Integration of Environmental Change Information

with Alaska-Yukon Arctic Ecoregion Assessment

Report of results on using change classes as a component of the cost suitability index

(The "Tom Ridge" Analysis)

submitted to Climate Change Initiative by Alaska Field Office

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ABSTRACT: By including the environmental change gradient data into SITES as a threat, or a component of the cost suitability index, the cost of the hypothetical reserve increases as predicted, but the size of the reserves decreases. Interestingly, the number of targets not meeting their representation goals does not always increase. In 15 of 22 SITES runs (68%), the number of targets not meeting their representation goals did increase, but the other 32% were not significantly different than the baseline run with no ECG data included in the cost suitability index. The runs that were not different than the "No ECG" run had an increased portfolio size at the higher weighting factor for both the Hadley A2 and B2 scenarios and corresponding fewer targets not meeting their representation goals.

INTRODUCTION:

This report summarizes the results of one of three analyses conducted by the Alaska Field Office at the request of the Climate Change Initiative to investigate the effect on an ecoregional portfolio of incorporating environmental change information. In this analysis, we integrated environmental change data into the existing cost suitability index (CSI), or threats index, developed for the Alaska-Yukon arctic ecoregion assessment. In this analysis, higher change magnitudes have higher cost, and lower change magnitudes have lower cost.

The objective of the analysis was to answer the following questions:

- does the 'cost' (final objective function) of the portfolio increase when climate change is a threat?

- are additional areas picked up for inclusion in the portfolio when climate change is a threat?
- do fewer targets meet their goals when climate change is a threat?
- is there a point where increasing the weighting factor of climate change data as a threat has a negligible effect on the resulting portfolio?

Two preliminary analyses were run to set baselines:

(1) Environmental change not included in CSI (the 'original' (albeit, hypothetical) portfolio)

(2) Environmental change as the *only* component of a CSI

Subsequent to setting the above baselines, we incorporated the environmental change gradient (ECG) data into the existing threats index as a continuous variable. We ran SITES with ECG data exerting influence on the cost suitability index in increasing increments to determine where the 'tipping point' is (e.g., at what level does climate begin impacting the objective cost function?). This was done using both the A2 and the B2 scenario data.

To quantify the results of the analysis, we investigated the results of three SITES runs: 1) without environmental change gradient data in the CSI; 2) using ECG data in a Hadley A2 scenario; and 3) using ECG data in a Hadley B2 scenario in the CSI. All other SITES variables—targets, goals, and boundary modifier--were held constant. The degree of difference among SITES results was measured in three ways:

1. objective function, which describes the 'cost' of the solution;
2. results of 'sum runs,' which reveals whether different areas were selected under different scenarios;
3. number of targets whose goals are not met in the portfolio

Null Hypothesis: With the addition of the environmental change gradient (ECG) data, the optimal solution (e.g. hypothetical portfolio) will change significantly. We predict an increased 'cost' of the portfolio solution; increased area (number of planning units, or PU's); and an increased number of conservation targets that do not meet their representation goals.

METHODS:

The environmental change grids developed by the Climate Change Initiative were averaged per planning unit in the Alaska-Yukon Arctic Ecoregion. The average ECG values per planning unit were incorporated into the CSI in SITES for the Alaska-Yukon Arctic Ecoregional Assessment. Separate averages were calculated for the A2 and B2 scenarios.

To correspond to the ECG grid data, we converted the planning units (5,000 hectare hexagons) shapefile from a vector format into a grid. We used a 90 meter cell size for the grids so that we would not lose the shape and detail of our fine scale data. Hadley A2 and B2 ECG grids were resampled to a cell size of 90 meters to correspond with the planning unit grid (the ECG data values were not changed in this process).

