terrestrial solutions, implementation of climate adaptation strategies also increased the size and connectivity and reduced the fragmentation of high-priority sites across the domains (Figure 1, Figure 4a, 4b).

Overlap of solutions

The climate solution's solid footing in, and expansion of, standard-solution priority sites was most prominent in the terrestrial domain—nearly all high-priority planning units (selected ≥ 60% of the time and not in currently protected areas) in the standard solution were included in those for the climate solution (Figure 5). This was also illustrated in the mapped differences between terrestrial standard and climate solutions (see Map 28 from Nature Conservancy of Canada, 2010b; also in Horn 2011). The domain was dominated by areas more often selected in the climate solution than the standard solution (orange and dark red areas in Map 28). Only a few of the standard solution's priorities were given up in the climate solution (blue areas; e.g., in Fraser Valley the vicinity of Quesnel).

By comparison, in the freshwater domain, roughly one-third of the standard solution's high-priority watersheds (both by number and area) were not included in climate solution priorities (Figure 5). The difference map between freshwater standard and climate runs (see Map 30 from Nature Conservancy of Canada, 2010b) also reflected this pattern, with a number of watersheds favoured in one run and not the other (e.g., in the Upper Peace River ecological drainage unit). Still, a fair portion (one-third by number, half by area) of the climate solution's high-priority watersheds was carried along from the standard solution.

Geographic dependence

The domain-wide pattern of more high-priority planning units selected in climate solutions than in standard solutions also held for all ecoprovince subunits in the terrestrial assessment (Figure 6b) and all ecological drainage units in the freshwater assessment (not shown). The pattern was nearly universal for drainage units in terms of the total area of high-priority watersheds (Figure 6a).

The response to climate-adaptation criteria tended to be stronger in northern drainage units (Figure 6a) and ecoprovince subunits (Figure 6b) than for their more southerly counterparts. This was more evident in a zonal aggregation of drainage units (Figure 7) and at the ecoprovince level, with a greater response in the Sub-Boreal versus Central Interior (Figure 8a). In addition, a south-to-north shift was evident in the terrestrial assessment with Central Interior planning units preferentially selected over Sub-Boreal ones in the standard solution and the reverse in the climate solution, with Sub-Boreal sites preferred over those in the Central Interior (Figure 8b).

A north–south selection bias was also apparent in the difference map between freshwater standard and climate solutions (see Map 30 from Nature Conservancy of Canada, 2010b). Watersheds strongly favoured in the standard solution but not the climate solution tended to be in southerly ecological drainage units (e.g., Middle Fraser, Thompson) and those favoured in the climate solution over the standard solution tended to be in northerly drainage units (e.g., Upper Peace, Upper Skeena), though with a fair bit of variability within these units.

