Research Report

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Central Interior Ecoregional Assessment: Freshwater analysis

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Abstract

The Nature Conservancy of Canada recently completed a project to identify priority watersheds for conservation action in British Columbia's Central Interior and Sub-Boreal Interior ecoprovinces. These watersheds will be focus areas for conservation action to protect freshwater ecosystems and species. Conservation planning techniques described in this article include determining conservation targets and goals, identifying these targets with coarse- and fine-filter approaches, and using Marxan software to identify priority watersheds for conservation actions such as land purchase and management actions. Methods to incorporate connectivity within freshwater ecosystems are also discussed, along with methods to include climate change in broad-scale conservation planning. We identify 2257 priority watersheds within the Central Interior and Sub-Boreal Interior ecoprovinces, covering 33% of the freshwater analysis study area.

KEYWORDS: *biodiversity; British Columbia; Central Interior Ecoregional Assessment; climate change; conservation planning; freshwater species; Marxan analysis; Nature Conservancy of Canada.*

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Introduction

The Nature Conservancy of Canada's mission is to protect areas of biodiversity for their intrinsic value through land purchases and other land protection measures. Before taking action, it uses conservation planning methods to identify priority areas. The Nature Conservancy has recently completed a broad-scale conservation planning exercise, called an ecoregional assessment, for the Central Interior of British Columbia. Here, we describe the methods involved in the freshwater analysis component of this assessment and discuss the results within the context of these methods. The freshwater analysis involves an assessment of the biodiversity and threats to freshwater species and ecosystems within the study area. The results will be used to provide a regional-scale, biodiversity-based context for implementing conservation efforts. The accuracy of the results reflects the quality of the data available, and as such the purpose of this data is to inform regional-scale planning. Individual watershed planning can be informed by the context of these results but should also incorporate watershed-specific data and local expertise at the finest scale possible.

The Nature Conservancy's approach for the freshwater analysis recognizes that freshwater ecosystems require a different methodology than do terrestrial systems because they exist within interconnected river corridors in which species and nutrients move (Vannote et al. 1980; Gomi et al. 2002; Wipfli 2005). Freshwater ecosystems also face particular threats (e.g., dams and other water obstructions) that affect these ecosystems differently than a terrestrial ecosystem (Richter et al. 2003; Dudgeon et al. 2006). For example, a dam affects terrestrial species and ecosystems in the immediate vicinity, but the ramifications on aquatic systems extend both upstream and downstream. Dams can restrict migration of aquatic species, water and nutrient flow, and alter patterns in water flow. Differences between the freshwater and terrestrial analyses for the Central Interior Ecoregional Assessment relate to the connectivity within freshwater ecosystems. To address the connectivity of freshwater ecosystems, watersheds are designated as assessment units then grouped into ecological drainage units as described below. We outline other special considerations for freshwater ecosystems and species representation and describe how they have been incorporated into the ecoregional assessment methods. We also explore the implications of the results for freshwater conservation and provide recommendations for future work.

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Freshwater analysis boundary

The freshwater analysis boundary is based on ecological drainage units, the boundaries of which encompass the boundary of the Central Interior and Sub-Boreal Interior ecoprovinces (Figure 1). These drainage units are part of an ecological aquatic classification system for British Columbia developed by Ciruna et al. (2007). Ecological drainage units represent "distinct major drainage basins that contain unique fish assemblages based on broad zoogeographic, physiographic and climatic patterns" (Ciruna et al. 2007:12). The British Columbia classification system identifies 36 drainage units within the province, nine of which are included in this freshwater analysis (Middle Fraser, Upper Fraser, Thompson, Homathko-Klinaklini, Bella Coola–Dean, Upper Skeena, Upper Peace, Upper Nass, Iskut–Lower Stikine). The classification system nests river and lake ecosystem types within ecological drainage units, which are nested within freshwater ecoregions. The five defined freshwater ecoregions are based on patterns of fish re-colonization after the last glacial recession. These classification units are conceptual; although the units are based in well-established mapping, they await further ground-truthing. Based on the Ecological Aquatic Unit classification, we expect that each drainage will contain freshwater systems with similar patterns of drainage density, gradient, hydrologic characteristics, and connectivity. Ecological drainage units provide a means of stratifying freshwater systems and species to set appropriate goals for freshwater biodiversity conservation.

Because of the hydrologic and biologic connectivity within ecological drainage units, we followed past ecoregional assessment protocol (Iachetti et al. 2006; Pryce et al. 2006) and assessed only complete drainage units.

