Appendix C. Using Marxan to Delineate Important Areas for Boreal Caribou

Introduction

What is Marxan?

Marxan software (Ball et al. 2009) was used to delineate important areas for boreal caribou based on seasonal habitat preference maps and boreal caribou collar data from the NWT.

Marxan software is a decision support tool for conservation network design that has been used in conservation planning around the world (Game and Grantham 2008, Ardon et al. 2010), including the NWT (Gah et al. 2008). Marxan is a spatial optimization program that is designed to achieve minimum targets for representation of conservation features for the smallest possible cost or within the smallest area possible (Game and Grantham 2008). Marxan can assist with identifying a range of potential solutions to complex planning spatial planning processes but is intended to be used in collaboration with other forms of knowledge and final solutions may require fine-tuning based on stakeholder input and expert opinion (Ardon et al. 2010).

The following is a summary of information provided in the Marxan user manual (Game and Grantham 2008) and Marxan tutorials developed by Morrell et al. (2015, 2017):

To use Marxan, conservation planning areas are broken down into smaller conservation planning units. Once conservation targets and objectives are defined, Marxan assigns scores to planning unit configurations, which are based on the particular configuration's ability to meet the conservation objective while minimizing the cost. The lower the score, the better the solution. Using a heuristic algorithm known as "simulated annealing", Marxan compares a large number of possible configurations and finds the one with the overall lowest score that meets the conservation target. This process can be repeated multiple times to see which planning units are consistently selected in the lowest score configuration. Marxan assigns a score to each planning unit configuration based on a mathematical formula called the **objective function**. The formula for the objective function is:

Score of the configuration being tested = $(\Sigma Cost)$ +
+ $(Boundary\ Length\ Modifier \times \Sigma Boundary\ Length\ of\ the\ reserve\ system)$
+ $(\Sigma Species\ Penalty\ Factor \times Penalty\ incurred\ for\ unmet\ targets)$

"Cost" can be represented by area of planning units or as missed opportunity costs of displaced activities (as a monetary value or on some relative qualitative scale of cost). The lower the cost of a unit, the more likely it will be included in the Marxan solution.

The boundary length of a reserve system is a way to quantify the connectivity of configuration of planning units (or the edge to area ratio). By setting a higher "boundary length modifier" value, Marxan will assign higher scores to configurations with many small and isolated patches, and lower

scores to configurations with a more clumped distribution. Because Marxan identifies the configuration with the lowest score, more clumped solutions will be identified when the boundary length modifier value is increased.

A "species penalty factor" can also be included that increases the score (i.e., assigns a penalty) when planning units that fail to meet conservation targets (e.g., don't contain a target species) are selected, and this lowers the likelihood that these planning units will be represented in the final solution.

