Comparing global and regional maps of intactness in the boreal region of North America: implications for conservation planning in one of the world’s remaining wilderness areas

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# Abstract

Though North America’s boreal forest contains some of the largest remaining intact ecosystems in the world, human activities are systematically reducing its extent. Consequently, forest intactness and human impact maps are increasingly used for monitoring and conservation planning in the boreal region. We compare ten forest intactness and human impact maps to provide a multi-model assessment of intactness in the boreal region. All maps are global in extent except for Global Forest Watch Canada’s 2000 and 2013 Intact Forest Landscapes (IFL) maps, although some global maps are restricted to areas that were at least 20% treed. As a function of each maps spatial coverage in North America, the area identified as intact ranged from 56% to 79% in Canada and from 32% to 84% in Alaska. Comparisons of spatial similarity between the maps revealed some broad patterns of agreement with regional variations due to differences in resolution, input data, mapping methods, and width of anthropogenic zones of influence. A regional assessment of the accuracy of the 4 most recent maps using finer-resolution datasets from Alberta, BC and Yukon revealed that seismic lines and mining sites are often misclassified as intact while recent cutblocks are generally accounted for. In frontier ecosystems such as Canada’s boreal region, where detailed regional mapping does not exist, we recommend high-resolution maps such as Global Forest Watch Canada’s 2013 IFL map but recognize its limitations and emphasize the need to match map characteristics to conservation objectives. Moreover, in landscapes that are undergoing rapid change due to development, maps that are regularly updated using standard procedures are highly desirable.

# Introduction

Wilderness or intact areas support biodiversity, ecological and evolutionary processes including large natural disturbances, and ecosystem services such as carbon capture and sequestration (Mittermeier et al. 2003, Leroux et al. 2010, Watson et al. 2016). They also play an important role in climate change mitigation (Price et al. 2013, Melillo et al. 2016) and can serve as ecological baselines (Arcese and Sinclair 2016). Despite their importance and recent calls for the expansion of protected areas in wilderness or intact regions (Betts et al. 2017, Dinerstein et al. 2017, Tilman et al. 2017), the global erosion of wilderness areas exceeds the rate of protection (Watson et al. 2016). To identify and conserve additional wilderness and intact areas, reliable and up-to-date spatial information is required. This has led to the production of several global, national, and regional products that attempt to map anthropogenic disturbances or their complement, areas with little or no evidence of human activities (McCloskey and Spalding 1989, Bryant 1997, Sanderson et al. 2002, Potapov et al. 2008b, Woolmer et al. 2008, Hansen et al. 2013). The maps vary in methodology, spatial and temporal characteristics, and most importantly, the area estimated to be intact. Consequently, a comparison of map products would assist conservation planners and researchers with the selection of the most appropriate product(s) to use in a given region.

Globally, boreal regions include some of the last remaining large expanses of wilderness or intact areas (Potapov et al. 2017). In North America, these areas are threatened by the rapid expansion of industrial activities such as forestry, mining, oil and gas extraction into increasingly accessible landscapes (Bradshaw et al. 2009, CEC 2010, Schindler and Lee 2010, Brandt et al. 2013, Venier et al. 2014). The region covers 6.3 million km2, of which 88% is in Canada and 12% is in Alaska (Brandt et al. 2013). In Canada, 8.9% of the boreal region is currently protected, with a substantial amount of that area classified as strictly protected (i.e., IUCN categories I-IV) (OMNR 2013, CCEA 2016). There is increasing recognition of the need to expand protected areas while opportunities remain. In response, the Governments of Ontario and Quebec have committed to setting aside 50% of the boreal region of each province in various levels of protection in anticipation of future resource development (Government of Quebec (Minister of Natural Resources and Wildlife) 2009, Hansen et al. 2010). Several major forest companies and environmental organizations have signed the Canadian Boreal Forest Agreement (CBFA 2010), which aims, amongst several key goals, to complete a network of protected areas that is representative of ecosystem diversity across the boreal region. The Agreement also seeks to secure ecological benchmarks (*sensu* Arcese and Sinclair (Arcese and Sinclair 2016)), defined as areas of intact forest large enough to sustain biodiversity and support large-scale ecosystem processes such as fire with minimal external inputs (Lee et al. 2006, Potapov et al. 2008b, Cyr et al. 2009, Potapov et al. 2017). For example, intact areas are often favoured in protected area design and as control areas against which the impacts of human activities on biodiversity can be compared within an adaptive management framework (Lindenmayer et al. 2006, Watson et al. 2009).

In the boreal region where forests dominate the landscape, wilderness or intact areas have much in common with the concept of intact forest landscapes (Potapov et al. 2008a) (Box 1). Intact areas become non-intact through the accumulation of human impacts such as road construction, logging, mining, and urban development. Maps that measure intactness can be used along with other information to evaluate the sustainability of forest management (Heilman et al. 2002, Wulder et al. 2008), monitor trends in biodiversity and other forest resources (UNEP 2002, Alkemade et al. 2009, Coops et al. 2009, Fraser et al. 2009), assess the effectiveness of conservation strategies (Haines et al. 2008, Leroux and Kerr 2013), and inform conservation planning and policy decisions (Myers et al. 2000, Wiens et al. 2009, Leroux et al. 2010). Intact forest landscapes are increasingly considered a policy instrument in forest conservation and management. For example, they have been integrated into the certification standards of the Forest Stewardship Council (FSC 2015) with implications for forest management policies (Rotherham 2016).

Somewhere in the introduction we need to add recent references esp., Venier et al. (Venier et al. 2018) and Bernier et al. (Bernier et al. 2017)

Several global and national maps have been developed that can be used to identify intact areas in the boreal region of North America. Specific definitions for intactness differ by map product, but in general, the products consider intactness to be a structural descriptor of landscapes that reflects the absence of anthropogenic disturbances as measured from thematic (e.g., roads) and remote sensing data. The availability of a broad range of maps may lead to confusion about the suitability of the various products for conservation planning. To make a choice, it would help to not only understand the differences in characteristics and assumptions of each map, but also how well their predictions agree with each other and against independent and higher-resolution regional maps. Consequently, we compare map characteristics and intactness estimates, and quantify inter-map agreement. We then illustrate the strengths and limitations of the maps at accurately identifying three specific anthropogenic disturbances common in the boreal region: oil and gas exploration, logging and mining. Our goal is to inform conservation planning in one of the world’s remaining wilderness areas.