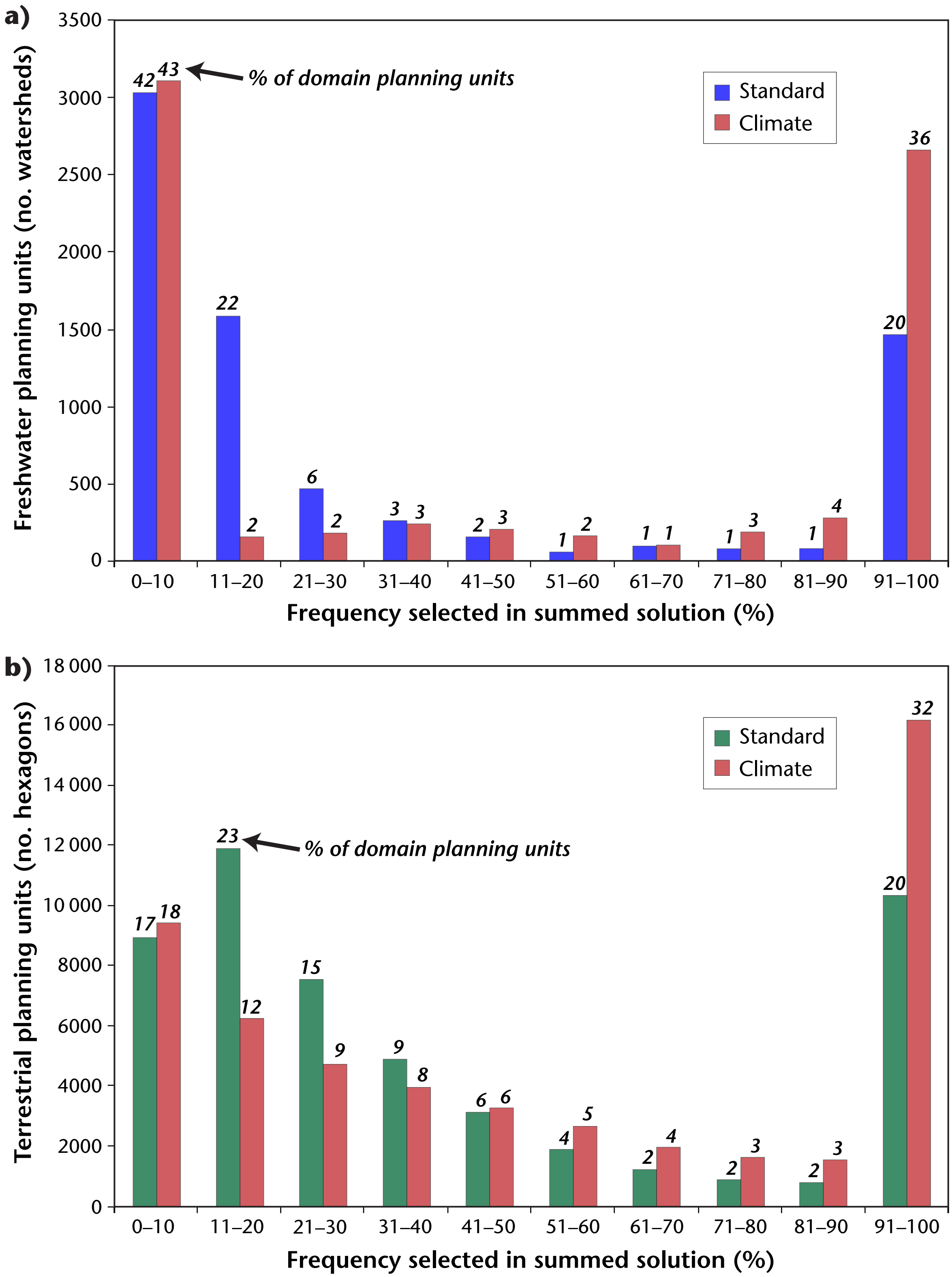

FIGURE 2. Number of (a) freshwater and (b) terrestrial planning units versus percent frequency selected in standard and climate summed solutions for the British Columbia Central Interior. Bars are labelled with percent of freshwater or terrestrial planning units. Planning units include those in currently protected areas.

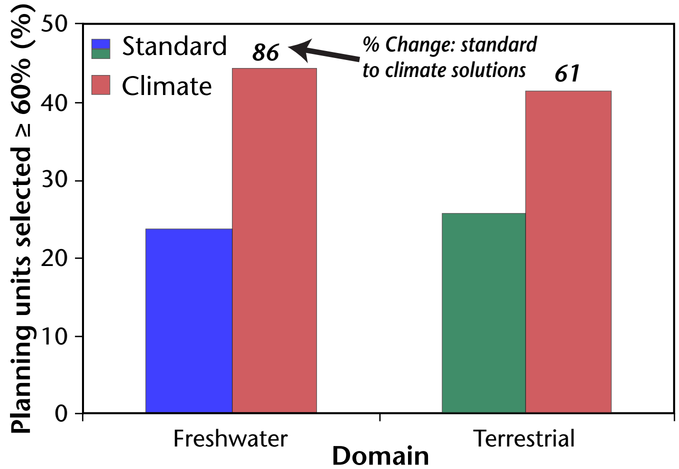

FIGURE 3. Percent of freshwater and terrestrial planning units selected at least 60% of the time in standard and climate summed solutions. Labels on climate bars give the percent change from standard to climate summed solutions. Planning units include those in currently protected areas.

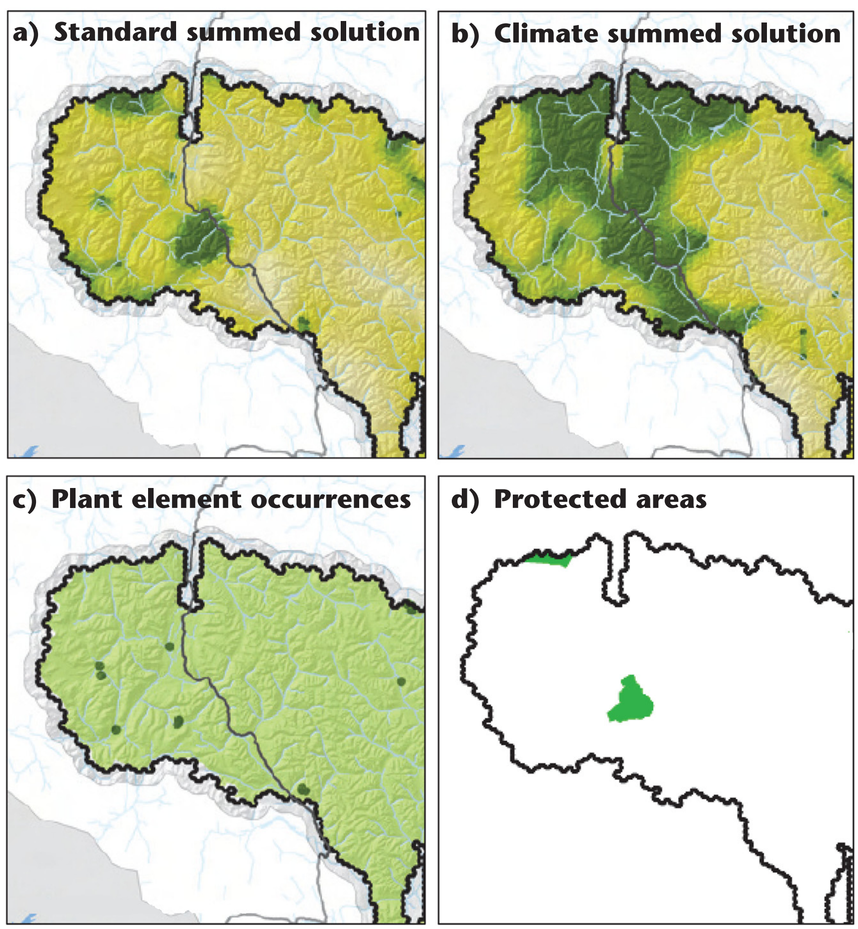

FIGURE 4. Detail of terrestrial summed solutions for the northwest corner of the ecoregional assessment area for (a) standard and (b) climate solutions, compared to (c) plant element occurrences and (d) currently protected areas. Maps (a) and (b) are details of Figures 1c and 1d, respectively, and use the same colour scale. Map (c) is from Map 6 in Nature Conservancy of Canada, 2010b. Map (d) is from Map 3 in Nature Conservancy of Canada, 2010b.