Methods

Preparation and inputs for spatial planning units

ArcGIS Desktop 10.8 software (Esri Inc.) was used to prepare the spatial data layers that were needed to create the data input files for the Marxan analyses. The NT1 boreal caribou range was overlaid with a hexagonal grid of 5 km^2 "planning units". Planning units were assigned a code to represent the range planning region that they fell within. The seven seasonal predictive map layers (based on models in DeMars et al. 2020), current to 2019, were summarized as seven separate "conservation features" in the planning unit layer (Appendix B). These layers consist of 30 m x 30 m raster cells, each having a resource selection function (RSF) bin score ranging from 1 to 10, with bin 1 representing cells most likely to be avoided by caribou and bin 10 representing cells most likely to be selected ("preferred") by boreal caribou. Predicted RSF bin values were summed by season within each of the 5 km^2 hexagonal cells, resulting in seven columns in the attribute table each representing the summed seasonal RSF scores by planning unit (**Figure C-1**). The seasonal RSF rasters were used as separate conservation features to ensure representation of seasonally preferred habitat types, which can differ substantially throughout the year, rather than relying on the all-year RSF model which tends to average habitat selection patterns across the year and may not reflect seasonal nuances.
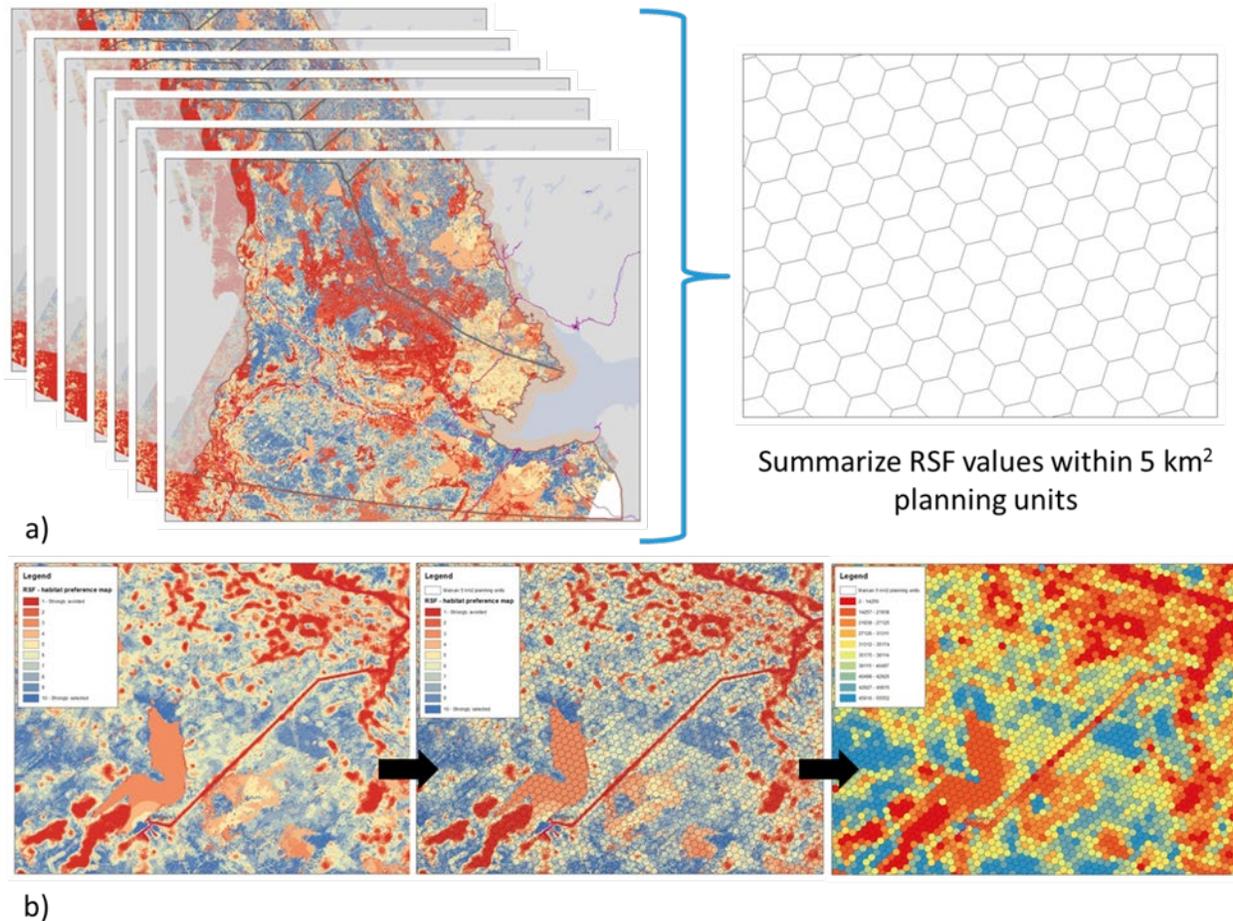
Figure C-1. (a) Seven seasonal maps (calving, summer, early fall, late fall, early winter, mid-winter and late winter) were overlaid with a grid of 5 km² hexagonal cells representing planning units used in Marxan analyses. (b) An illustration from the Sambaa K'e (Trout Lake) area of how bin scores were summed within 5 km² hexagonal cells representing planning units.

Marxan analyses

Marxan analyses were run using planning units for the entire area of the NT1 range for which seasonal predictive maps could be generated from the models in DeMars et al. 2020 (**Figure C-2**). This excluded an area in the northwestern part of the NT1 range that extends into the Yukon, and part of the southeastern corner of the range that occurs within Wood Buffalo National Park. Marxan analyses considered planning units from across the entire area, but representation targets on the seasonal values had to be met within each of the range planning regions. This approach was taken so that areas of preferred habitat that span regional range planning boundaries were not artificially split, as would have been the case if layers had first been clipped to the range planning regions and Marxan analyses run separately on a region-by-region basis.