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| **BOX 1. Mapping wilderness and intact areas**  Several initiatives have attempted to map the world’s last remaining large wilderness or intact areas in the past 30 years. All have relied on the use of existing maps and satellite imagery to identify areas with little or no human disturbances. We briefly review four initiatives, three of which we compare in this paper, in order of chronology.  *Wilderness Areas*. The World Wilderness Areas map was the first global initiative that attempted to map areas with little or no human influence (McCloskey and Spalding 1989). To qualify, areas had to be ≥ 4,000 km2 after eliminating all areas within 6 km of human infrastructures e.g., roads and settlements. More recently, the IUCN has used the term wilderness to describe “landscapes and seascapes that are biologically and ecologically largely intact, with a low human population density and that are mostly free of industrial infrastructure” (Kormos et al. 2017). The minimum size for inclusion is 10,000 km2 with human densities of ≤ 5 people per km2 and retaining at least 70% of historical habitat extent (Mittermeier et al. 2003).  *Frontier Forests*. The Frontier Forests initiative attempted to map the world’s remaining large intact natural forests, which the authors defined as forests that are “relatively undisturbed and big enough to maintain all of their biodiversity, including viable populations of the wide-ranging species associated with each forest type” (pp. 12) (Bryant 1997). Similar to wilderness areas, human disturbances due to traditional activities are considered acceptable. No explicit minimum size for inclusion was specified. The concept has been questioned for its utility for identifying high priority conservation areas because of the methods and criteria used to define intact forests (Innes and Er 2002).  *Last of the Wild*. The Last of the Wild was derived from the human footprint map (Sanderson et al. 2002), an initiative which, in contrast to the other initiatives, focused on assessing the levels of human activity and not on the identification of intact areas. However, it was subsequently used to identify the least disturbed areas within each biome, by reclassifying all areas with a human influence index of ≤ 10 to represent areas with little or no disturbances. In this paper, we used more recent versions of the human footprint maps (Venter et al. 2016a) and considered human index values of 0 as representing intact areas.  *Intact Forest Landscapes*. Intact forest landscapes (Potapov et al. 2008b) are defined as “a seamless mosaic of forest and naturally treeless ecosystems within the zone of current forest extent, which exhibit no remotely detected signs of human activity or habitat fragmentation and is large enough to maintain all native biological diversity, including viable populations of wide-ranging species” ([www.intactforest.org](http://www.intactforest.org)). The working definitions include criteria related to minimum size, type and buffer width of disturbances (Tables 1 and 2). The specific definition in Canada diverges from the global definition with respect to some of the criteria, for example the treatment of fires (see Discussion). |

# Methods

## Study area and map products

Our study area comprises the spatial extent of the boreal and boreal alpine regions (i.e., the boreal region) of Canada ~~and Alaska~~ (Brandt 2009) (Figure 1). We selected nine recent national and global maps that are freely available and that, at a minimum, covered a large portion of the region. All maps are global in extent except for the three developed by Global Forest Watch Canada for the Canadian boreal and temperate forests. Three of the maps have been produced for 2-3 time periods (Table 1). The maps can be broadly categorized into four groups. Three of the maps use similar methods to measure intactness as the absence of conspicuous anthropogenic disturbances: Frontier Forests (FF1996) map for 1996 produced by the World Resources Institute (Bryant 1997); Global Forest Watch’s (GFW) global intact forest landscapes (IFL) maps for the years 2000, 2013 and 2016 (GIFL2000, GIFL2013 and GIFL2016) (Potapov et al. 2008b, 2017); and GFW Canada’s (GFWC) IFL maps for the years 2000 and 2013 (CIFL2000 and CIFL2013) (Lee et al. 2010, Smith and Cheng 2016). All maps buffer disturbances except for FF1996. In contrast to the CIFL maps, the GIFL maps include wildfires occurring near infrastructure as an anthropogenic disturbance (Lee 2008). Five of the maps were developed by mapping cumulative human pressures on terrestrial ecosystems: Low Impact Areas for the year 2015 (VLIA2015) (Jacobson et al. 2019), Global Human Modification for the year 2015 (GHM2015) (Kennedy et al. 2019), Human Footprint maps for the years 1993 and 2009 (HF1993 and HF2009) (Venter et al. 2016a, 2016b), Canada’s Human Access map for 2010 (HA2010) (Lee and Cheng 2014), and Boreal Ecosystem Anthropogenic Disturbance for the year 2010 (BEAD2010) (Pasher et al. 2013). The final map, Anthropogenic Biomes for the year 2000 (AB2000), is a regionalization map that includes three wildland categories (wild forest, sparse trees, and barren) that are of primary interest.

We compared each map based on general characteristics including geographic extent, format, resolution, measurement scale, and source of input data. We also compared the methods used to develop the maps, including methods used to delineate or stratify the maps, minimum size of an intact area, disturbance types considered, and whether areas surrounding disturbances were excluded.

## Intactness estimates and agreement

The maps reviewed varied in geographic coverage, mapped values, scale, coordinate system, and GIS file format. To make comparisons of intactness estimates across maps at national ~~and regional~~ scales, we converted all maps to an Albers Equal Area projection, clipped to the boreal region of Canada (see Supp Info for Alaska), and vectorized the raster datasets. We then reclassified the maps, where necessary, to binary “intactness” maps, with 1 indicating little or no human impact and 0 identifying non-intact areas. For the human footprint maps (HF1993 and HF2009), the global human modification map (GHM2015) and low impact areas map (VLIA2015), all areas with little or no human influence (pixel values=0) were assigned a value of 1 while remaining areas were assigned a value of 0. Similarly, for the HA2010 and BEAD2010 maps we assigned a value of 1 to all pixels that were not identified as disturbed areas. For the frontier forest map (FF), all frontier forest polygons were assigned a value of 1, irrespective of their threat level. For the AB2000 map, we assigned a value of 1 to the three wildland categories i.e., wild forest, sparse trees, and barren. Following map reclassifications, we calculated, for each map, the geographical coverage of the mapped product within the boreal region as well as the total area identified as intact.