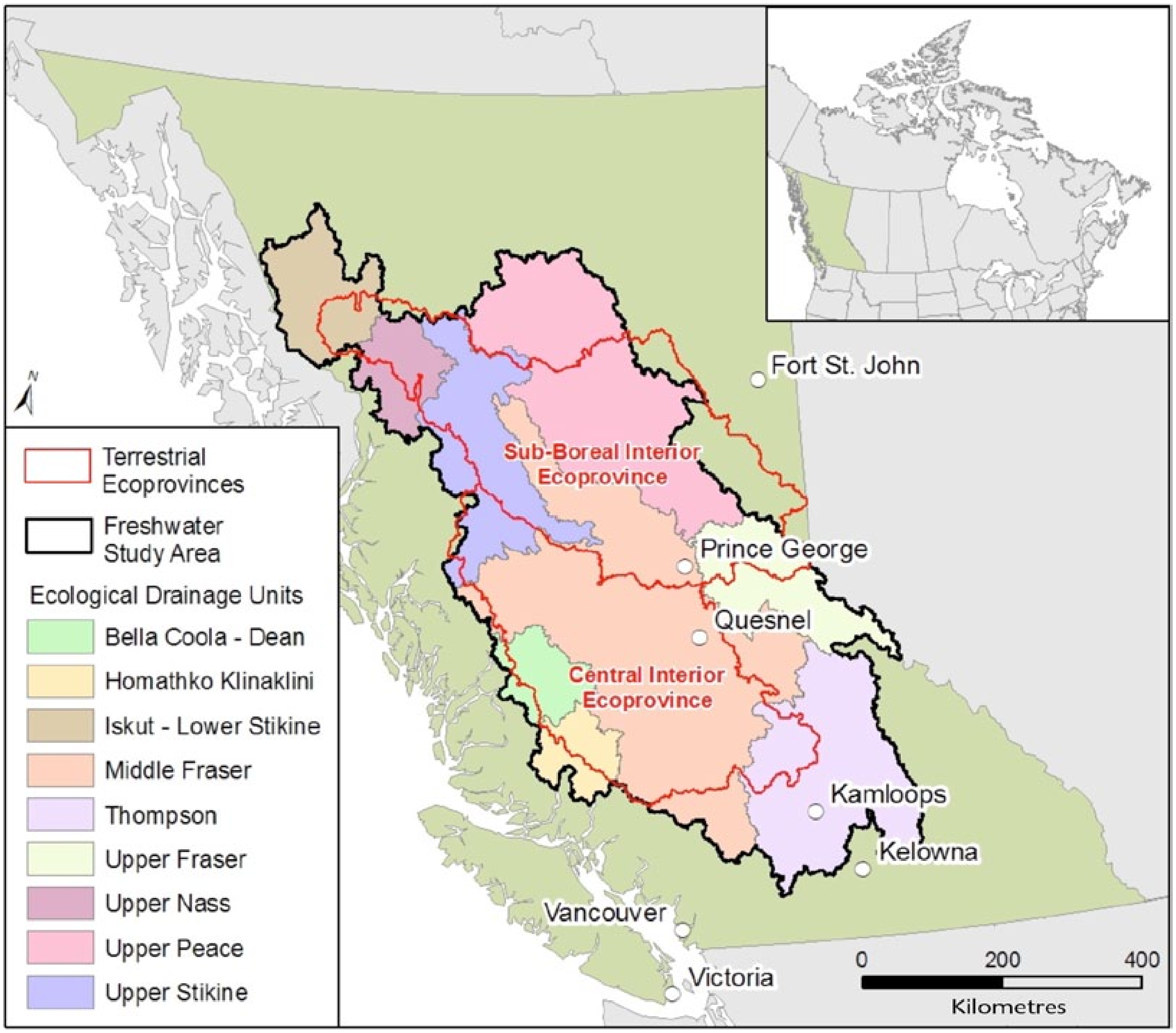

FIGURE 1. Freshwater study area and ecological drainage units for the Central Interior Ecoregional Assessment.

Consequently, the freshwater analysis boundary extends beyond the terrestrial boundary in some areas, with small gaps in perimeter locations. Gaps within the terrestrial boundary have been assessed in previous ecoregional assessments (Heinemeyer et al. 2004; Rumsey et al. 2004) or will be assessed in upcoming work (e.g., Canadian Boreal Forest Agreement; *http://www.canadianborealforestagreement.com/index.php/en*).

Methods

The Nature Conservancy of Canada's approach for the Central Interior Ecoregional Assessment builds on methods developed by The Nature Conservancy (USA) (Groves et al. 2000; Groves 2003) and two of the most recent assessments completed in British Columbia—the Okanagan (Pryce et al. 2006) and the North Cascades (Iachetti et al. 2006.) We used Marxan, freely available conservation planning software, to help in identifying priority conservation areas (Loos 2011).

The Marxan process involves selecting conservation targets (i.e., important ecosystems and species) and identifying threats to those targets. Threats are characterized by a "suitability index," a method that weighs the threats as a cost to selecting a particular watershed against the benefits of ecosystems and species in that watershed. Each watershed contains values for targets and threats and Marxan tries to select a group of watersheds that meets the conservation goals for targets while minimizing threats. Conservation goals are what we want Marxan to include in the final solution. For example, we use a target goal of 30% of watersheds from each river ecosystem type, meaning that the final solution should contain a combination of watersheds consisting of at least 30% of each type in the study area. We also use a target goal of 30% for certain species; this means that the final Marxan solution represents at least 30% of the species known distribution in the study area. Loos (2011:88–97) provides more details on the Marxan methods used in this analysis.

Assessment units

Third-order watersheds from the *British Columbia Watershed Atlas* (***http://www.env.gov.bc.ca/fish/watershed_atlas_maps/index.html***) are used as assessment units. These are drainages delineated from federal 1:50 000 NTS mapping. Our rationale for using watersheds as assessment units is based on increasing agreement in the literature that watersheds are appropriate units for analyses of freshwater species and ecosystems (Higgins et al. 1998; Braun et al. 2000; Coast Information Team 2004; Nel et al. 2009) and have been used in many previous ecoregional assessments (Wood et al. 2004; Iachetti et al. 2006; Pryce et al. 2006). The 1:50 000 third-order watershed layer is widely used as a common spatial unit for aquatic analysis and includes units that range from third order up to seventh order. Watersheds are given equal treatment in the analysis regardless of order and range in size from 0.26 km^2 to 2555 km^2. All coarse-filter ecosystem types and fine-filter species data are attributed to one particular unit.

Connectivity in freshwater systems is represented spatially quite differently than in terrestrial ecosystems, thus requiring a modification to the Marxan application. Watersheds are connected to each other by flowing water, resulting in more connectivity between watersheds upstream and downstream and within the same drainage basin than watersheds that may be physically adjacent to one another but outside of the same drainage basin. For example, two neighbouring watersheds may meet at a ridgeline with each watershed draining into a separate drainage basin. So, although the two watersheds are adjacent, they may not have hydrologic connectivity.[1] This presents a potential problem for our reserve selection software, since Marxan is programmed to preferentially group adjacent units. In aquatic systems, adjacent assessment units are not necessarily hydrologically connected. To address the connectivity issue, we used a method called "vertical stacking" that forces Marxan to preferentially group watersheds within the same "Major Watershed" group.

The Nature Conservancy's Michael Schindel developed the vertical stacking method to accommodate these types of relations, where adjacency does not necessarily mean connectivity (Vander Schaaf et al. 2006).[2] Vertical stacking uses the hierarchical watershed codes to tell Marxan which watersheds to consider as adjacent (watersheds within the same river network). We used the Major Watersheds layer[3] to define river reaches that are within the same river network and are smaller than the ecological drainage units (Table 1).