Figure C-2. Spatial extent of 5 km² planning units, which were used in Marxan analyses.

To determine an appropriate boundary length modifier (BLM), Marxan analyses were initially run using a representation target of 50% of the cumulative RSF value in each region for each season, and boundary length modifier values ranging from 0.1 to 3.0[1]. Low boundary length modifier values tend to provide an over dispersed (scattered) solution with many small patches, and high values can produce an overly clumped solution, which tends to "sweep in" more planning units with low caribou habitat value. A consistent "cost" value of 2,500 was used across all planning units, and a species

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[1] Boundary length modifier values tested included 0.1, 0.175, 0.25, 0.375, 0.5, 0.75, 1.0, 1.5, 2.0, and 3.0.

penalty factor of 10 was applied. A boundary length modifier of 0.75 was determined to provide the best balance between overdispersion and overly clumped solutions (**Figure C-3**).
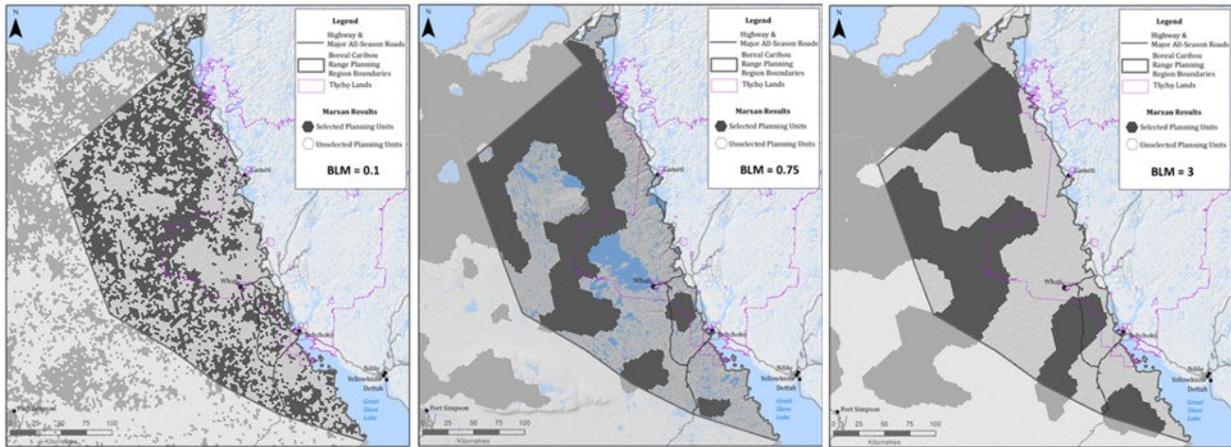

Figure C-3. Marxan results from runs using a 50% representation target on regional cumulative RSF values and BLM values of 0.1 (left), 0.75 (middle) and 3.0 (right).