Prior to evaluating the spatial agreement of datasets, we rasterized or resampled all maps to a 250-m resolution. No information was lost when resampling to a smaller cell size. We estimated the area of spatial agreement and disagreement between the 250-m intactness maps using the raster package (Hijmans 2016) in R 3.63 (Team n.d.). For the CIFL, GIFL and HFP maps, we used the most recent maps for the comparisons. We restricted the spatial extent of the analysis to the intersection of the GIFL, CIFL, and BEAD2010 datasets. We then constructed a contingency table, also known as an error or confusion matrix, to summarize the results.

## Regional assessments

We conducted three case studies to assess the ability of intactness maps to account for specific disturbance types common in the boreal region and to illustrate the benefits of using higher resolution regional data sources, when available, to create a more complete assessment of current landscape conditions (Figure 2, Table 5). The case studies focused on oil and gas exploration in Alberta, forest harvesting in British Columbia, and disturbances related to placer mining in the Yukon. For each intactness map in each study area, we calculated the total area (or length) that was misclassified as being intact. Estimates were based on removing disturbed areas only in BC and the Yukon, not buffered areas as used by some intactness maps (i.e., CIFL, GIFL, and HF maps); consequently, estimates for those maps are conservative. In Alberta, both buffered and unbuffered linear disturbances (seismic cutlines) were calculated.

The first case study is from northern Alberta (Figure 2a), where oil and gas exploration has expanded at a rapid pace in recent decades, leading to a proliferation of seismic lines across the landscape (Lee and Boutin 2006). To identify seismic lines, we used the high-resolution human footprint index maps developed by the Alberta Biodiversity Monitoring Institute (ABMI) (Alberta Biodiversity Monitoring Institute 2017). The ABMI footprint maps consist of 1:15,000 vector polygons which map the distribution of 24 anthropogenic disturbances related to energy extraction, forestry, agricultural, and human settlements. The maps are produced approximately every two years (2007, 2010, 2012, 2014, 2016, 2017) using a variety of field data, aerial photography and high-resolution satellite imagery (Alberta Biodiversity Monitoring Institute 2017). We used ABMI2007 to evaluate HF2009, ABMI2010 to evaluate HA2010 and BEAD2010, ABMI2012 to evaluate CIFL2013 and GIFL2013, ABMI2014 to evaluate GHM2015 and VLIA2015, and ABMI2016 to evaluate GIFL2016. We did not evaluate the other intactness maps due to the large temporal disconnect with the earliest ABMI map produced. Prior to the analysis, we converted the raster intactness maps to polygonal shapefiles. The seismic cutlines were all buffered by 3- or 6-m except for the ABMI2016 map. Consequently, we applied an average buffer of 4.5-m to the ABMI2016 map. We then intersected each intactness map with the matching ABMI footprint map and tabulated the area of the seismic line footprint type that was located within areas identified as intact.

The second case study is from northeast British Columbia (Figure 2b) where forest harvesting has been occurring extensively for the past several decades. We used the most recent dataset of harvest cutblocks available from DataBC[[1]](#footnote-1) to evaluate how well the intactness maps captured and removed recent cutblocks. The cutblocks dataset maps the location of harvested areas that occur on public lands in British Columbia and also provides and estimate of the year of harvest for each cutblock. For each intactness dataset, we calculated the cumulative area of cutblocks within areas identified as intact and divided this amount by the total area harvested in the study region to derive the proportional area misclassified as intact. Depending on the intactness dataset, we only used cutblocks that occurred up to 30 years prior to the date that the intactness map was developed.

The third case study is from central Yukon Territory near the Alaska border (Figure 2c) where placer mining, the technique of recovering gold from gravel along streams and rivers, is a relatively common land use activity with claims extending across more than 2,200 km2 of the Territory. The study area consists of the Indian River watershed, an area comprising numerous streams and rivers that are actively being mined for gold. We used two recently produced datasets to identify linear and polygon disturbances associated with placer mining. The earlier dataset was developed in 2010 for an area larger than the Indian River watershed[[2]](#footnote-2) while the later dataset was an update for a smaller area i.e., the Indian River watershed[[3]](#footnote-3). As with the other two case studies, we intersected the vectorized versions of the intactness maps with the two linear and polygonal disturbance maps to identify areas that were erroneously mapped as being intact. As with the Alberta case study we matched the year of the disturbance data to the closest year of the intactness map i.e., we used to the 2017 disturbance datasets to evaluate GIFL206, VLIA2015 and GHM2016 and the 2010 datasets to evaluate HA2010, CIFL2013, HFP2009, and AB2000. Two intactness datasets, FF1996 and BEAD2010, were not used since they did not occur in the study area..

# Results

## Map characteristics

Six of the 9 datasets that we evaluated have global or near-global extents, the exceptions being the national-scale CIFL and HA2010 maps, and the BEAD2010 map which covers a large portion of the boreal region (Table 1). Map resolutions varied from relatively fine (CIFL, GIFL and HA2010 effective resolution ≈ 0.25 km2) to the relatively coarse AB2000 (resolution ≈ 16 km2) and FF1996 (resolution ≈ 16 km2) maps. The 9 datasets were generated from combinations of remote-sensing data and thematic maps representing land use, land cover, human infrastructure, and other spatial and non-spatial information. Thematic maps were used in all cases to represent anthropogenic features such as roads, settlements, and population density. With the exception of the FF1996 map, satellite imagery was used to map forested areas and identify areas with detectable human activity. In some cases, the use of the same input data resulted in different estimates due to how disturbances were treated. For example, in contrast to the CIFL maps, the GIFL maps considered all stand-replacing fires near settlements and infrastructure as being non-intact (Lee 2008). Data production methods differed with respect to study area delineation and minimum mapping unit. For example, minimum patch size for the HFP and GIFL maps was 50,000 ha while for the CIFL maps it was 5,000 ha. In contrast, the HA2010 map did not have a minimum patch size. In addition, methods differed in the process by which areas of human impacts were detected and delineated. Some of the maps distinguished between types of human disturbances and assigned different zones of influence to different disturbance types using buffers. This strongly influenced the distribution and abundance of areas identified as intact forests. Three maps used buffer zones to either eliminate non-intact areas or to rank areas by the degree to which they were influenced by roads, powerlines and navigable waterways. For example, the HA2010, CIFL and GIFL maps systematically eliminated areas within 0.5-1 km of all human disturbances as measured from pre-existing thematic maps or as visually identified on Landsat Thematic Mapper imagery. In contrast, the AB2000 map used cluster analysis to identify and map 19 zones based on factors such as human population density, land use and land cover, including the wild woodlands and wild treeless and barren lands that were use in the analysis.