Conservation targets

Identify conservation targets

Conservation targets are species and ecosystems selected for their importance to freshwater biodiversity conservation. Coarse-filter targets focus on ecological systems and their functions whereas fine-filter targets represent rare or vulnerable populations of species and habitats that may not be adequately represented within coarse-filter targets. Our approach is to establish conservation goals for all targets and to identify a suite of watersheds that meet conservation goals for all targets. In theory, effective conservation of all watersheds identified will sustain freshwater biodiversity. Effective conservation does not necessarily mean restricted use or access to all parts of the watershed; rather, a combination of protected areas (through land purchase or donation, conservation covenant, government designation), management planning, and education may protect freshwater ecosystems and species while still allowing some human activities in the watershed.

Coarse-filter targets – Coarse-filter targets in the context of the freshwater analysis are freshwater ecosystems characterized by their physical habitats, environmental regimes, energy exchanges, and nutrient dynamics. Freshwater ecosystems are generally connected to and depend on one another, and as such they form drainage networks that constitute even larger ecological systems. In this analysis, we have defined

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[1] Schindel, M. 2004. Optimization and integration of conservation targets with SITES. The Nature Conservancy, Portland, Oreg. Unpublished.

[2] *Ibid*.

[3] All data layers used for mapping were acquired by the Nature Conservancy of Canada through the Land and Resources Data Warehouse (***http://www.lrdw.ca***).

TABLE 1. Fine-filter data sources used in freshwater analysis for Central Interior Ecoregional Assessment

Data source	Target species	Data type
Conservation Data Centre	American Bittern, Olive Clubtail, Mountain Sucker, Great Basin Spadefoot, Western Painted Turtle (Intermountain population), Western Screech-Owl (*macfarlanei*), Brassy Minnow, Torrent Sculpin, American White Pelican, White Sturgeon (Nechako River population), White Sturgeon (Upper Fraser River population), White Sturgeon (Middle Fraser River population)	Element occurrence
Ducks Unlimited Canada	American White Pelican, Canvasback, Lesser Scaup	Element occurrence
Fisheries Information Summary System	Pacific Lamprey	Element occurrence
B.C. Ministry of Environment and Glen Dunsworth	Western Toad	Proportion of watersheds containing species
NatureServe	Coastal Tailed Frog, Northern Pintail, Eared Grebe	Proportion of watersheds containing species
Royal British Columbia Museum	Beaverpond Basketpail, Black Petaltail, Forcipate Emerald, Hagen's Bluet, Kennedy's Emerald, Plains Forktail, Quebec Emerald, Umbilicate Sprite, Western River Cruiser	Element occurrence
Watershed Evaluation Tool (WET)	Arctic Grayling (Williston Watershed), Burbot, Coastal Cutthroat Trout, Kokanee, Bull Trout, Chinook, Chiselmouth, Chum, Coho, Sockeye, Steelhead, White Sturgeon (Nechako River population), White Sturgeon (Upper Fraser River population), White Sturgeon (Middle Fraser River population)	Proportion of watersheds containing species (watersheds with greater than 90% probability of occurrence)

freshwater coarse-filter targets using British Columbia's Ecological Aquatic Unit classification (Ciruna et al. 2007), which classifies river ecosystem types (associated with third-order watersheds) and lake ecosystem types. The river and lake ecosystem types are groupings of rivers and lakes hypothesized to share similar physical habitat and dominant environmental processes and thus share similar freshwater communities.

Wetlands are also included in the freshwater coarse filter. We used the *British Columbia Freshwater Atlas* (***http://www.env.gov.bc.ca/fish/watershed_atlas_maps/index.html***) to identify and group wetlands based on size and adjacency to other wetlands to approximate connectivity. Wetlands are also included as targets in the terrestrial assessment. Our rationale for including wetlands in both analyses is that wetland-dependent species often require both the aquatic and upland areas and so it is reasonable to represent wetlands in both analyses. We acknowledge that this may result in overrepresentation of wetlands in the final outcome; however, as wetlands are such important ecosystems and face many threats, we preferred overrepresentation to underrepresentation.

Within the Central Interior freshwater boundary, 18 of the 23 provincial river ecosystem types occur (see Map 11 from Nature Conservancy of Canada, 2010b; and Table 1 from Nature Conservancy of Canada, 2010a) and all 12 of the lake ecosystem types (see Table 2 from Nature Conservancy of Canada, 2010a). British Columbia's Ecological Aquatic Unit classification groups river and lake ecosystems using physical habitat attributes (e.g., gradient) and dominant environmental processes (e.g., streamflow) (Ciruna et al. 2007). Based on The Nature Conservancy and NatureServe recommendations (Comer 2001, 2003) and previous Nature Conservancy of Canada ecoregional assessments (Iachetti et al. 2006; Pryce et al. 2006), a conservation goal of 30% was set for each freshwater coarse-filter target type, which was then stratified by ecological drainage unit to ensure representation across drainage units.

Fine-filter targets – Freshwater ecosystems support an exceptional concentration of biodiversity (Higgins et al. 1998; Groves et al. 2000, 2002; Leveque et al. 2008). Freshwater species face numerous threats (Dudgeon et al. 2006) attributed, for example, to higher stream temperatures, sedimentation, chemical discharges, and invasive species, and are predicted to face higher extinction rates than either terrestrial or marine species (Ricciardi and Rasmussen 1999; Strayer and Dudgeon 2010). The richness of freshwater species includes a wide variety of plants, fishes, mussels, crayfish, snails, reptiles, amphibians, insects, micro-organisms, birds, and mammals that spend much of their time in or on the water. Many of these species depend on the physical, chemical, and biological processes and interactions found within freshwater ecosystems to trigger stages in their life cycles (Amis et al. 2009). Species selected for the freshwater fine-filter list reflect this diversity.

The Freshwater Team's objective was to develop a list of target species that require special attention and, it is assumed when considered collectively, represent the conservation needs of all freshwater species in the study area. In theory, effective conservation of all watersheds in the conservation areas will sustain freshwater biodiversity overall. Spatial data represent either observed species occurrences or probability of occurrence and are used to help identify priority areas for conservation. Freshwater fine-filter targets are defined as those species that are currently at risk (imperiled, threatened, endangered, or of special concern). For comparison, we also used British Columbia's Conservation Framework (see ***http://www.env.gov.bc.ca/conservationframework***) to select species and test the impact on the results. A full description of freshwater species selection criteria is available in the Freshwater Analysis Appendix (Nature Conservancy of Canada 2010a).