Using the boundary length modifier of 0.75, Marxan runs were then carried out using representation targets of 20%, 30%, 40%, 50%, 60% and 70% of the regional cumulative seasonal RSF values. The cumulative regional seasonal RSF values represent the sum of the seasonal RSF values across all planning units within each range planning region for each season. A total of 100 runs were completed for each representation target (600 runs total), and the frequency that each planning unit was selected in the Marxan solution from each of the 100 runs was calculated. It was assumed that planning units that were more frequently selected across the 100 runs represented areas of higher importance to boreal caribou because they correspond to planning units with high RSF values across most seasons. A 'super sum' solution was then calculated by adding the selection frequencies for each planning unit across the six different representation targets, yielding the number of times that a planning unit was selected out of 600 runs (**Figure C-4**). Maps of the results from each of the representation targets and the 'super sum' solution were colour coded into three categories: red = planning units that were never selected in any runs; yellow = planning units that were selected in more than one but less than half the runs; and blue = planning units that were selected in more than half the runs.
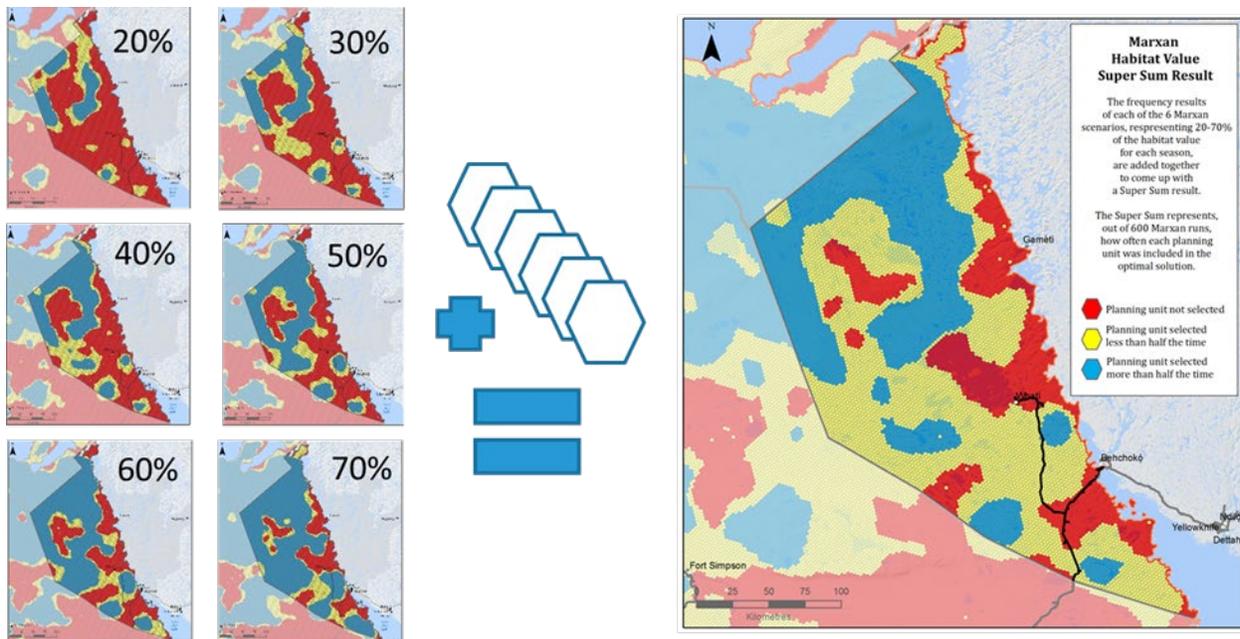
Figure C-4. Marxan results based on representation targets of 20% to 70% of the cumulative regional RSF value for each season (100 runs per target; left panel) and the 'super sum' solution (right panel) representing the selection frequency of planning units across the 600 runs from all representation targets. Planning units were colour coded by selection frequency: red = planning units that were never selected in any runs; yellow = planning units that were selected in more than one but less than half the runs; and blue = planning units that were selected in more than half the runs.