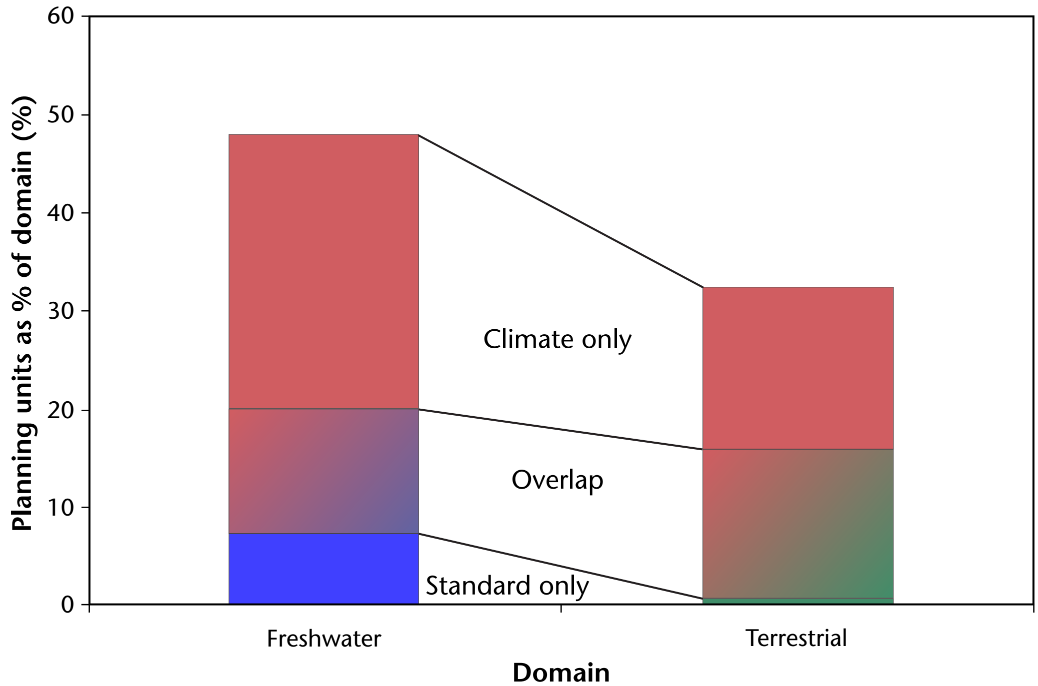

FIGURE 5. The degree of overlap between standard and climate high-priority planning units (selected ≥ 60% of the time and not in currently protected areas) for freshwater and terrestrial summed solutions (as percent of corresponding domain).

A shift was also evident in drainage basin position in the selection of high-priority watersheds in standard versus climate solutions. The number and area of high-priority watersheds substantially increased in headwaters and tributaries in the climate solution over the standard solution, whereas a decrease or little change was evident in mainstem and coastal watershed types (as defined by Howard and Carver 2011) (Figure 9). This retreat upstream was coupled with the northward tendency in this assessment.

Summary and discussion

Results overview

In summary, the consideration of climate change in determining site-selection goals had a broad impact on the ecoregional assessment. Specific consequences for the assessment included the following.

- Implementation of climate adaptation strategies affected both terrestrial and freshwater assessments, influencing them in similar ways.
- A greater number of high-priority planning units was selected in climate solutions versus standard solutions. Likewise, a greater total area of watersheds was selected by the climate solution in the freshwater assessment.
- Climate solutions generally built on units selected in the standard solutions, resulting in a large overlap, as opposed to developing an essentially different solution. Nearly all standard solution units were in the climate solution for the terrestrial assessment, whereas in the freshwater assessment a substantial amount (one-third) was not carried forward.
- To build on the standard solution, climate solutions selected less favoured sites to meet higher target goals but, as with the standard solutions, also avoided least desirable locations.
- Climate solutions increased the size and connectivity of high-priority areas, reducing fragmentation. This was often accomplished by expanding standard-run selected sites to include those adjacent to conservation element occurrences and currently protected areas, increasing site buffering.
- The domain-wide increase in number and total area of high-priority planning units was reflected at the level of ecoprovinces and their subunits and at the level of freshwater ecological drainage units, as opposed to seeing increases in some regions and decreases in others. Nonetheless, the increase in number and total area of high-priority planning