The target list for this analysis was compiled by querying the British Columbia Conservation Data Centre and NatureServe databases for native fish, mollusks, crustaceans, insects, and waterfowl at risk, red-listed, or blue-listed in the province. Several experts and regional reviewers evaluated a draft of the species list. The final species list consists of 50 species: 3 amphibians, 7 birds, 17 fish, 9 dragonflies, 1 mollusk, and 1 turtle. Of the 50 target species, only 38 had adequate spatial data to be included in the Marxan analyses (see Table 4 in Nature Conservancy of Canada, 2010a). Adequate spatial data are considered to be species observations that have been confirmed, are linked to geographic co-ordinates, and include the date of observation and the observer. Data-deficient species are listed in Table 5 of the Freshwater Analysis Appendix (Nature Conservancy of Canada 2010a). After experts reviewed and agreed on the species list, we searched for spatial data to represent species occurrences. We then established conservation goals for all targets used to direct Marxan in its identification of watersheds that together meet goals for all targets.

Throughout the species selection process, we collaborated with the Central Interior Ecoregional Assessment Terrestrial Animals Team members (Horn 2011) and incorporated their input. From the outset, we defined species to be included in the freshwater analysis as those that live in freshwater ecosystems, or depend on them for some part of their life cycle (Dudgeon et al. 2006). This results in minimal overlap with the Terrestrial Animals Team in species targets (e.g., western painted turtle). The Terrestrial Animals Team also identified species that it did not include in its assessment because these species were better addressed in the freshwater assessment (e.g., American bittern).

Data sources – Data for freshwater fine-filter animal targets were obtained from various sources, primarily the Watershed Evaluation Tool (Reese-Hansen and Parkinson 2006) and the British Columbia Conservation Data Centre. Other sources include the Royal British Columbia Museum, the B.C. Ministry of Environment's Fisheries Information Summary System, Ducks Unlimited Canada, and NatureServe (Table 1). Data were screened across sources to eliminate inaccurate and duplicate occurrences.

Using these data sets, species occurrences are represented by point occurrences, polygons, and species probability of occurrence values. The Watershed Evaluation Tool fish probability values are attributed to third-order watersheds and reflect the probability of a particular species being observed. We included watersheds as having occurrences if the probability of occurrence for a species was above 90%. The Watershed Evaluation Tool is a modelled probability of occurrence for salmon species across all watersheds in the province and has been tested and refined based on confirmed species occurrences. It is particularly well suited to this type of analysis because it provides an indication of whether a salmon species is likely to be present in watersheds across our entire study area.

Species data are often biased toward easily accessible areas relatively close to transportation routes and are not evenly spread across the landscape. We assumed that other freshwater species are present in watersheds beyond their recorded observations; however, without a data set similar to that of the Watershed Evaluation Tool, we could not know which watersheds were more likely to contain a particular species.

Set goals for each species and ecosystem target

Freshwater fine-filter animal targets and goals are stratified by ecological drainage unit and in the Marxan analysis each drainage unit was processed independently. The majority of the species data is actually related to watersheds (Watershed Evaluation Tool fish probability of occurrence) or polygons, so we based the initial conservation goals for each target on the Nature Conservancy/NatureServe recommendations (Comer 2001, 2003), starting at goals of 30% of polygons (i.e., at least 30% of Marxan selected polygons had to contain occurrences of the species target). Following expert review and advice, some species goals were increased to reflect higher levels of conservation concern. The goals for all salmon species, for example, were increased from 30% to 50% of watersheds. Increasing conservation goals for salmon follows the precedent set in previous ecoregional assessments (Iachetti et al. 2006; Pryce 2006), where salmon were considered to be of higher concern because of their complex life histories and various declining populations. Some species, such as white sturgeon, have populations of such high concern (red-listed, expert opinion) that goals were increased to require that 100% of watersheds included in the final solution must have a high probability of occurrence. Setting goals is a difficult exercise because "how much is enough" is a hard question to answer (Tear et al. 2005). For a complete list of conservation targets and goals see Table 6 in the Freshwater Analysis Appendix (Nature Conservancy of Canada 2010a).

Climate change – Each Central Interior Ecoregional Assessment team was asked to consider potential effects of climate change and adjust goals accordingly for a "climate change" analysis in which Marxan is run the same number of times but with adjusted conservation goals. We decided to keep the coarse-filter goals the same in determining the climate change Marxan solution. British Columbia's Ecological Aquatic Unit classification is relatively new and still in need of ground-truthing and testing; thus, currently there is insufficient basis to quantitatively raise the conservation goals for particular ecosystem types under a climate change scenario.

The Freshwater Team reassessed fine-filter targets when considering potential climate change effects on species and habitats. We consulted the literature and considered what might be the primary mechanisms to affect each species, such as increasing water temperatures and changes in stream flow. In 2007, two climate change workshops conducted by Dr. Timothy Kittel for all ecoregional assessment technical teams led to the attribution of primary mechanisms to particular species based on expert opinion. Kittel et al. (2011:7–35) summarizes the overall approach to including climate change in these analyses. We combine the possible mechanism of change with knowledge of species life history requirements to give each species a climate change vulnerability rating ranging from 1 to 5 (5 being the most vulnerable). Species vulnerability rankings and rationales are available in Table 7 of the Freshwater Analysis Appendix (Nature Conservancy of Canada 2010a). Depending on the severity of the climate change vulnerability ranking, we adjusted the original Nature Conservancy of Canada goal. For example, arctic grayling has the moderate goal of 30% of watersheds with a high probability of occurrence in the "regular" Marxan runs; however, after considering potential climate change effects of higher tributary temperatures and earlier ice-out resulting in decoupling of predator–prey cycles, we increased the goal to 50% for the "climate change" runs. A high vulnerability ranking resulted in a goal being increased, a low vulnerability ranking resulted in it being maintained or even lowered if we thought a species might benefit under climate change.