## Intactness estimates and agreement

All maps except for the BEAD2010 and the GIFL maps covered at least 98% of the boreal region of Canada as defined by Brandt (Brandt 2009) (Table 2, Figure S1). The CIFL maps were restricted to the Canadian boreal region, covering 98% of the region while the three GIFL maps covered 86% of the boreal region of Canada. The BEAD2010 dataset was the least extensive, covering 79% of the boreal region. The total area identified as intact within each map, ranged from 36% for the GHM2015 map to 95% for the BEAD2010 map. The CIFL maps identified 16.1% and 15.2% more intact area in 2000 and 2013, respectively, then the GIFL maps. For the three maps produced in 2-3 different years (HFP, CIFL, and GIFL), the most recent maps identified between 1.2% and 3.6% less intact area. In Alaska, the area identified as intact also varied widely as in Canada (Table S2): from 23% for the GHM2015 map to 91% for the AB2000 map. The GIFL2013 map identified 5.2% less intact area than the GIFL2000 map while the difference between the HFP2009 and HFP1993 maps was only 0.4%.

Spatial agreement between the intactness maps varied widely between comparisons and depending on which map was , from a low of 40% (GHM2015 over BEAD2010 and AB2000) to a high of 100% (BEAD2010 over CIFL2013 and GIFL2013) (Table 3, Figure 3). The highest agreement was between the HA2010 map and both the GIFL2013 and CIFL2013 maps, where 99% of the CIFL2013 and GIFL2013 is present in the HA2010 map. In contrast only 85% and 68% of the HA2010 map is present in the CIFL2013 and GIFL2013 maps, respectively. This is not surprising since the HA2010 map identifies significantly more intact landscapes than the CIFL2013 and GIFL2013 maps. A similar pattern occurred between the GIFL2013 and CIFL2013 maps, where 98% of the GIFL2013 map is present in the CIFL2013 map but only 79% of the CIFL2013 map is present in the GIFL2013 map. This discrepancy is also related to the fact that the CIFL2013 map identifies > 800,000 km2 more intact landscapes than the GIFL2013 map. Even though inter-map agreement is relatively high, it is important to also consider the total area of disagreement; in this case, 43,652 km2 of the GIFL2013 map is not classified as intact by the CIFL2013 map while 685,641 km2 of the CIFL2013 map is not classified as intact by the GIFL2013 map. The lowest agreement was between the WILD and GIFL2013 maps, where only 59% of the WILD map was present in the GIFL2013 map. This corresponds to an area of 1.6 million km2 that disagrees. Overall, there was relatively high inter-map agreement (i.e., ≥80%) in half of the 72 comparisons.

## Regional assessments

*Seismic lines in Alberta*. Most of the seismic lines occurred in the southern half of the study area and were established prior to 2007 (S4 Fig). Between 2007 and 2012, an additional area of only 2 km2 was created. All intactness maps were relatively poor at accounting for seismic lines, probably because they are difficult to detect without aerial photos (Figure 3, Table 5a, S4 Fig). The GIFL2013 and CIFL2013 maps erroneously classified 18% and 48% of seismic lines as intact, respectively. The difference is due in part to a large section of the study area being identified as non-intact in the GIFL2013 map in comparison to the CIFL2013 map, possibly due to differences in the treatment of wildfires (see Discussion). The HF2009 failed to identify the majority of seismic lines (92%), with the exception of a few in the northwest that were removed by the placement of a buffer around the navigable Peace river.

*Forest harvesting in British Columbia*. The total area identified as having been harvested by the two disturbance datasets, C2C and CanLaD, was very similar when all years were combined (Table 5b1-b2 and S5 Fig). The CIFL2013, GIFL2013, and HA2010 maps were relatively effective at identifying and removing cutblocks from intact areas, especially in comparison to the CanLaD dataset, with only 0-6% of harvested areas retained in the intactness maps. The areas wrongly classified as intact were somewhat higher using the C2C dataset, ranging from 8 to 13% of the total area harvested. The other datasets, HF2009, FF, UNUSED and WILD, were poor at identifying and removing cutblocks from intact areas, with 22-96% of harvested areas retained in the intactness maps. For example, the lower elevation Peace River valley in the southern half of the study area has been extensively logged more recently (1995-2005) and this is reflected in the CIFL2013, GIFL2013, HF2009, and UNUSED maps but not the FF and WILD maps.

*Placer mining in the Yukon*. Over-estimation of intactness varied greatly in the Yukon study area, ranging from 4% for the GIFL2013 map to 44% for the HF2009 map. Interestingly, both of those maps also estimated the least amount of the study area as being intact (51% and 55%, respectively) in comparison to the HA2010 and CIFL2013 maps (89% and 80%, respectively). Other maps were more moderate in over-estimating intactness. The CIFL2013 and GIFL2013 maps both removed many but not all placer mine footprints (Table 5c and S6 Fig). The CIFL2013 map omits approximately three times as much area as the GIFL2013 map. The HF2009 map removes 44% of mining disturbance areas, specifically those that are within a buffer distance of roads and navigable rivers.

# Discussion

There is growing interest in conserving intact forests (Watson et al. 2016, Dinerstein et al. 2017, Tilman et al. 2017) prior to land conversion and natural resource development (Brandt et al. 2013, Venier et al. 2014). The North American boreal region remains relatively intact in comparison to much of the globe but is under increasing pressure from forestry, oil and gas operations, mining and hydroelectricity development (Bradshaw et al. 2009, Leroux and Kerr 2013, Venier et al. 2014). Efforts are underway to increase the level of protection in the boreal, and these efforts are focusing on areas that are presently intact, or little-influenced by humans. Intactness is an emerging criterion in conservation planning (Haines et al. 2008, Lee et al. 2010, Watson et al. 2016, Dinerstein et al. 2017), but there is no universally accepted means to measure it over large extents. We compared 10 global and regional maps depicting forest intactness or human impacts on ecosystems to explore the nature, extent, and spatial agreement between maps. Overall, the proportion of the boreal region identified as intact ranged from 48% (GIFL2013) to 83% (HA2010) in Canada and 32% (FF) to 84% (WILD) in Alaska. The relatively low percentage identified by the GIFL maps is due in part to its restricted coverage within the boreal region compared to the other maps, and its treatment of all wildfires occurring in proximity to infrastructure as being considered non-intact (Lee 2008).