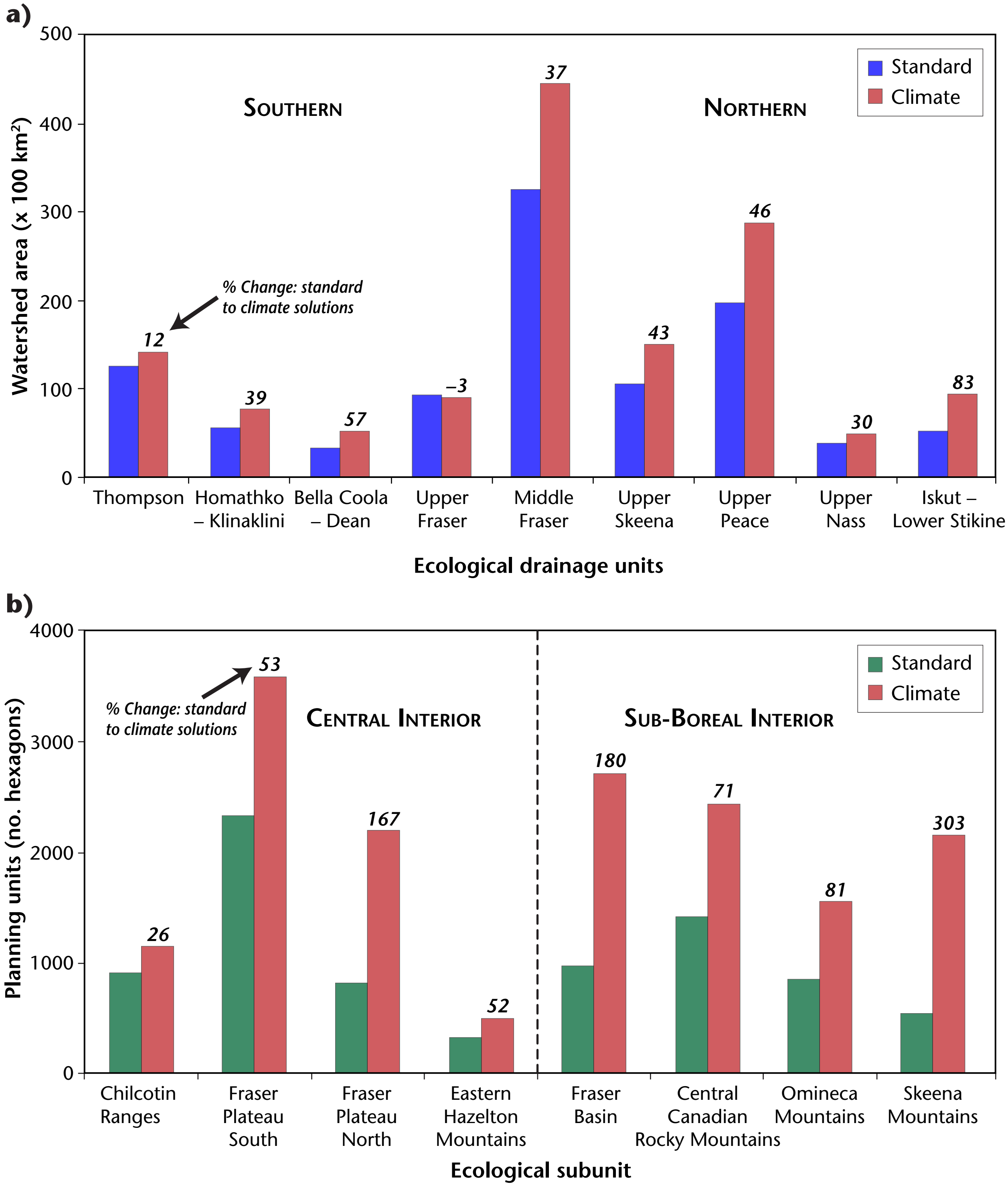

FIGURE 6. The distribution of (a) the area of high-priority watersheds by ecological drainage unit and (b) the number of terrestrial planning units by ecoprovince subunits. Plots compare distributions in standard versus climate summed solutions. Labels on climate bars give the percent change from standard to climate solutions. In (a), general southern or northern positions of the ecological drainage units are indicated (Middle Fraser is central and extensive, with southern and northern regions). In (b), subunits are grouped by ecoprovince: the more southerly Central Interior or northerly Sub-Boreal Interior.

units tended to be stronger in the northern portions of both terrestrial and freshwater domains.

- The freshwater climate solution also favoured watersheds in headwaters and tributaries over mainstem and coastal watersheds.

Discussion: No-regrets outcomes for climate adaptation

Inclusion of climate adaptation strategies in the British Columbia Central Interior Ecoregional Assessment substantially modified the regional conservation plan