Conservation Framework pilot – When we were selecting species targets and deciding on goals, the B.C. Ministry of Environment was introducing its new Conservation Framework (see ***http://www.env.gov.bc.ca/conservationframework***). We were interested in this initiative because, rather than focus only on species already at risk (i.e., the typical Nature Conservancy of Canada approach), the Conservation Framework also focussed on species vulnerable to becoming at risk (i.e., keeping common species common). To get a sense of how our target lists and goals would change by considering the Conservation Framework's species rankings, we conducted a small pilot project. Freshwater and terrestrial animal targets and goals were reassessed based on the Conservation Framework. We included any species that was ranked as a high priority by any of the three framework goals.

For freshwater animals, we arrived at our same list of species plus two additional fish species ranked as high priority by the Conservation Framework (*Hybognathus hankinsoni* and *Cottus rhotheus*). We then assigned the species goals based on their highest rank in the Conservation Framework. We processed three different framework runs by including

1. only species identified as high priority in any Conservation Framework goal;
2. species identified in our runs and any additional species identified by the Conservation Framework; and
3. only species in the Conservation Framework list that had a habitat action listed as a priority in its action bin.

Suitability index

The suitability index is a composite measure of threats to freshwater biodiversity applied in the Marxan algorithm as a "cost measure" that influences whether a polygon is selected for conservation purposes. We initially identified a long list of threats to freshwater ecosystems and species but because of data limitations we focussed on three factors: (1) dams and diversions, (2) stream road crossings, and (3) licensed surface water use. For each of the three data sets, values are assigned to each watershed assessment unit. These values are then scaled between 0 and 1 and summed to provide one overall suitability index value for each watershed. Loos (2011) explains the methods for using the suitability index to characterize threats.

Freshwater portfolio

Watersheds included in the Marxan "best solution" are grouped into portfolio sites based on their hydrologic connectivity and size, consistent with the Nature Conservancy of Canada's approach elsewhere. Portfolio sites are assemblages of adjacent units all of which drain to one point in the portfolio and may or may not receive flow from outside the portfolio. This grouping process is challenged by large mainstem watershed polygons in the 1:50 000 watershed layer. As a result, some portfolio sites are very large in order to accommodate these mainstem river polygons. Following the analyses, 18 watersheds were added for connectivity based on expert opinion. There are 180 freshwater portfolio sites ranging in size from 25 km^2 to 4108 km^2. The average portfolio size is 717 km^2 and the total area of portfolio sites is 129 732 km^2 (33% of the freshwater analysis study area).

Results

Conservation goals for all 38 species and 306 ecosystem targets (river, lake, and wetland types) were met in the final Marxan solution. The final freshwater solution that meets all conservation goals is made up of 2257 watershed units and an area of 129 732 km^2. The final solution consists of 31% of the watersheds in the study area and 33% of the freshwater analysis study area (Figure 2). Of the 2257 watersheds in the final portfolio, 1683 of these are classified as headwaters, 499 as tributaries, 70 as mainstems, and 4 as coastal (small coastal systems that drain directly to the ocean). When broken down by the percent area of each river ecosystem type in the final portfolio, 27% of the portfolio area is composed of headwaters, 36% of tributaries, 34% as mainstems, and 3% as coastal (Figure 3). Of the 500 times Marxan was run, 1384 watersheds were selected each time. To reflect areas already protected, we locked in 264 watersheds with more than 80% of their area in parks or protected areas. The locked-in watersheds cover 12% of the freshwater solution area. The remaining solution represented Marxan's attempt to meet conservation goals. The remaining selected watersheds in each of the 500 runs have combinations of high numbers of species and ecosystems targets and low threat levels to contribute to an efficient Marxan solution. We can consider watersheds that were selected in each of the 500 runs as more robust and important for successful freshwater conservation because, despite the randomness of the Marxan process, these watersheds were necessary to complete the most efficient solution possible.

Overlap with terrestrial solution

Integration of freshwater and terrestrial conservation targets and goals has been tried in the past by the Nature Conservancy of Canada and others (Iachetti et al. 2006; Pryce et al. 2006; Amis et al. 2009) and was found lacking because it did not adequately meet either set of goals. Rather than integrate the freshwater targets and goals, we ran separate Marxan analyses for both realms and maintained communication between freshwater and terrestrial technical teams throughout the process. The results of the separate analyses were then overlaid to look for areas of overlap, with the assumption that these areas would be of even higher conservation priority because they represented priority areas in each realm.

The overlaid freshwater and terrestrial results showed over 40 000 km^2 of overlap, equivalent to