Among map characteristics, important factors are spatial resolution and year of production or image capture of the underlying spatial data (i.e., thematic maps and satellite imagery). The UNUSED and WILD maps had the coarsest resolution. This likely resulted in many finer-scale anthropogenic changes and disturbances not being detected in those maps in comparison to the HA2010, CIFL and GIFL maps, which used finer-resolution Landsat imagery. Some global-scale maps relied on older thematic maps such as the Digital Chart of the World to represent infrastructure. Increasingly, maps are using freely available satellite imagery or satellite-based land cover maps as inputs (e.g., Landsat) (White et al. 2017). The age of the imagery could have important implications for the suitability of these maps in conservation planning, especially in areas that are rapidly changing, including the boreal plains of western Canada, and southern parts of the boreal shield in Ontario and Quebec (Government of Quebec (Minister of Natural Resources and Wildlife) 2009, OMNR 2013).

Methodological differences among maps were mostly related to study area delineation, minimum polygon size, and map age. For example, some of the discrepancy between the FF and CIFL maps is due to the delineation of the FF forest zone, which excluded northern, less densely forested portions of the Canadian boreal. Similarly, many disagreements occurred where older maps did not reflect areas of recent rapid development along southern boundaries. Some of these characteristics may explain why the CIFL maps are more consistent with the known history of development over the past 20 years than some of the other maps. The GIFL maps used a satellite-based global tree cover map to define their study area, resulting in some parts of the boreal region being excluded because tree canopy was < 20%. Forest fragment size also contributed to discrepancies among maps, with four of the maps specifying a minimum size. Some of the maps, for example the GIFL maps, considered that an intact forest should have a minimum size of 50,000 ha (Potapov et al. 2017). In contrast, the CIFL maps used a minimum threshold of 5,000 ha for boreal ecozones and 1,000 ha for temperate ecozones (Smith and Cheng 2016); the latter only occurred along the southern edge of the boreal region. Consequently, a greater total area of intact forests was identified by the CIFL maps. Other maps, such as the HA2010 map did not have a minimum area requirement and consequently identified an even greater amount of intact area. Ideally, the minimum size of intact forest patches for conservation planning should be related to habitat requirements for focal species and ecological processes (Haddad et al. 2015). Consequently, conservation planners should consider minimum polygon size and map age as when evaluating the suitability of intactness data sets for their applications.

The assumed widths of human influence zones also contributed to differences in the extent of mapped intact areas. For example, the HF maps (and, by association, the UNUSED map) considered up to 15-km wide zones of influence around features such as roads, major rivers and coastlines, since they are often used as transportation corridors or have high population densities. While there is plenty of evidence that human activities can have impacts beyond the point source (e.g., wolf avoidance of areas with human activities (Shepherd and Whittington 2006); use and effectiveness of riparian buffers (Richardson and Béraud 2014)), this arbitrary threshold eliminated many areas considered intact by the HA201, CIFL and GIFL maps. This may be justified in some coastal zones of Europe and more populated regions of North America, but it is not as well supported in remote areas of the northern boreal forest, where population density is negligible.

Overall, the HA2010, CIFL and GIFL maps were most similar in methodology. However, there were minor differences in the disturbance types included that resulted in relatively important differences in the areas identified as intact in some parts of the boreal region. The GIFL maps excluded burned areas near settlements. Fires play crucial roles in the dynamics of Canadian boreal forests, where most of the area burned is due to lightning-caused fires which were therefore not excluded in the CIFL maps. This alone would account for an under-estimation of 400,000 km2 of intact boreal and temperate forests in Canada by the GIFL maps (Lee 2008). Another source of disagreement was due to the treatment of rivers affected by hydroelectric power generation, which were excluded using a 1-km buffer by the GIFL maps but not by the CIFL and HA2010 maps. The use of simple buffers around disturbances, common with several maps, limits the user’s ability to use a more flexible and nuanced approach to allocating degrees of intactness within areas that have not been disturbed but are close to a disturbance. For example, when identifying reserves for species that have strong avoidance of human-impacted areas such as caribou (Environment Canada 2008), these buffers may be appropriate, and would not represent an underestimation of intact areas. However, when conservation efforts focus on less sensitive species, these buffers may be too conservative and underestimate the amount of suitable habitat. To be most flexible, future intactness mapping projects should avoid using buffers. The intactness maps also varied in the amount of area they identified as intact in the boreal region of both Canada and Alaska, likely due to differences in resolution, precision, methodology and date of input data sources. This is reflected in the inter-map comparison between the 1 km2 intactness maps, in which the proportion of agreement between maps in the Canadian boreal region ranged between 59-99%.

The three case studies assessed the ability of intactness maps to account for specific disturbance types in regions of the Canadian boreal forest that are currently undergoing rapid industrial development (Brandt et al. 2013, Venier et al. 2014, Geist et al. 2017, White et al. 2017). They also highlight the need to complement existing intactness maps with up-to-date high-resolution disturbance datasets to provide a more complete and detailed assessment of landscape conditions for regional conservation planning. Overall, industrial development in the boreal is occurring rapidly and even recently produced intactness maps are quickly out-of-date, suggesting the importance of updating maps on a regular basis, ideally annually. For example, linear disturbances such as seismic lines are poorly discriminated by all intactness maps. A reduction in their width over time likely resulted in some newer and narrower lines being undetected using satellite imagery (Lee and Boutin 2006, Van Rensen et al. 2015). In such cases it may be possible to identify these areas using aerial photographs or historical datasets, for example using older resources inventory maps. In the case of forest management, the more recent CIFL2013, GIFl2013 and HA2010 maps were much more effective than the other maps, identifying and removing most cutblocks from intact areas. This is likely due to the shared use of 30-m Landsat imagery by those intactness maps and the two forest disturbance datasets. In general, the GIFL2013 map had the smallest omission rate among the seven maps in the Alberta and Yukon study areas, however it also identified much less intact area than the HA2010 and CIFL2013 maps. Both the CIFL2013 and GIFL2013 identified a large proportion of seismic lines and placer mining disturbances but only half of harvested areas. Surprisingly, the HA2010 map was less effective than the CIFL2013 and GIFL2013 maps at identifying all 3 disturbance types. The Human Footprint maps (HF1993, HF2009) appear to be insensitive to certain types of disturbances common in the boreal, especially seismic lines and small cutblocks, and would need to be combined with recent large-scale disturbance datasets (e.g., (Hansen et al. 2013, White et al. 2017)) to enhance their usefulness for conservation planning. The use of wide buffer zones around human activities also excludes a lot more potential intact area than do the CIFL2013 and GIFL2013 maps. However, the HF maps do allow the possibility of modifying the threshold of intactness (we used 0 as a strict cutoff) and the extent of buffer zones by manipulating the 8 underlying human footprint rasters. Two of the intactness (UNUSED, WILD) were too coarse and relied on older landcover data (GLC2000) and so were unable to reliably identify any of the recent industrial development activities. The FF map was also too coarse and out-of-date to identify disturbances post 1996.