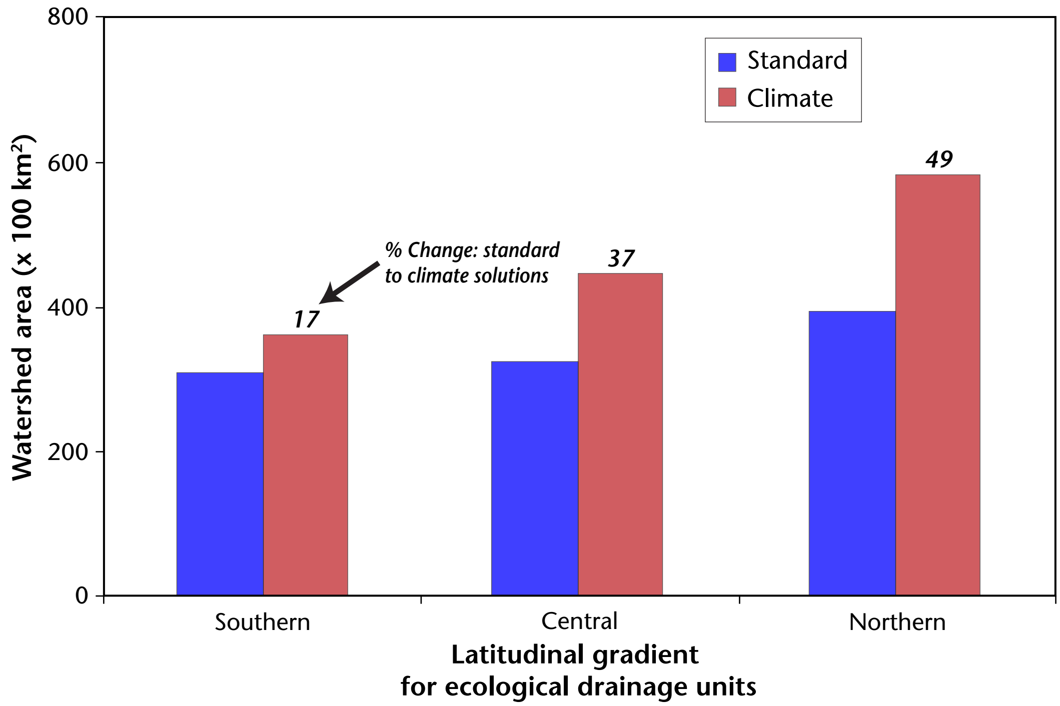

FIGURE 7. The area of high-priority watersheds by ecological drainage unit latitudinal zone for standard and climate summed solutions. Ecological drainage unit latitudinal zones are as indicated in Figure 6a, with the Middle Fraser making up the central zone. Labels on climate bars give the percent change from standard to climate solutions.

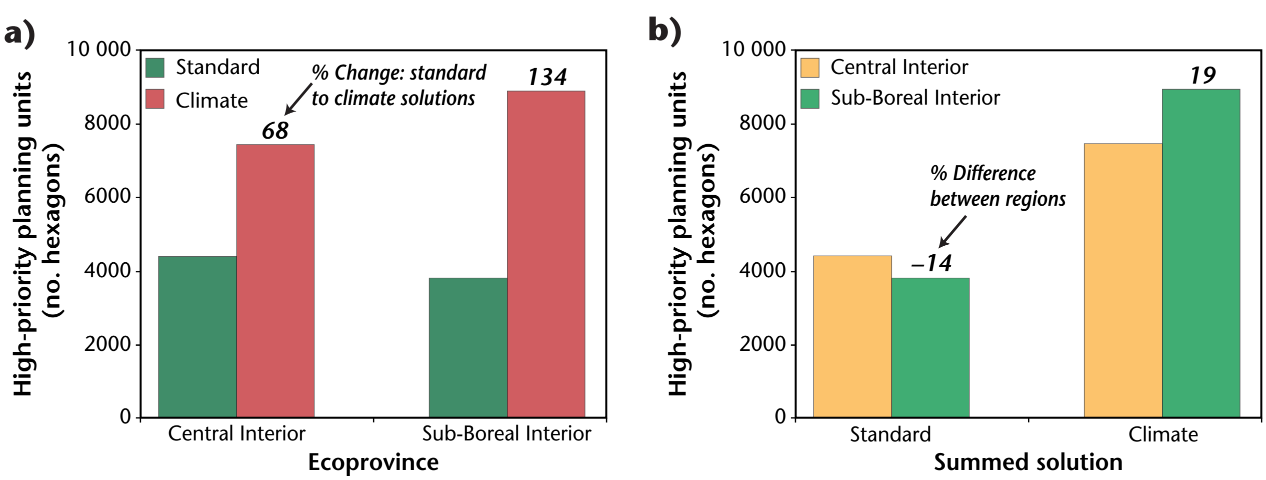

FIGURE 8. The geographic distribution of high-priority terrestrial planning units between Central Interior and Sub-Boreal ecoprovinces for standard and climate summed solutions. Graphs (a) and (b) have the same information: arranged in (a) to show the change within an ecoprovince due to the consideration of climate and in (b) to show differences between ecoprovinces for standard and then climate solutions. Labels on bars in (a) give percent change from standard to climate solutions and in (b) give percent difference from Central to Sub-Boreal Interior.

over one derived using the standard approach. This was in response to conservative changes in site-selection criteria, mostly through moderate increases in goals for the most climate-vulnerable species while not altering ecological system goals.

Terrestrial and freshwater planning outcomes were no-regrets solutions; they increased the number, size, and connectivity of high-priority sites and largely included and built upon sites that would have been selected without criteria based on climate change (i.e., in standard solutions). In addition to selecting highest-quality sites, climate solutions drew more on moderately favourable sites, often buffering critical species occurrences and existing protected areas. To the extent that not all high-priority sites in standard solutions were selected in climate solutions, merging both sets of sites would further support a no-regrets strategy.

An alternative no-regrets strategy could be to simply increase goals across all conservation targets. Climate adaptation site selection based on the climate vulnerability of conservation targets differs from such an across-the-board approach in two ways.

1. Vulnerability-based site selection gives more weight to site requirements of species and ecosystems considered most vulnerable to climate change.
2. With climate vulnerability as an added rationale for selecting conservation targets, site-selection criteria are expanded to incorporate the conservation goals of these additional targets.