The results of the 'super sum' solution from the Marxan runs based on the seasonal RSF values were then evaluated for how well they captured areas of known use by boreal caribou based on collar data. It was apparent that there were areas with high concentrations of collar locations that were not being captured in the Marxan solutions (**Figure C-5**). One explanation for this is that collar data from the Mackenzie study area was not included in the RSF models developed by DeMars et al. (2020) because these collars were deployed following a large fire from 2014 and there was concern that inclusion of this data would bias the RSF models towards predicting selection of recent burns. Despite excluding this data from the RSF models, DeMars et al. (2020) found evidence for selection for recent burns during the calving and summer. Because boreal caribou showed greater selection for areas that haven't burned in >60 years during the fall and winter seasons, the RSF models predict moderate to lower suitability habitat in the Mackenzie study area throughout most of the year because most of it is in recent burns. Another example is the exclusion of planning units corresponding with islands within Lac La Martre that had evidence of use based on collar data. These may have been excluded from the Marxan solution because they represented more isolated planning units that would have increased the 'cost' of the solution if they had been included due to boundary length modifier.
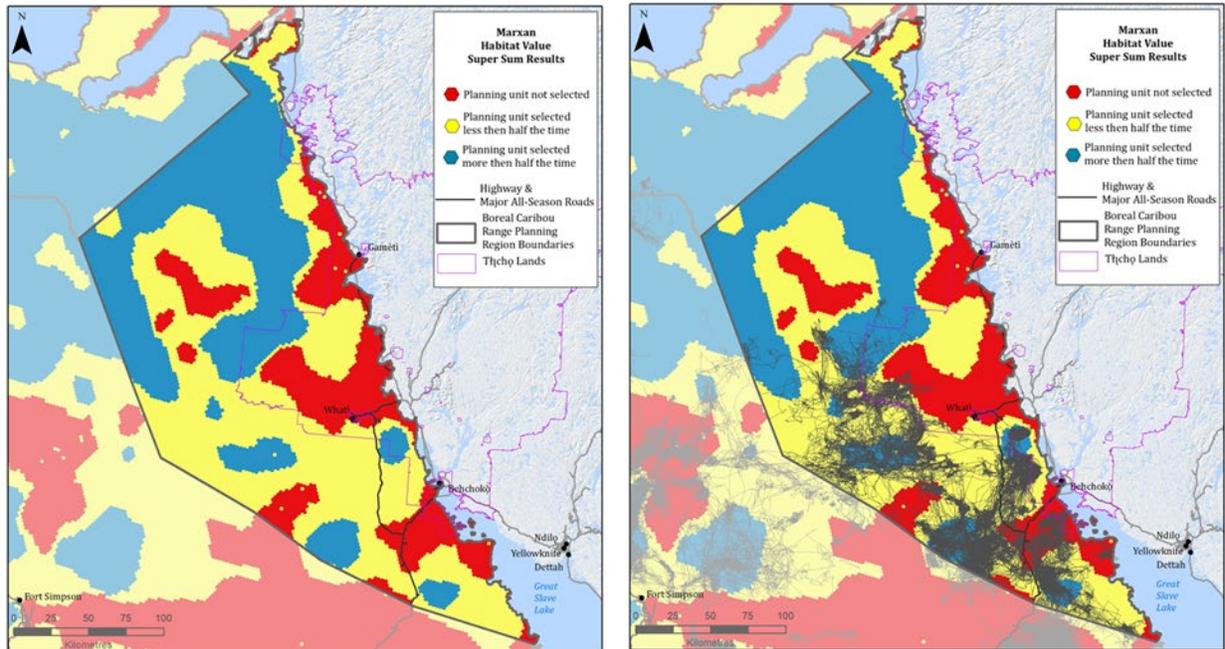
Figure C-5. Side-by-side comparison of the Marxan 'super sum' solution based on 20%-70% representation targets for regional cumulative seasonal RSF values without (left panel) and with (right panel) movement paths of collared boreal caribou (grey lines). The black rectangles illustrate areas with known use by boreal caribou that were not included in Marxan solution (i.e., planning units were never selected).