To incorporate the ECG data into the CSI, we followed the methodology used to create the original CSI for the Alaska-Yukon Arctic Ecoregional Assessment. The original CSI was calculated using three main components: infrastructure, management status, and species richness. All three components were attributed to the planning units and the areal extent of each data layer was calculated and normalized for comparison across planning units and among components (see Update #9, TNC 2004, at nature.org/alaska). The original CSI was calculated as the sum of twice infrastructure plus management status divided by the species richness. This is expressed by the following equation:

$$\text{COST} = \frac{(2 * \text{norm. infrastructure}) + \text{norm. management status}}{\text{norm. species richness}}$$

To incorporate the ECG data into the CSI we calculated the average ECG value per planning unit. This value was included in a master CSI table containing 5 components: infrastructure, management status, species richness, average Hadley A2 ECG value, and average Hadley B2 ECG value. The 3 original components of the CSI were normalized by dividing each component by its maximum value, and then multiplying by 100. The Hadley A2 and B2 ECG scenarios were normalized by dividing each scenario by the maximum average ECG value of the Hadley A2 scenario, and then multiplying by 100. We normalized the Hadley B2 scenario by the maximum value from the Hadley A2 model to scale the two models similarly. For instance, the maximum value for the A2 scenario was 1.9999; normalized, it equaled 100. The maximum value for the B2 scenario was 1.4483; normalized, it equaled 72.4176. This way, we could directly compare the two scenarios. We varied the weight of the ECG data in relation to the other factors for both the Hadley A2 and B2 runs. The new cost suitability indices (CSI) were calculated as the sum of twice infrastructure plus management status plus either the A2 or B2 ECG value multiplied by a factor x (where x = weight values between 1 – 24), all divided by the species richness. This is expressed by the following equation:

$$\text{COST} = \frac{(2 * \text{norm. infrastructure}) + \text{norm. management status} + (x * \text{norm. ECG})}{\text{norm. species richness}}$$

In all, we used 10 weights (1,2,3,6,9,12,15,18,21,24) for the A2 and B2 ECG data, creating 20 CSI tables. In addition, we created 2 CSI files that *only* included the A2 or B2 ECG data (i.e., no infrastructure or management factors) divided by species richness. This resulted in 22 SITES runs overall.

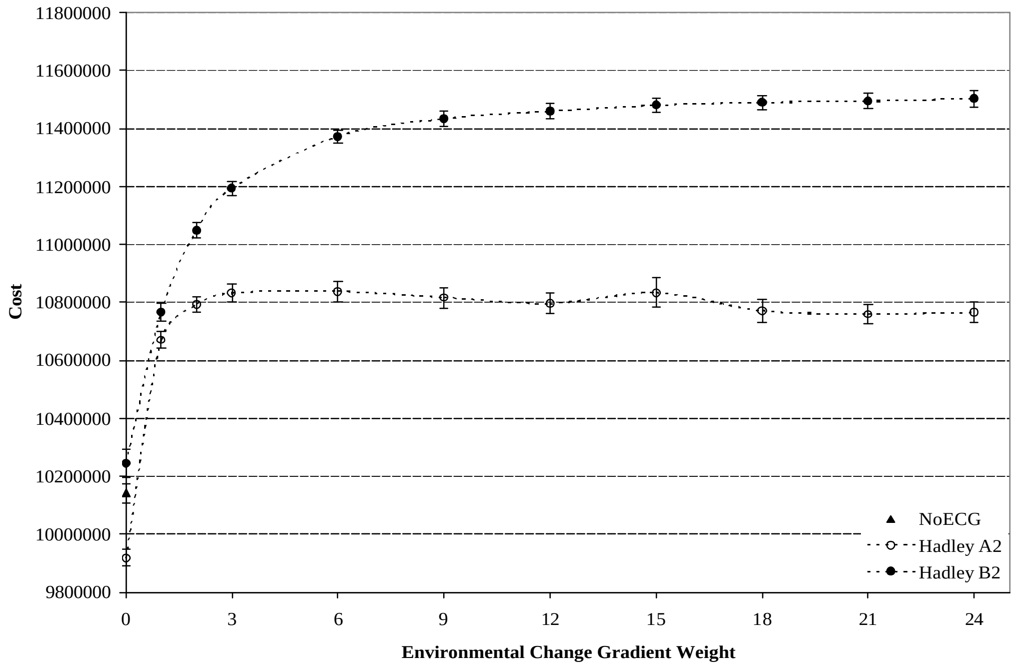
The SITES program was run with each of the new CSI tables created above. The resulting outputs from the 22 SITES runs were combined with the original SITES run (using the CSI without the ECG data) into a single dataset with a grouping variable assigned for each run. We compared the twenty-three runs using a one-way analysis of variance (ANOVA) and used post-hoc comparisons (using the Fisher LSD test) to single out key differences.