Global maps such as HF, UNUSED and WILD may be appropriate for broad-scale conservation planning where finer resolution data are not available. For example, this approach was used by Mittermeier et al. (Mittermeier et al. 2003) to identify and prioritize global wilderness areas. However, obtaining more detailed and up-to-date regional maps of intactness or disturbances should be a priority for any systematic conservation planning exercises, in the boreal or elsewhere. Although we are not aware of other regional intactness maps in the boreal region of Canada, there exist several examples of regional maps in other parts of the world. For example, the GIFL methodology has also been applied at regional and national scales to map remaining intact forest landscapes in Russia (Aksenov et al. 2002), Alaska (Strittholt et al. 2006), and Venezuela (Bevilacqua et al. 2002). Similarly, the Human Footprint approach has been applied at regional scales in the United States (Leu et al. 2008, Woolmer et al. 2008). Other recent related initiatives have aimed at characterizing landscape patterns, forest fragmentation, and forest change at regional (Raiter et al. 2017), national (UNEP 2002, Wulder et al. 2008, Pasher et al. 2013, Guindon et al. 2014, White et al. 2017) and global scales (Hansen et al. 2013).

## Conclusions

In general, and in comparison to the other intactness maps, the use of the CIFL, GIFL and HF maps are recommended since they are actively maintained, have now been developed for two points in time, use consistent methods across time, and have been partially validated with ground truth data. However, unlike the HA2010, CIFL and GIFL maps, the HF maps does not target forestry activities in the boreal and so may be more appropriate for use in the southern boreal forest where land conversion to agricultural and urban areas is more common. The choice between the HA2010 or CIFL2013 maps versus the GIFL2013 maps largely comes down to 2 factors. The first is the treatment of recent fires, which in the case of the former, is treated as a natural disturbance and included in intact areas. The second is the definition of the forest zone which defines the extent of coverage of the maps. In the case of the GIFL maps, this resulted in only 86% of the Canadian boreal region being mapped versus 98% for the CIF maps. The HA2010 map provides more flexibility than the CIFL maps because there is no restriction on the minimum patch size. However, unlike the CIFL maps, it has not been updated since 2010. The FF is interesting from a historical perspective as it is one of the original intactness-type maps, but it is too old to be useful for either regional or national conservation planning. The UNUSED has some overlap with HF2009 but is less complete and uses older input datasets.

The choice of map to use for broader-scale spatial conservation planning and research prioritization depends in part on the geographic location and extent of the study region. For example, an assessment of the conditions of existing protected areas in North America may select the Human Footprint maps which cover the entire region and also allow an analysis of change over time. Conversely, for the boreal region of Canada, the HA2010 and CIFL maps may be the best choice since they provide higher resolution data than the HF maps for two time periods and, in contrast to the GIFL maps, they don’t consider wildfires as anthropogenic disturbances. In the case of an analysis of forest change in North America, the GIFL maps would be the best choice since they provide the most current assessment of forest intactness at a continental or global scale. Moreover, updating and improving on existing maps will result in some important cost savings. In the end, each map has strengths and weaknesses and their suitability should be judged relative to the objectives of each project.

# Supporting information

The following supplementary tables and maps are available at <https://github.com/beaconsproject/intactness>

* **S1 Fig**. Distribution of intactness datasets within the boreal region of North America. Intact areas are shown in green overlaying the boreal region in brown.
* **S2 Fig**. Cross-classification of intactness maps within the area of intersection of all datasets. Green and yellow areas indicate areas that are jointly identified as intact or non-intact, respectively.
* **S3 Fig**. Seismic lines in Alberta
* **S4 Fig**. Forest harvesting in BC.
* **S5 Fig**. Placer mining in the Yukon.
* **S1 Table**. Description and coverage of intactness maps from Canada and Alaska.
* **S2 Table**. Examples of recent remote sensing based disturbance datasets from Canada and Alaska.
* **S1 Code**. R and Python code used to reclassify maps, estimate intactness, and calculate inter-map agreement.