To address this issue, a new layer was created that represented a collar data density index within planning units to highlight areas of higher known use by boreal caribou (**Figure C-6**). Boreal caribou monitoring study areas were first separated into distinct non-overlapping polygons. The number of collar locations was then counted within planning units falling inside each of these polygons (based on one collar location per day per individual). The number of collar locations in each planning unit was divided by the total number of collar locations in the study area polygon and multiplied by 100 to represent the percentage of that study area's collar locations contained in each planning unit. This index was then standardized among study areas by dividing each planning unit's value by the maximum value of all planning units in that study area and multiplying by 100. This resulted in a collar data density index that range between 0 and 100, that was more comparable among the different study area polygons, because some areas have had monitoring programs in place for longer periods of time or have had higher collar deployment effort. A series of Marxan runs with representation targets of 20% to 70% of the cumulative regional collar data density index were then performed (not including the RSF layers), and the 'super sum' solution was created from the 600 runs. Planning units were then binned into three categories of selection frequency: red = planning units never selected; yellow = planning units selected in more than one run but less than half the runs; and blue = Planning units that were selected in more than half the runs (**Figure C-6**).
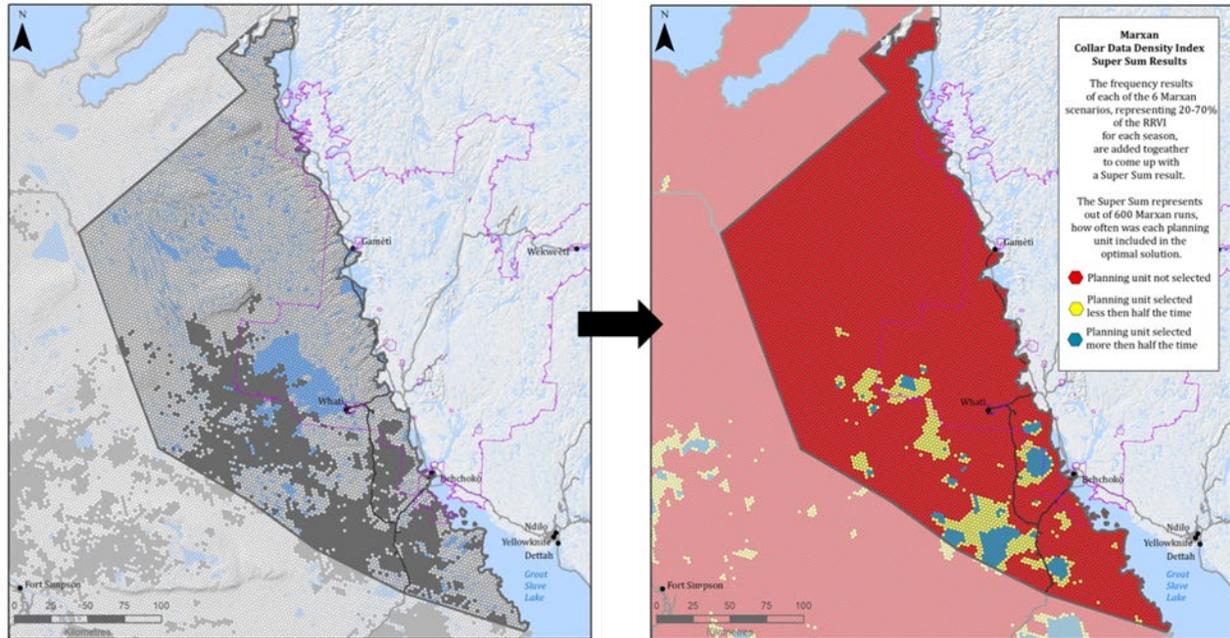
Figure C-6. Planning units containing collar locations (dark grey; left panel) and 'super sum' result from Marxan runs using representation targets of 20%-70% of the cumulative regional collar data density index (100 runs per target; 600 run total). Planning units were binned into three categories: red = planning units that were never selected in any runs; yellow = planning units that were selected in more than one but less than half the runs; and blue = planning units that were selected in more than half the runs.