RESULTS:

The ANOVA test is designed to test for significant differences between means. Statistical significance is denoted by the p-value; a p-value of .05 or less is customarily treated as a 'border-line acceptable' error level. We performed three separate ANOVA tests on our SITES data to determine the significance of differences between the twenty-two portfolios with ECG data and the one without ECG data. The three ANOVA tests involved (1) the cost of the objective function; (2) the number of planning units selected in the portfolio; and (3) the number of targets not meeting goals.

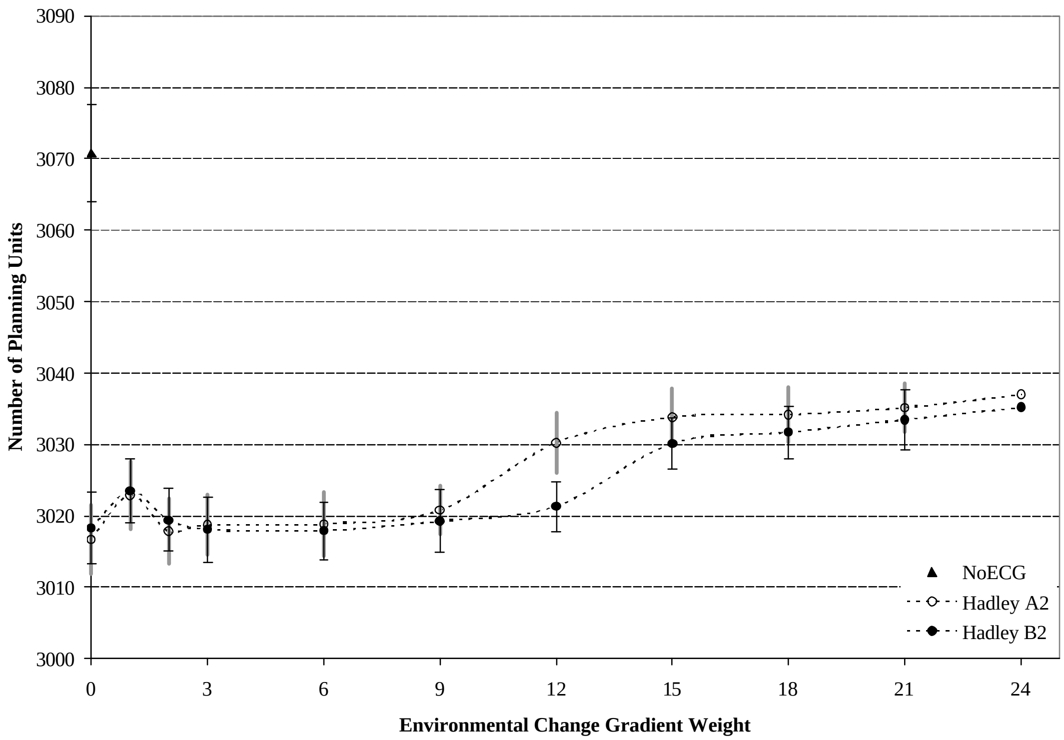
(1) A one-way ANOVA of the SITES information revealed significant differences among the 'costs' of the objective functions in the SITES runs ($F (22, 2277) = 19627$, $p < .0000$) (Table 1, Figure 1). Post hoc comparisons using the Fisher LSD test revealed that the costs of the portfolios with ECG data included were all significantly different than the cost of the portfolio without ECG data. Whereas the run that contained *only* the Hadley A2 ECG data divided by species richness had significantly lower cost than the 'original' portfolio (i.e., original CSI without ECG data), all other runs had significantly greater costs than the 'original' run.

Figure 1. The 'costs' of the objective functions in each of the SITES runs with ECG at varying weights in the CSI and their relation to the SITES run with no ECG data in the CSI. Data points for the runs with *only* the Hadley A2 and B2 data are represented by the weight of 0 on the figure.



(2) A one-way ANOVA revealed significant differences among the SITES runs when looking at the number of planning units selected for inclusion in the portfolios ($F(22, 2277) = 725.43$, $p < .0000$). (Table 1, Figure 2). Post hoc comparisons using the Fisher LSD test revealed that, in runs where ECG data were included in the CSI, the number of planning units selected by SITES was always significantly lower than the number of planning units selected in runs where ECG data were not included in the CSI. In other words, adding ECG data tended to reduce the size of the portfolio. As the weighting factor increases above 12 for the Hadley A2 data and above 15 for the Hadley B2 data the number of planning units selected increases, but the size of the portfolio was still significantly smaller than the run with no ECG data in the CSI.