In addition, vulnerability-based strategies are guided by generalized change scenarios. Latitudinal and elevational environmental shifts in these scenarios will be reflected in site-selection biases, as seen here in the modest bias toward more northern areas and to higher reaches of drainages under a warming scenario. In contrast, we expect site selection based on across-the-board increases to be geographically neutral or to reflect biases in the distribution of available sites (e.g., expansion into less-favourable areas might give a low-elevation bias as selection moves from remote, intact areas to more human-influenced zones).

By incorporating climate adaptation strategies, the ecoregional assessment provided for larger, less fragmented, more buffered, and more connected conservation sites in a manner that addresses what is known of the climate vulnerability of conservation targets. This climate adaptation, no-regrets regional plan sets the stage for local conservation site design and management plans whose goals are to reduce species and ecosystem vulnerability to multiple threats including climate change.

Improving the process

Implementation of the framework can be improved in regard to:

- the breadth and nature of scenarios we generated and applied,
- gaps in our understanding of climate sensitivities and adaptive capacities of target organisms and ecosystems, and
- the degree to which we considered interactions with other stressors.

Improvements can be instituted in the near term by expanding each team's knowledge base of existing information on vulnerabilities, threat synergisms, and alternative strategies through external review and expert elicitation protocols. Second, in the longer term, we can introduce improvements through adaptive planning: revisiting change scenarios, conservation target vulnerabilities, and climate adaptation strategies as our understanding of species and ecosystems improves through monitoring, research, and experience in implementing strategies in local conservation site design.

Next steps

We developed additional climate adaptation assessment procedures and strategies for implementation in regional and local conservation plans. Although not applied here, we recommend their consideration in other ecoregional assessments. These cover additional strategies for inclusion in Marxan site-selection criteria, regional portfolio review, and local conservation site design.

Additional Marxan site-selection strategies

Although inclusion of the climate adaptation strategies in the ecoregional assessment led to substantial changes in freshwater and terrestrial assessments, not all strategies developed by the expert teams were implemented in Marxan runs for programmatic reasons (Howard and Carver 2011; Kittel et al. 2011). We recommend that these strategies be considered in other regional assessments. Summarized, these recommendations are to incorporate:

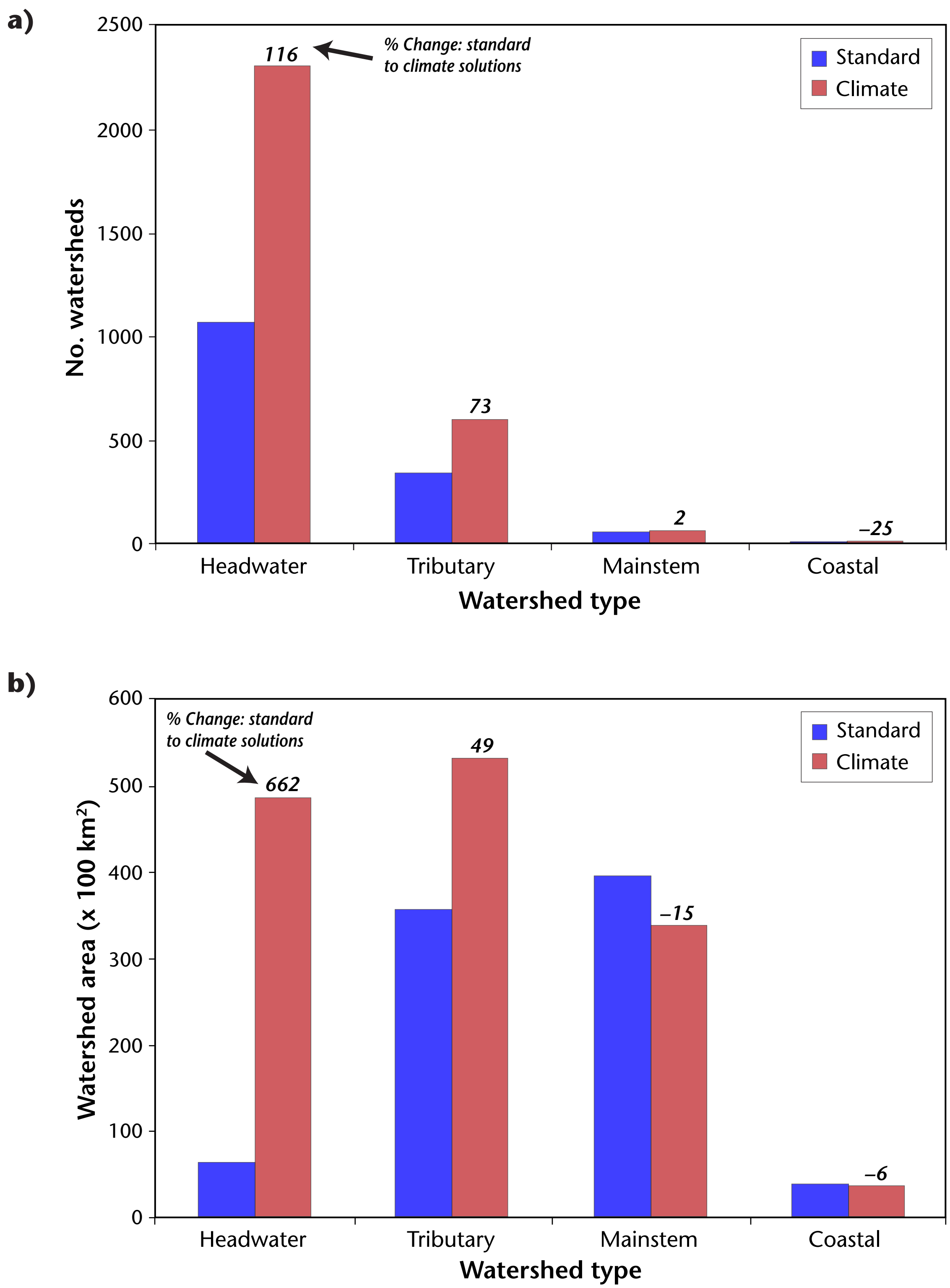

FIGURE 9. (a) The number and (b) area of high-priority watershed distribution by river ecosystem type (based on drainage basin position; Howard and Carver 2011) for standard and climate summed solutions. Labels on climate bars give the percent change from standard to climate solutions.

- Freshwater ecosystem climate adaptation strategies based on hydrologic and thermal regimes. For the British Columbia Central Interior, river ecosystem types identified as particularly vulnerable were those with snowmelt-dominated flow regimes or cold-water regimes. Particularly vulnerable lakes and wetlands were those hydrologically isolated, with small volumes, or in cold-water regimes.
- Terrestrial ecosystem climate adaptation strategies that:
  - Increase ecosystem and physical landscape target goals as a stronger response (than originally implemented) to severe change scenarios.
  - Consider climate-related disturbance regime change scenarios (e.g., increased fire frequency) through implementation of a minimum dynamic area size criterion in Marxan runs and increasing this minimum size as a climate adaptation strategy.
  - Favour selection of sites at the northern limits of specific species as a strategy considering ecological change scenarios of poleward vegetation shifts with warming.

We also recommend that ecoregional assessments include climate adaptation strategies for terrestrial invertebrate species of concern (Horn 2011) and ecosystem services. Regarding the latter, site selection for the conservation of regional ecosystem services was also a core component of the standard runs (Chan et al. 2011). An ecosystem-services expert team developed climate adaptation strategies, although these were also not incorporated for programmatic reasons.[2] These strategies were for carbon storage, timber production, freshwater provisioning, flood mitigation, and recreation. The team considered climate change interactions with other threats such as mountain pine beetle infestation, forest fire risk, and land use change.

Regional site selection review

After an optimal set of sites was generated for the ecoregional assessment from standard Marxan runs, expert teams reviewed the selection and manually added critical features and complementary criteria (e.g., connecting isolated sites) not included in the Marxan analysis (Loos 2011; see Maps 17 and 20 from Nature Conservancy of Canada, 2010b). Although not undertaken here, a similar review of climate runs could incorporate additional, or augment existing (Marxan-implemented), climate adaptation strategies. These could be, for example, to further enhance buffers and connectivity at the ecoregional level (e.g., Rose and Burton 2011; see Map 31 from Nature Conservancy of Canada, 2010b).

Landscape- and site-level climate adaptation strategies

The ecoregional assessment is intended to be a decision-support tool for local conservation site design and management plans (Iachetti and Howard 2011). To this end, we made climate adaptation recommendations for implementing the regional plan at finer scales (Horn 2011; Howard and Carver 2011; Kittel et al. 2011). These are:

- For freshwater species and ecosystems –
  - Enhance landscape connectivity between breeding and feeding sites (e.g., for amphibians and migratory fish).
  - Restore degraded wetlands, rivers, lake shores, and other aquatic habitats (to enhance ecological integrity and site suitability as a climate adaptation strategy).
  - Restore flow, water level, and temperature regimes in managed rivers and lakes (e.g., for salmon: Nelitz et al. 2007).
- For terrestrial ecosystems –
  - In local conservation site design, consider minimum dynamic area in establishing the size of sites and increase this minimum size as a climate adaptation strategy relevant to scenarios of increasing climate-related disturbance (e.g., fires, wind-throw, flooding).
- For terrestrial vertebrate species –
  - Increase buffers and connectivity in conservation site design—with these considered at different spatial scales (to allow for within-drainage, elevational, and regional movement) and time frames (e.g., to connect seasonal habitats across landscapes) (Table 2).
  - Duplicate features within sites to provide redundancy against a loss of habitat types under climate change (including losses from climate-related changes in disturbance regimes).

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[2] Hoshizaki, L. and K. Chan. 2009. Climate change in the Central Interior of British Columbia: Impacts on ecosystem services and adaptation strategies. Nature Conservancy of Canada, Victoria, B.C. Unpublished Climate Assessment Report.

  - Prioritize conservation sites that have intact ecological processes and that are structurally and compositionally diverse—with the objective of supporting ecosystem resistance.
- In addition, for plant and animal species restricted in range and capable of only short-distance dispersal –
  - Give higher site-selection priority to landscapes with greater microhabitat diversity to increase the chance that poor dispersers can re-establish under shifting microsite conditions within the same location (e.g., Pyke 2005).
  - Anticipate the need to assist species at greatest risk of extirpation or extinction to colonize new locations as current sites lose their ability to support these species (McLachlan et al. 2007; Hoegh-Guldberg et al. 2008).
- And overall, in local conservation site design and management plans –
  - Implement monitoring and research programs to observe and understand how species and ecosystems change. Initiate this task from the onset to maximize the length of record.
  - Incorporate adaptive management protocols to update conservation plans in light of observed change and new insights for climate adaptation (Williams et al. 2007; Keith et al. 2011).