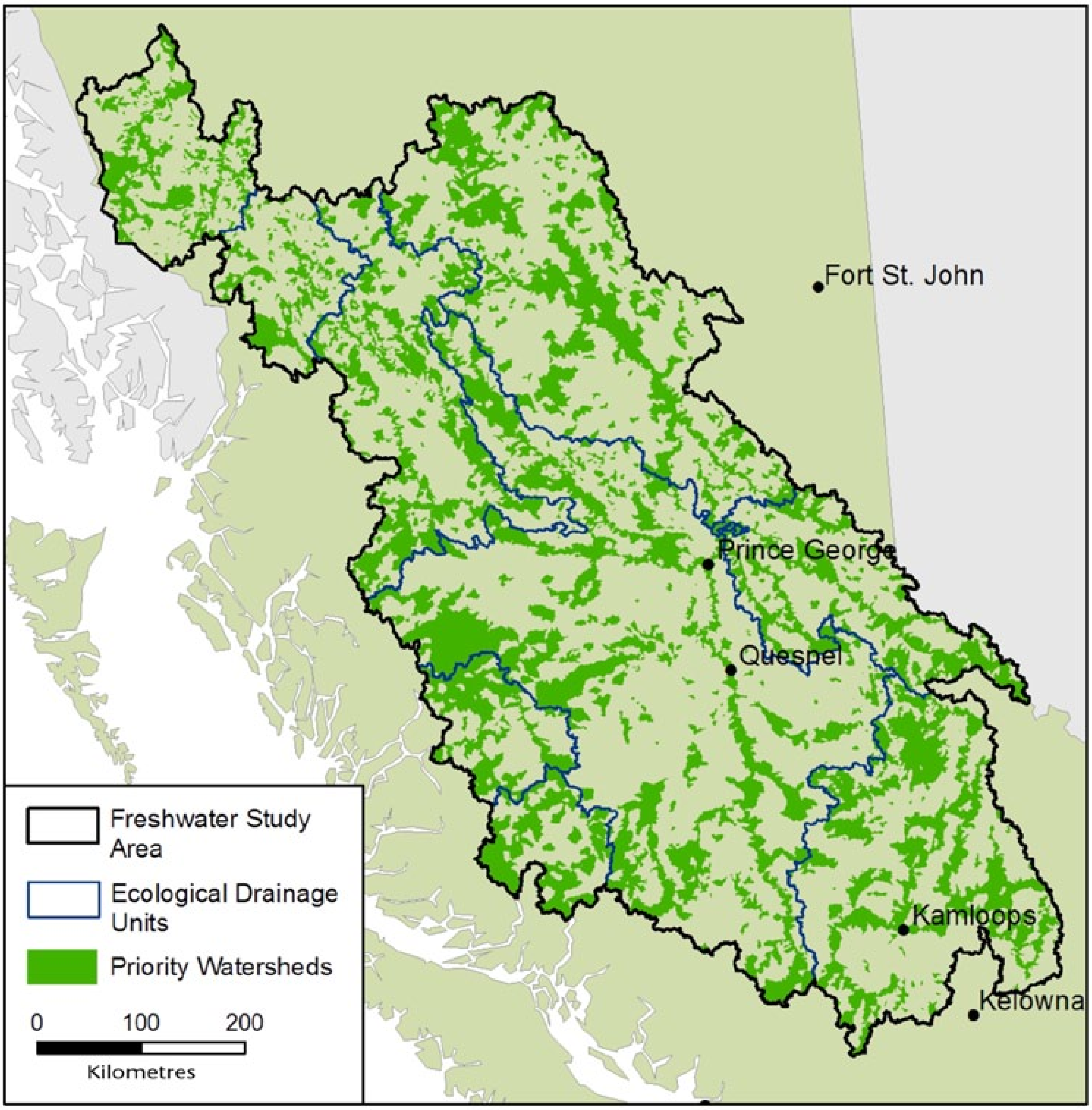

FIGURE 2. Priority watersheds for the Central Interior Ecoregional Assessment.

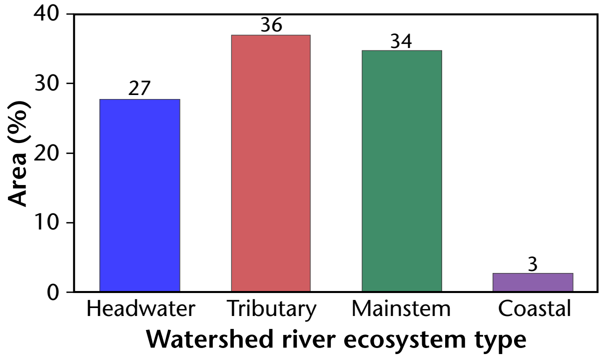

FIGURE 3. Percent area of each watershed river ecosystem type.

30% of the freshwater final solution and 38% of the terrestrial solution. Many of the areas with overlap are in, or adjacent to, parks and protected areas, because these areas were locked-in for both analyses.

Watershed and portfolio prioritization

Additional analyses to help prioritize conservation areas contribute to efforts to make the best use of limited resources. Prioritization of conservation areas also provides decision makers with the flexibility to pursue other options when portions of the portfolio are too difficult to protect. Assigning a relative priority to all conservation sites in the portfolio informs decision makers about their options for conservation action.

We used outputs of the Marxan process to generate two indices that reflect the relative importance of every assessment unit: (1) conservation value (biodiversity) and (2) vulnerability (threats). We based our methods of determining conservation value on those in previous ecoregional assessments (Wood et al. 2004; Iachetti et al. 2006). Conservation value is a function of rarity, richness, and diversity of species within the watershed combined with the irreplaceability value for the watershed. Rarity is calculated on the basis of NatureServe's conservation global rank for the species, where G1 species are given the greatest weight because they are critically imperiled, G2 species are weighted less than G1 but more than G3 because they are imperiled, and G3 species are vulnerable (see ***http://www.natureserve.org***). To calculate richness and diversity, we divided the total number of targets in a watershed by the total number of targets in the watershed ecological drainage unit. Irreplaceability is an index that represents the relative conservation value of a watershed by using the percentage of runs in which each watershed was selected out of the 500 Marxan runs. The more often a watershed is selected, and many individuals were selected in each of the 500 runs, the more important that watershed is for meeting conservation objectives. Of course, the frequency with which a watershed is selected depends on the data representing threats (suitability index) and biodiversity values (conservation targets). Marxan can work with only the data we supply, and we certainly do not have data that represent perfectly what is found on the landscape; however, the same imperfect data is also used in more conventional decision-making processes. The advantage of Marxan is the ability to integrate many data sets and rarity, richness, diversity, and irreplaceability can be averaged to determine the conservation value for each watershed (Loos 2011).

Conservation value is plotted against the suitability index, thereby plotting the biodiversity of a watershed against its vulnerability or degree of threats to that watershed (see Map 16 from Nature Conservancy of Canada, 2010b). We follow the methods of Margules and Pressey (2000), Noss et al. (2002), and Iachetti et al. (2006) and group watersheds into four categories:

1. high value and high threat,
2. high value and low threat,
3. low value and high threat, and
4. low value and low threat.

The majority of the portfolio area (55%) is in the high-value/high-threat category, only 6% of the portfolio area is in the high-value/low-threat category, 18% is in the low-value/high-threat category, and 21% is in the low-value/and low-threat category. In the high-value/high-threat category, the largest group of watersheds by area is classified as mainstem watersheds (30 745 km^2), followed by tributaries (22 500 km^2), and headwaters (15 571 km^2).

Climate change

Additional Marxan runs were carried out to incorporate climate change. Although the effects of climate change are uncertain, we used expert opinion to evaluate the potential changes on freshwater species and ecosystems from three main factors:

1. the effect of precipitation changes on stream flow and stream temperature,
2. effects of changes in air temperature on stream temperatures, and
3. the overall consequences of increased storm events.