Figure 2. The number of planning units selected in runs with ECG at varying weights and their relation to the run with no ECG data in the CSI. Data points for the CSI with *only* the Hadley A2 and B2 data are represented by the weight of 0 on the figure.



(3) A one-way ANOVA revealed significant differences among results of SITES runs when measuring the number of conservation targets not meeting their representation goals (F (22, 2277) = 12.12, p < .0000) (Table 1, Figure 3). Post hoc comparisons using the Fisher LSD test revealed that the number of conservation targets not meeting their representation goals in runs with the ECG data included were not all significantly different than the number of targets not meeting their representation goals in SITES runs without ECG data. The SITES runs with CSI files that *only* contained the ECG had significantly lower number of conservation targets not meeting their representation goals than the 'original' portfolio (CSI without ECG), whereas 15 of the 22 other runs (CSI including ECG data at varying weights) had significantly greater number of conservation targets not meeting their representation goals than the 'original' portfolio (Table 1, *note superscript*). This is to say that the '*only* ECG' runs did better at meeting goals than the

'original' portfolio. And when ECG data were added to the CSI, some runs (68%) did worse at meeting goals than the 'original' portfolio, but some runs did better, and some were not significantly different.

Figure 3. The number of targets not meeting representation goals in runs with ECG at varying weights in the CSI and their relation to the SITES run with no ECG data in the CSI. Data points for the CSI with *only* the Hadley A2 and B2 data are represented by the weight of 0 on the figure.

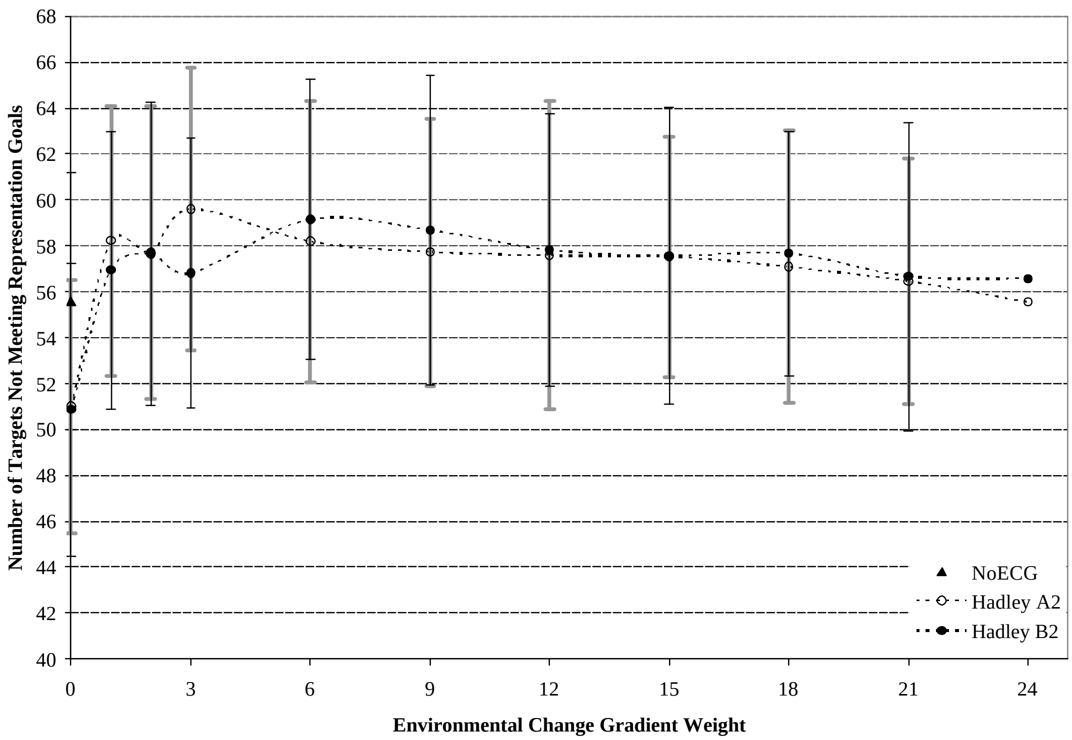


Table 1. Descriptive statistics of select SITES objective function components. *Costs* are the cost of the planning units selected in the optimal SITES solutions. *PU*'s are the number of planning units selected in the optimal SITES solutions. *Missing* are the number of conservation targets not meeting their representation goals in the optimal SITES solutions.