Conclusion

Modification of the ecoregional assessment process to incorporate climate adaptation strategies was straightforward (applying standard conservation concepts) and readily accomplished (through expert teams). Implemented for the British Columbia Central Interior Ecoregion, the result was a set of site-selection solutions that were easily interpretable (increasing site number, size, and connectivity) and that met goals to devise regional strategies to cope with climate change uncertainty. Climate adaptation strategies were based on established knowledge of the climate vulnerability of conservation targets and were independent of specific regional climate and ecological projections. Inclusion of these strategies substantially modified the regional conservation plan in ways that complemented rather than replaced one using the standard approach.

To develop these climate adaptation strategies for the regional conservation assessment, we integrated scenario generation, vulnerability assessment, and no-regrets approaches. Faced with climatic and ecological uncertainty, these approaches gave us the framework to understand these uncertainties, to allow for uncertainty in designing conservation strategies, and to reduce the effects of uncertainty in these strategies. We implemented this framework with expert teams composed of conservation practitioners and scientists. Vulnerability of conservation target species and ecosystems was assessed relative to qualitative change scenarios that spanned moderate near-term to severe long-term climate-driven environmental disruption. These were derived by visualizing expected as well as less probable but plausible futures. We synthesized knowledge of target vulnerabilities to generate a range of possible outcomes for species and ecosystems that the regional conservation plan had to address. To reduce these vulnerabilities, we constructed climate adaptation strategies for the selection of conservation sites. These strategies were guided by a no-regrets objective—such strategies lower uncertainty in conservation action as they benefit conservation targets regardless of how climate change occurs. Strategies that focussed on near-term planning horizons included adding climate vulnerability as a rationale for listing a species as a conservation target, increasing site-selection goals for vulnerable species and habitats, and favouring higher-elevation and more northern target goals. Long-term strategies emphasized the conservation of physical landscapes. Although limited by our understanding of the vulnerability and adaptive capacity of species and ecosystems, the vulnerability-based framework generated climate adaptation strategies that make sense in the face of climatological and ecological uncertainty, are easy to implement, and are consistent with current conservation practice.

Although limited by our understanding of the vulnerability and adaptive capacity of species and ecosystems, the vulnerability-based framework generated climate adaptation strategies that make sense in the face of climatological and ecological uncertainty, are easy to implement, and are consistent with current conservation practice.

Acknowledgements

Many thanks to Sarah Loos and Dušan Markovic who managed Marxan runs, data analysis, and mapping. We are also grateful to Carmen Cadrin, Jennifer Burleigh, Andrew Harcombe, Nancy-Ann Rose, Trevor Murdock, Lara Hoshizaki, and other members of the British Columbia Central Interior Ecoregional Assessment Freshwater Team, Terrestrial Animal, Plant, and Systems teams, Ecosystem Services Team, and Climate Change Working Group for their key contributions to this work. Thanks to anonymous reviewers whose valuable comments improved this article. Lastly, we would like to thank the British Columbia Ministry of Forests, Lands and Natural Resource Operations, B.C. Ministry of Environment, the Fraser Salmon and Watersheds Program, GeoConnections, and the McGeachy Foundation for their support of the British Columbia Central Interior Ecoregional Assessment.

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ARTICLE RECEIVED: **December 26, 2010**

ARTICLE ACCEPTED: **April 13, 2011**

Production of this article was funded by Nature Conservancy of Canada and, in part, by the British Columbia Ministry of Forests, Lands and Natural Resource Operations.

Test Your Knowledge . . .

A vulnerability-based strategy to incorporate climate change in regional conservation planning: Framework and case study for the British Columbia Central Interior

How well can you recall some of the main messages in the preceding Research Report?
Test your knowledge by answering the following questions. Answers are at the bottom of the page.

1. For conservation planning and land management, what features of climate model projections for future climate change are important to understand?
   A) Model projections tell us that climate is sensitive to anthropogenic forcing in ways that have substantial ecological impacts
   B) High uncertainty surrounding model projections means we cannot rely on their geography and timelines for planning
   C) Both

2. In implementing the climate vulnerability framework for a British Columbia ecoregional assessment, what tasks were expert teams charged with?
   A) Develop qualitative scenarios of expected and less expected but plausible climate and ecological change
   B) Synthesize established knowledge of the vulnerability of species and ecosystems to climate change
   C) Both, plus specify corresponding no-regrets climate adaptation strategies for site selection

3. For the Central Interior Ecoregional Assessment, what was accomplished by incorporating climate adaptation strategies into the site-selection process?
   A) Climate adaptation strategies provided for larger, more buffered, and more connected conservation sites
   B) Selection of conservation sites using climate adaptation strategies was consistent with a no-regrets goal—climate adaptation-based outcomes that serve other conservation objectives, such as reducing vulnerabilities to other threats
   C) Both, plus climate-adaptation site selection gave more weight to sites with the most vulnerable species and ecosystems and incorporated sites for species not previously considered of concern

ANSWERS

1. C 2. C 3. C