The climate change Marxan runs resulted in differences in the number of times individual watersheds were selected out of the 500 possible runs (see Map 29 from Nature Conservancy of Canada, 2010b). Target goals are adjusted to account for these changes. To get a better sense of which watersheds change the most in their selection frequency, we calculated the difference in the number of times each watershed is selected (irreplaceability) in the climate change runs when compared with the original Marxan runs (see Map 30 from Nature Conservancy of Canada, 2010b). The results show that most of the watersheds that are selected significantly more often (> 60%) in the climate change runs are north of Prince George, B.C. It is hard to say, without further analysis, how much variation is due to random variation in Marxan solutions (there will always be some) and how much is due to the change in climate change goals.

Conservation framework

Little difference was evident between the Nature Conservancy's solution and the Conservation Framework solution. As with the climate change results, it is difficult to tease out how much of the difference is due to changes in goals and how much is due to the variation inherent in the Marxan runs; however, the large overlap in species identified using the framework versus the standard Nature Conservancy method of species at risk (only two species are added using the framework) implies that the Nature Conservancy's method is already doing a good job of capturing most of these species.

Online watershed tool and Hectares BC

Many of the input data layers and all of the results of this project are available on Hectares BC (*http://www.hectaresbc.org*). To accommodate watershed-based analyses, the 1:50 000 watershed layer is now available within Hectares BC. This project's freshwater analysis data can be queried along with the numerous data sets already available in Hectares BC. Data layers and results from this project are also available for download from the Hectares BC website.

Discussion

The freshwater analysis for the Central Interior Ecoregional Assessment identified 2257 priority conservation watersheds within the nine ecological drainage units included in this study. Although the point of this exercise is to identify priority watersheds in which to work toward conservation, of equal importance are some of the other products of this process, such as rating watersheds by conservation value and human threats across the study area. The information from these products is available for all watersheds in the study area (see Nature Conservancy of Canada [2010b] and HectaresBC). Important opportunities for conservation action or restoration may occur outside priority watersheds. The range of data sets produced for this project will help stakeholders weigh new threats and opportunities as they arise. This will also help the Nature Conservancy of Canada to co-ordinate its efforts with provincial approaches, such as Fisheries Sensitive Watersheds, and federal approaches, such as the Wild Salmon Policy and Salmon Conservation Units.

Within the group of priority conservation watersheds, mainstem watersheds are identified as the largest group of watersheds (45%) within the high-value/high-threat category of conservation value, tributaries constitute 33% of this category and headwaters 22%. This is no surprise considering mainstem watersheds are recognized to have higher biodiversity than smaller rivers upstream (Vannote et al. 1980; Williams et al. 2003; Nel et al. 2007). It is also no surprise that these watersheds often coincide with human uses such as roads and settlement (Dudgeon et al. 2006).

We recognize that sources of bias may have contributed to mainstem watersheds forming a large portion of the high-value/high-threat category of conservation value. The 1:50 000 watershed layer could have affected this outcome because many of the mainstem polygons are very large. To reduce the bias of polygon size on the results, we excluded watershed area from the factors Marxan considered when selecting watersheds; however, it is also true that large polygons tend to be more data-rich (easy accessibility, closer proximity to urban areas, etc.), making them more likely to be chosen to meet conservation goals despite having higher threat rankings in many cases. Tributaries, and especially headwaters, are very important as nutrient and energy sources for mainstem systems (Vannote et al. 1980; Meyer et al. 2007) and can contain fewer but often more vulnerable species (Gomi et al. 2002). Tributaries, according to British Columbia's Ecological Aquatic Unit classification, are a transitional unit linking headwaters and mainstems, and given their proximity to the mainstem units, it is also perhaps not surprising that a greater area of tributaries than headwaters were in the high-value/high-threat category.

The purpose of locking-in watersheds in current parks and protected areas was to incorporate the reality of protected areas already on the landscape. In early testing, we found that many of the same watersheds were selected in both analyses (i.e., locked-in and not locked-in), which could reflect higher data collection in parks or lower threat rankings in parks, or both. Some differences, though, could set the stage for an interesting follow-up analysis. For example, the analysis could be rerun without locking-in parks to identify areas where protected areas are doing a good job of safeguarding important freshwater ecosystems and species, as well as identifying locations where they might not be and determining why this is so.

To ensure representation across watersheds, the coarse-filter goals of 30% for all river, lake, and wetland ecosystem types drives Marxan to select at least 30% of watersheds containing each ecosystem type. So even if more fine-filter data are present in mainstem watersheds, representation within tributary and headwater river ecosystem types is still achieved (Loos 2011). This helps to moderate bias that may be present due to the size of the mainstem polygons. A potential solution to the disparity in watershed polygon area has recently emerged with the *British Columbia Freshwater Atlas* (Carver and Gray 2010), which offers a watershed layer of more uniform size. An interesting next step of this analysis could be to repeat the Marxan runs using the Freshwater Atlas watersheds as assessment units. This would require digitally comparing, or crosswalking, the Freshwater Atlas data set with the Ecological Aquatic Unit data set to appropriately "spatialize" the species occurrences in river and lake ecosystems. With species data more accurately represented in watersheds of roughly uniform size, it would be interesting to see whether the solution would contain as many watersheds along the mainstem corridors.

In the climate change scenario, we adjusted species (fine-filter) conservation goals depending on an expert assessment of their vulnerability to climate change (see Kittel et al., 2011, and Table 7 in the Freshwater Analysis Appendix, Nature Conservancy of Canada, 2010a). Given the untested nature of British Columbia's Ecological Aquatic Unit classification system and the uncertainty surrounding how climate change will develop spatially in this large area, the coarse-filter ecosystem targets were not adjusted to shape this outcome. Future assessments could potentially consider how climate change may affect coarse-filter targets through attributes in the Ecological Aquatic Unit data set. Each watershed in this data set is attributed with information such as the percent of glacial or tundra influence within each watershed, modelled maximum July water temperature, and modelled monthly precipitation. Thresholds within these attributes could be identified to highlight watersheds more sensitive to climate change. For example, watersheds with a strong glacial influence, or with maximum July water temperatures already over 25°C, may justify a higher conservation goal because of the potentially higher vulnerability of their current ecosystems.