		Cost		PU's		Missing	
Group	N	Mean	SD	Mean	SD	Mean	SD
NoECG	100	10143192	33039	3070.79	6.808	55.59	5.603201
A2 *only*	100	9918870	29130	3016.69	4.4579	51.00	5.855154
B2 *only*	100	10245118	47247	3018.32	5.2855	50.87	6.754953
A2x1	100	10671089	30024	3022.91	4.7802	58.22	5.504048
B2x1	100	10766790	30041	3023.47	5.0160	56.95[1]	6.382386
A2x2	100	10792925	27076	3017.84	4.7156	57.70	5.864635
B2x2	100	11047783	25833	3019.41	4.4678	57.65	6.042568
A2x3	100	10832872	31251	3018.74	4.5828	59.59	6.372439
B2x3	100	11194703	24271	3018.11	4.4059	56.81[1]	6.593071
A2x6	100	10838291	36405	3018.86	4.2735	58.19	6.152432
B2x6	100	11372479	23888	3017.93	4.5377	59.15	5.862697
A2x9	100	10817306	35081	3020.78	4.4349	57.73	6.116471
B2x9	100	11434264	25288	3019.27	4.0122	58.68	6.091690
A2x12	100	10796694	35549	3030.21	3.4062	57.58	5.820861
B2x12	100	11460445	25505	3021.34	4.4432	57.81	6.766965
A2x15	100	10833607	50096	3033.81	4.2538	57.52	6.711185
B2x15	100	11480969	23380	3030.16	3.4865	57.56	5.946427
A2x18	100	10771168	40549	3034.15	4.0311	57.08[1]	5.250647
B2x18	100	11489830	23469	3031.71	3.5768	57.66	6.452969
A2x21	100	10759747	33935	3035.18	3.8596	56.45[1]	5.938022
B2x21	100	11494769	25987	3033.46	3.6966	56.66[1]	5.316679
A2x24	100	10766706	34472	3036.98	3.4494	55.55[1]	5.334044
B2x24	100	11502908	27670	3035.19	4.218	56.57[1]	6.701809
ANOVA Results F, P-value		F (22, 2277) = 19627, p < .0000		F (22, 2277) = 725.4, p < .0000		F (22, 2277) = 12.1, p < .0000	

[1] = not significantly different than "No-ECG" run at the p-value of .05 or less.

DISCUSSION:

We can not accept all parts of the *Null Hypothesis.* By integrating the environmental change gradient data into the cost suitability index, the cost of the hypothetical reserves increases, but the size of the reserves decreases, and the number of targets not meeting their representation goals does not always increase as predicted.

Does the 'cost' (final objective function) of the portfolio increase when climate change is a threat? As would be expected, the cost of the portfolio increased significantly for most runs when compared to the run with no ECG data, because with the addition of ECG data into the CSI, the areal extent of undesirable, or 'costly' areas that SITES must choose from is increased. The one exception to the rule of increased cost with the addition of ECG data is found in the run with *only* the Hadley A2 ECG data and species richness. In this particular run, the cost was significantly lower than in the 'original' run, the run with no ECG data in the CSI. Why this is remains to be determined. Alternately, why the B2 ECG-*only* run isn't <u>also</u> lower cost is undetermined.

An interesting outcome of the cost analysis is that the Hadley B2 scenarios (which represents a less severe change) always have a higher overall cost than the Hadley A2 scenarios. It may be that an 'irreplaceable' target occurrence happens to coincide with a high-magnitude B2 change class somewhere on the landscape which results in consistently higher-cost portfolios in B2 scenarios, although this is only supposition.

Are additional areas picked up for inclusion in the portfolio when climate change is a threat? With the addition of threats (here, represented by the ECG data) into the cost suitability index, the SITES algorithm tries to compensate for increased costs by selecting fewer planning units, which helps to keep costs down. Indeed, as we increased the weighting factor of the ECG data in the CSI, the portfolio size did decrease. But as the weighting factor of the ECG increases above 12 for the Hadley A2 data and above 15 for the Hadley B2 data, the number of planning units selected increases, increasing the size of the portfolio. This increase in size of the portfolio is negligible, however, and it is still significantly less than the size of the portfolio with out ECG data.