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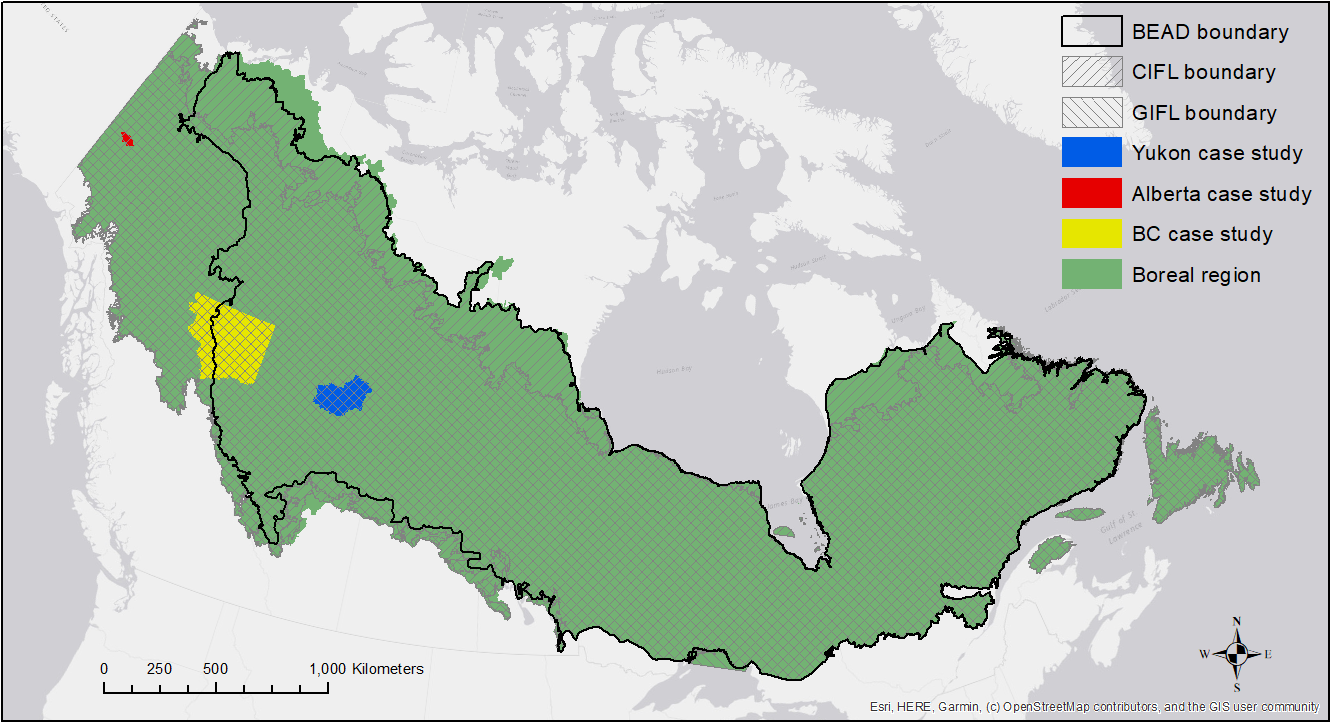
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# FIGURES

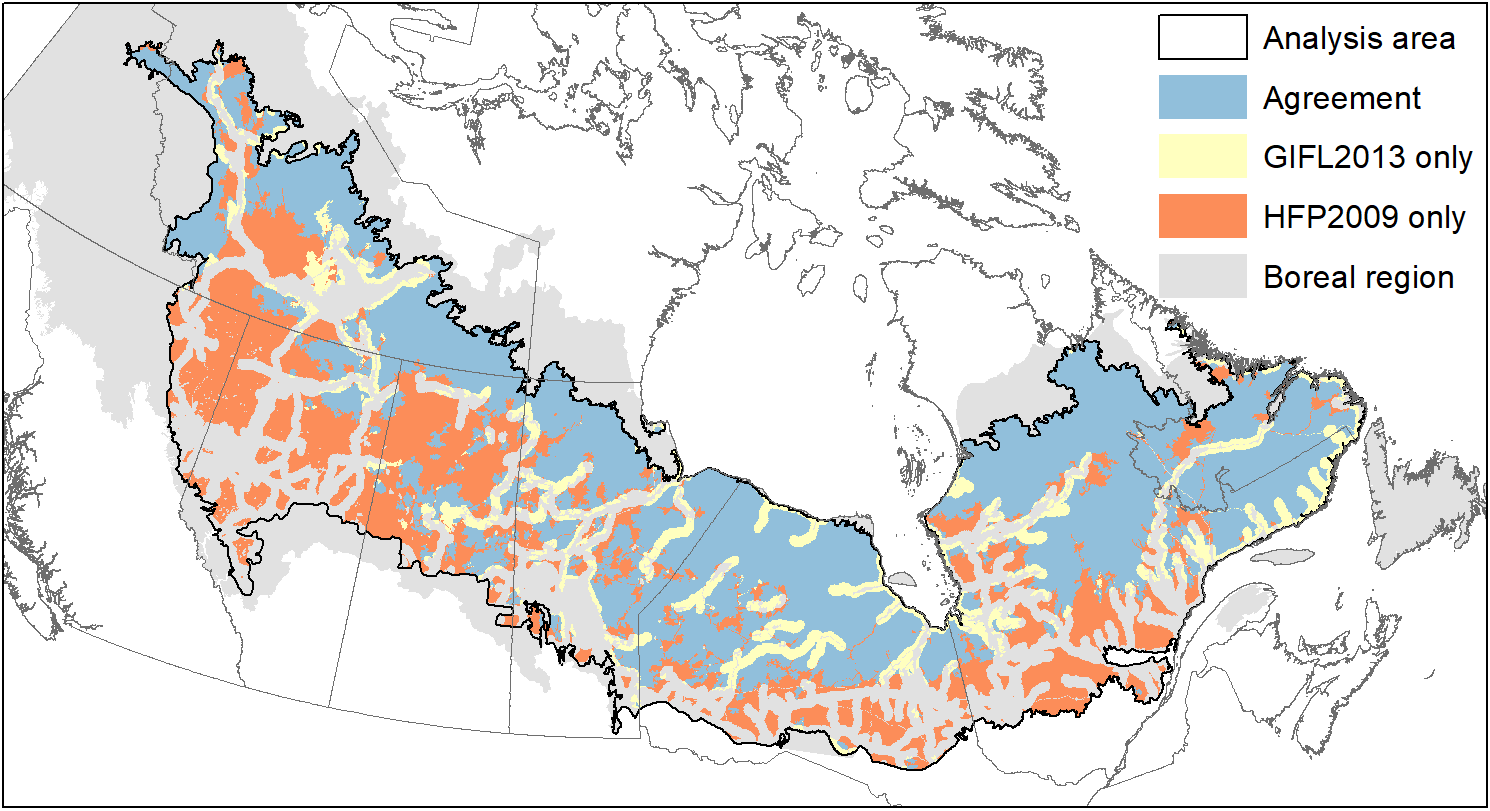
**Figure 1. Extent of boreal region in study area.** Extent of boreal region in North America, Canada, and Alberta based on Brandt's (2009) boreal and boreal alpine zones (Brandt 2009). The colored polygons indicate the location of case studies, from left to right, in Yukon, BC, Alberta, and Quebec. The crosshatch pattern indicates the area of intersection of the CIFL and GIFL maps while the solid black like indicates the limits of the BEAD dataset.