Although we did force Marxan to preferentially group watersheds within major watershed groups, some other options could be explored in future assessments, such as locking-in headwaters or tributaries. Using Marxan, Linke et al. (2010) tested the locking-in of tributaries and headwaters upstream of selected mainstem watersheds and found that this increased the total area of the solution, which is a consideration when resources are limited. Another option for future analyses is to lock-in intact watersheds (e.g., watersheds with a low road density) with a possibility of locking-in the watersheds upstream. A large solution area is not necessarily a problem, especially if an ecosystem-based management approach is to be taken. Information on conservation value and vulnerability could help guide the implementation of various management guidelines in different watersheds (Saunders et al. 2002).

A frequent challenge of ecoregional assessments is finding the data to represent ecosystem and species occurrences. We are fortunate to have the Ecological Aquatic Unit data set (Ciruna et al. 2007), which provides complete and consistent classification of freshwater river and lake ecosystems across our study area. We are also fortunate to have obtained information on probability of fish occurrence from the Watershed Evaluation Tool (Reese-Hansen and Parkinson 2006), which represents species occurrence information for most of the fish species on our target list. A major advantage of using this data is its availability across our entire study area. Obtaining other fine-filter species data is more challenging because inventory information for some amphibians, freshwater mussels, and invertebrates is very sparse. In fact, we have no data at all for 12 species targets (see Table 5 in the Freshwater Analysis Appendix, Nature Conservancy of Canada, 2010a).

Information obtained in this assessment of freshwater ecosystems and species will help to focus attention on a few priority areas within the Central Interior and Sub-Boreal Interior ecoprovinces, where the Nature Conservancy of Canada will continue with finer-scale conservation planning, land purchases, and other tools for conservation; however, the availability of private lands is limited, so effective implementation of this conservation plan will require partnerships with all levels of government (federal, provincial, municipal, First Nations), other environmental non-government organizations, and industry. Working with partners to identify future freshwater protected areas is another possible way to protect freshwater ecosystems and species over a large study area (Suski and Cooke 2007).

Including freshwater ecosystems and species in conservation planning presents unique challenges and methods to accomplish these assessments continue to evolve (Nel et al. 2009). Our analysis includes innovative methods to address some of the issues currently discussed in the literature, such as freshwater ecosystem connectivity (vertical stacking), integrating freshwater and terrestrial analyses (overlay), accurately representing fish occurrences (Watershed Evaluation Tool fish probability values) and climate change (expert adjusted goals). This analysis has applied a collection of novel methodologies to ask how best to protect aquatic ecosystems with limited resources. Although we recognize that this process stimulates many questions, we hope this case study will contribute to finding new opportunities to protect aquatic biodiversity.

> *This analysis has applied a collection of novel methodologies to ask how best to protect aquatic ecosystems with limited resources.*

Recommendations

The ecoregional assessment methods used by the Nature Conservancy of Canada evolve with each assessment as new data and techniques become available. The following recommendations are provided to improve or streamline future ecoregional or similar conservation assessments.

- When using watersheds as assessment units, use a data layer that identifies watersheds in a relatively consistent size range. In British Columbia, the use of the Freshwater Atlas is an option for future analyses. Investigate digitally comparing, or crosswalking, Ecological Aquatic Unit data with Freshwater Atlas data.
- Facilitate the ground-truthing of British Columbia's Ecological Aquatic Unit classification system to support its use in broad-scale planning.
- Encourage ecosystem and species inventory (to address species targets currently with no data).
- Work with partners to update water use data, stream road crossings, and upcoming independent power projects in formats accessible for analyses.
- Continue to build relationships and collaborative opportunities with First Nations, the Department of Fisheries and Oceans, the B.C. Ministry of Environment, and non-governmental initiatives such as the Fraser Salmon and Watersheds Program to bring groups together in the interest of watershed health. The results of this project could inform processes surrounding Salmon Conservation Units (Department of Fisheries and Oceans), Fisheries Sensitive Watersheds and Temperature Sensitive Streams (Ministry of Environment), and conservation and restoration priorities (Fraser Salmon and Watersheds Program).
- Collaborate with government and others to identify cumulative impacts to freshwater ecosystems and species.
- Work with partners to bring together these results with past ecoregional assessments and other freshwater conservation work to identify freshwater ecosystems of provincial importance.

Conclusion

The priority watersheds identified through this ecoregional assessment provide valuable information for the Nature Conservancy of Canada and its partners in working towards the protection of biodiversity. Incorporating new aspects, such as climate change and British Columbia's Conservation Framework, were valuable exercises and provide a base on which to build future ecoregional assessments. By disseminating the results and other data through the HectaresBC website, we hope to increase their accessibility for future work across disciplines. Conservation planning methods are continuing to evolve and we hope to engage broadly as we look for ways to effect conservation of freshwater ecosystems and species.

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Test Your Knowledge . . .

Central Interior Ecoregional Assessment: Freshwater analysis

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. Based on this article, how did the Nature Conservancy of Canada integrate freshwater and terrestrial analyses for the Central Interior Ecoregional Assessment?
   A) It integrated freshwater and terrestrial data into one combined analysis for the study area
   B) It collected information for both terrestrial and freshwater analyses and ran them separately; results from each analysis were then overlaid to look for areas of overlap
   C) It did not integrate freshwater and terrestrial analyses at all

2. Based on this article, approximately what percentage of the study requires some form of protection for aquatic species and ecosystems in order to protect freshwater biodiversity?
   A) 12%
   B) 33%
   C) 50%

3. Addressing hydrologic connectivity between watersheds was identified as an important component of freshwater conservation planning. What were some suggestions to improve how this connectivity is reflected in future analyses?
   A) Locking-in various watersheds when running Marxan, such as tributaries and headwaters upstream of selected mainstem watersheds
   B) Crosswalking one data set with another to appropriately spatialize the species occurrences in river and lake ecosystems
   C) Locking-in watersheds with high numbers of species occurrences
   D) A and B
   E) All of the above

ANSWERS

1. B   2. B   3. D