Is there a point where increasing the weighting factor of climate change data as a threat has a negligible effect on the resulting portfolio? One expects that at some weighting factor the overall increase in the cost of the portfolio would level off, or be negligible; that is, the cost of portfolio with ECG data at higher weighting factors would not continue to increase beyond a certain level. Indeed, there is an asymptote (or leveling off) in the cost of the portfolio at a weighting factor of 3 (a weighting factor of 3 is equal to the weight of the infrastructure and management status components of the CSI combined, see equation below) for the CSI with Hadley A2 data, and at a weighting factor of 9 (triple the weight of other components of the CSI) for the CSI with the Hadley B2 data.

$$\text{COST} = \frac{(2 * \text{norm. infrastructure}) + \text{norm. management status} + (x * \text{norm. ECG})}{\text{norm. species richness}}$$

Why there are three- and nine-fold differences in weighting factors to obtain the asymptote is unknown.

Do fewer targets meet their goals when climate change is a threat? With the observed decrease in portfolio size as a result of incorporating ECG data into the cost suitability index, there was a related increase in the number of targets not meeting representation goals. But it was not a straight relationship. Fifteen of 22 runs showed a significant increase in the number of targets not meeting goals, relative to the 'no ECG' run. Of the other seven runs, six showed an increase in the number of targets not meeting their goals, and one showed a decrease, but none of the changes were statistically significant. Comparing the 7 runs whose 'goals met' record was not significantly different than the 'no ECG' run, we see that 5 of the 7 runs were cases in which the weighting factor was greater than 18. In these 5 cases (A2x18, 21, and 24, and B2x21 and 24), there is both an increase in portfolio size and an associated decrease in the number of targets not meeting their goals.

It should be noted that the threshold in SITES for considering a goal met is 100%. However, we have found that it is more practical to consider a goal met at 95% or higher; this removes 'artifacts' from the data. In addition, given the somewhat arbitrary nature of goal setting and the intactness of this particular ecoregion, 95% is a reasonable standard. Using the 95% standard, we find that the number of targets not meeting their representation goals is considerably fewer (Table 2) than when the standard is 100% (Table 1).

Table 2. Number of conservation targets not meeting their representation goals.

Scenario	Number missed in SITES run at 100% goal[1]	Number of targets missed at 95% goal[2]	Number of subregional[3] targets missed at 95% goal[2]	Number of ecoregion-wide targets missed at 95% goal[2]
NoECG	56	12	11	1
A2 *only*	51	8	8	0
B2 *only*	51	4	4	0
A2x1	58	11	10	1
B2x1	57	10	9	1
A2x2	58	12	11	1
B2x2	58	8	7	1
A2x3	60	12	10	2
B2x3	57	10	9	1
A2x6	58	11	10	1
B2x6	59	8	7	1
A2x9	58	17	16	1
B2x9	59	12	11	1
A2x12	58	10	9	1
B2x12	58	8	8	0
A2x15	58	12	11	1
B2x15	58	10	10	0
A2x18	57	8	8	0
B2x18	58	16	13	3
A2x21	56	11	10	1
B2x21	57	12	12	0
A2x24	56	13	11	2
B2x24	57	16	16	0

1 Average of 100 runs, rounded to the nearest whole number.

2 Single value from best run of the 100 runs.

3 All targets have ecoregional goals, and some also have subregional goals to ensure representation.

In summary, by adding the ECG data as a component of the CSI in the Alaska-Yukon Arctic, the statistics tell us that the portfolio changes significantly. However, we still meet most of our goals, and the overall size of the portfolio only decreases by a maximum 53 planning units, which represents less than 1% of the area of the ecoregion. This might suggest that incorporating ECG information into our ecoregional assessments through integration in a cost suitability index has only a negligible effect on the overall outcome of the portfolio. And this may be true for the Alaska-Yukon Arctic ecoregion. However, it is important to note that the Alaska-Yukon Arctic is at the extreme end of what we call an intact landscape. Very little of the ecoregion has been altered, and the biodiversity is relatively homogeneous and widespread—three factors which help to make portfolio design very flexible. In the Alaska-Yukon Arctic there are many interchangeable portfolio options; should one planning unit become undesirable due to an increased cost, another less expensive planning unit with similar characteristics is often available. Results in other ecoregions that have more constricted options (e.g., more fragmented landscapes) may not be the same.