Marxan runs with the seasonal RSF layers were then re-run using the same 20%-70% representation targets, but this time the planning units with higher known use based on the collar data density index (blue units in **Figure C-6** – right panel) were then 'locked in' to the Marxan solutions. This means that Marxan had to select these planning units in each run, and this tended to create 'gravity' around the 'locked in' planning units because Marxan tried to arrive at a clustered solution. **Figure C-7** shows the results of the 'super sum' solution from the Marxan runs with areas of high known use 'locked in', with planning unit selection frequency shown on a relatively continuous scale (left panel) and binned into three categories. **Figure C-8** provides a side-by-side comparison of the Marxan 'super sum' solutions without (left panel) and with (right panel) areas of high known use based on the collar data density index 'locked in'. The right panel in **Figure C-8** provides a representation of "High" (blue), "Medium" (yellow), and "Low" (red) importance areas for boreal caribou on a relative scale.
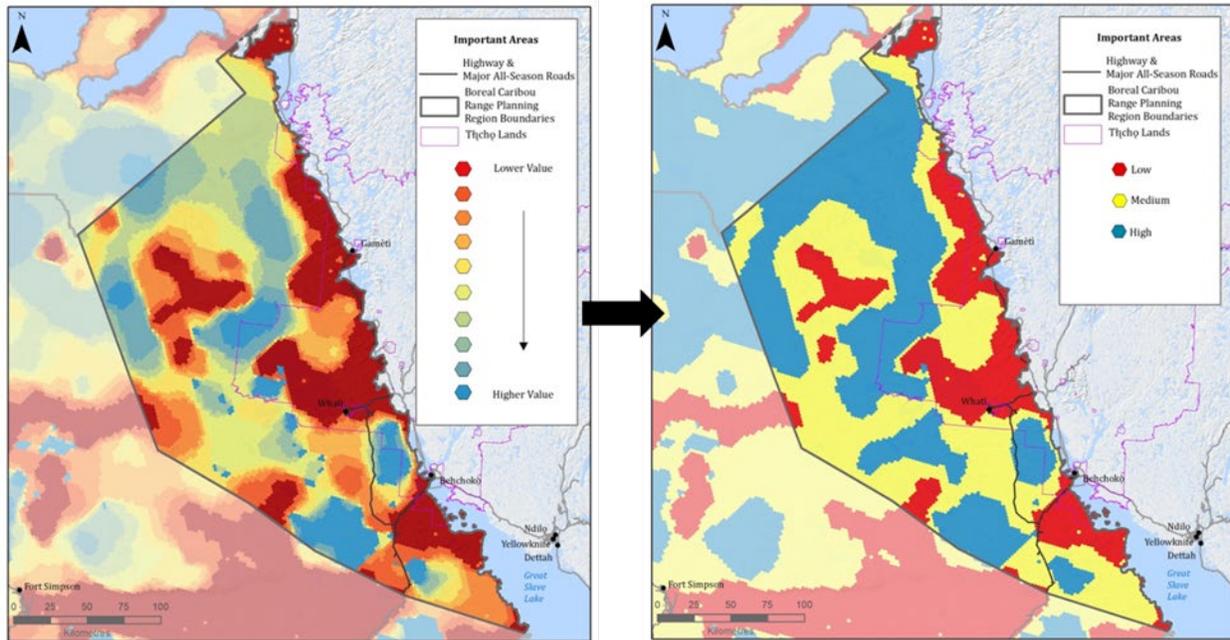
Figure C-7. 'Super sum' results from Marxan runs with 20%-70% representation targets for regional cumulative seasonal RSF value and areas of high collar data density "locked in". The left panel shows planning unit selection frequency binned into 10 classes from low (never selected) to high, and the right panel shows planning unit selection frequency divided into three bins representing relative habitat importance: Low (red) = planning units that were never selected in any runs; Medium (yellow) = planning units that were selected in more than one but less than half the runs; and High (blue) = planning units that were selected in more than half the runs.
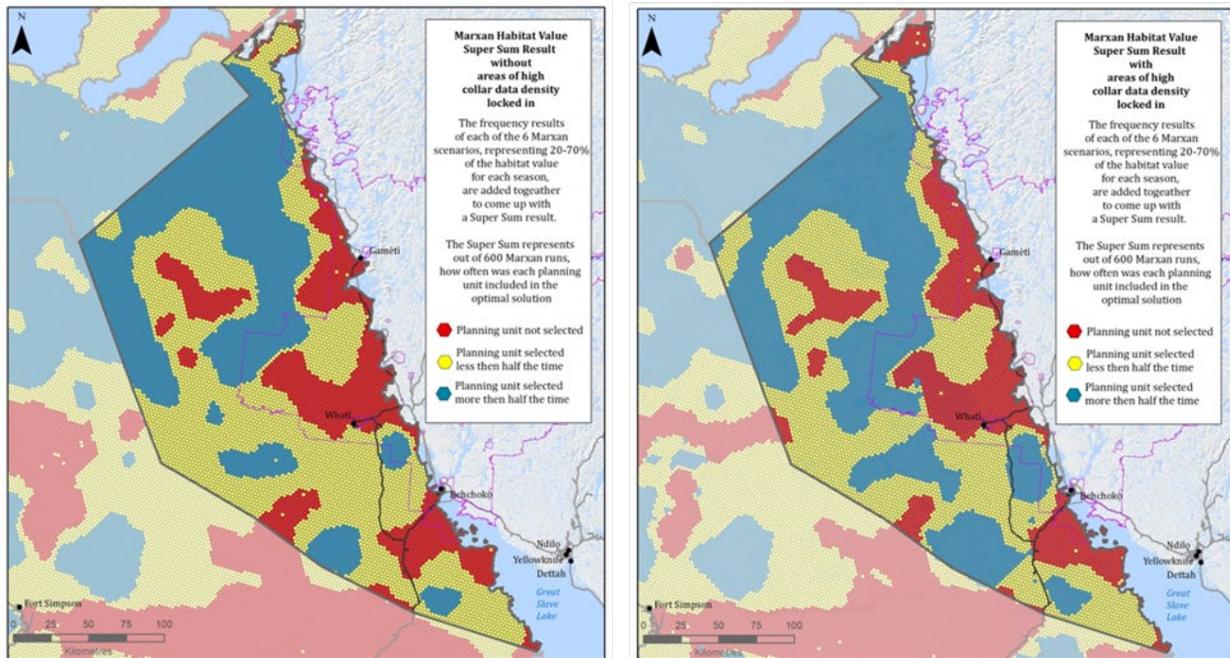
Figure C-8. Side-by-side comparison of the Marxan 'super sum' solutions without (left panel) and with (right panel) areas of high collar data density locked in.