**Figure 3. Distribution of disturbances and three most recent intactness maps in the case study regions.** The intactness maps are shown as a red outline (HF2009) and as green areas (GIFL2013, CIFL2013). The GIFL2013 map is shown in light green above the CIFL2013 map since its distribution is generally a subset of the CIFL2013 distribution. Only 3 intactness maps are shown in the figure to reduce the clutter; the full set of maps can be viewed in the supporting information (S4-6 Figs).

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**Figure 3**. Spatial agreement between the GIFL2013 and HFP2009 maps. The top map indicates that 84% of the intact area identified by the HFP2009 map is also identified as intact by the GIFL2013 map. Conversely, the bottom map indicates that only 66% of the intact area identified by the GIFL2013 map is also identified as intact by the HFP2009 map.

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# TABLES

**Table 1.** General characteristics of forest intactness and human impact maps reviewed in this study.Input data sources and methodological characteristics of forest intactness and human impact maps reviewed in this study.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Dataset** | **Year(s)** | **Geographic extent** | **Format** | **Resolution** | **Measurement scale** | **Buffer distance** | **Minimum patch size** | **Thematic maps** | **Satellite imagery** |
| Canada human access | 2010 | Canada; terrestrial ecosystems | Vector | 1:1,000,000  (~0.25 km2) | Binary - human access or not | 0.5 km | n/a | Linear features (roads, cutlines, etc.), reservoirs, agricultural croplands | anthropogenic disturbance layers (S2) |
| Boreal ecosystem anthropogenic disturbance | 2010, 2015 | Canadian Boreal – caribou ranges | Vector | 1:50,000 | Binary - human access or not | unbuffered | n/a | Hydro reservoirs (GFWC) | Landsat 5 imagery (2008-2010) |
| Canada intact forest landscapes | 2000, 2013 | Canadian Boreal; forested ecozones | Vector | 1:1,000,000  (~0.25 km2) | Binary - intact or not intact | 1 km around roads; 0.5 km around other disturbance types | 5,000 ha boreal & taiga ecozones; 1,000 ha temperate ecozones, which occur along southern edge of Brandt’s boreal | Linear features (roads, cutlines, etc.), reservoirs, settlements; HA2010 and BEAD2010 | Landsat 5 & 7 (1988-2006; 28.5m); Landsat composite (~2013; 30m); anthropogenic disturbance layers and forest disturbance dataset (S2) |
| Global intact forest landscapes | 2000, 2013, 2016 | Global; forested zones | Vector | 1:1,000,000  (~0.25 km2) | Binary - intact or not intact | 1 km | 50,000 ha, at least 10-km wide at broadest place, at least 2-km wide in corridors | Roads, settlements, scanned topographic maps | Landsat 5 (~1990; 30m) and Landsat 7 (~2000; 30m); MODIS VCF 2000 (percent tree cover; 0.5 km2); Landsat composite (~2013; 30m) |
| Human footprint | 1993, 2009 | Global; terrestrial ecosystems | Raster | 1 km2 | Interval - sum of ranks of 8 human pressures (0-50) | Two influence zones: 0-2 km & 2-15 km | 50,000 ha | 7 anthropogenic stressors (human population density, built-up area, cropland, livestock, forest cover change, roads, night-time lights) | Various including global land cover (GLC2000; 1 km2) and GlobCover 2009 (300m) |
| Anthropogenic biomes | 2000 | Global; terrestrial ecosystems | Raster | ~ 5 km2 | Categorical | n/a | n/a | 6 anthropogenic stressors (human population density, built-up area, cropland, rice area, irrigated area, pasture) | MODIS VCF 2000 (Percent Tree Cover; 0.5 km2) |
| Global human modification | 2015 | Global; terrestrial ecosystems | Raster | 1 km2 | Continuous 0-1 (proportion of landscape modified) | n/a | n/a | 13 anthropogenic stressors (human population density, built-up area, cropland, livestock, major roads, minor roads, two-tracks, railroads, mines, oil wells, wind turbines, power lines, night-time lights) |  |
| Low impact areas | 2015 | Global; terrestrial ecosystems | Raster | 1 km2 | Binary - |  |  | 7 anthropogenic stressors (human population density, built-up area, cropland, livestock, forest cover change, roads, night-time lights) |  |
| Frontier forests | 1996 | Global; terrestrial ecosystems | Vector | 1:8,000,000  (~16 km2) | Binary - frontier or not frontier, with threat levels | n/a | Generally, > 50,000 ha | World Forest Map and Wilderness Areas map (McCloskey and Spalding 1989) used by > 90 experts to define large forested areas free of roads, settlements, etc. | No |

1 If the year of the dataset is not provided, we use the date of latest imagery using as input.

2 Values in brackets for vector maps (CIFL and GIFL) indicate approximate effective grid resolution (Goodchild 1993), similar to minimum mapping unit for polygonal data. To make the maps comparable, we rasterized the CIFL and GIFL vector maps to 1 km2 and resampled the FF, UNUSED, and WILD raster maps to 1 km2.

3 Map categories or values that were reclassified to indicate intactness.

4 A key intermediate dataset was GFWC’s Canada Access 2010 dataset, which was created as the initial step in creating the IFL maps. https://globalforestwatch.ca/sites/gfwc/files/data/20140109B\_Canada\_Access\_2010\_metadata.html

5 HF1993 is an update to the original human footprint/human influence index dataset (circa 1993) [47]

6 Frontier forests are large, ecologically intact, and relatively undisturbed natural forests [9]

**Table 2.** Comparison of the areal extent of dataset coverage within the boreal region and areas identified as being intact within each dataset. See Supplementary Information for distribution maps of each map in Canada and Alaska

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Canada boreal region (5,519,764 km2)** | | | | **Alaska boreal region (737,008 km2)** | | | |
| **Dataset** | **Dataset coverage (km2)** | **Coverage of boreal (%)** | **Intact area (km2)** | **Intact area (%)** | **Dataset coverage (km2)** | **Coverage of boreal (%)** | **Intact area (km2)** | **Intact area (%)** |
| BEAD20101 | 4,371,942 | 79.2 | 4,134,336 | 94.6 |  |  |  |  |
| HA2010 | 5,394,980 | 97.7 | 4,511,406 | 83.6 |  |  |  |  |
| CIFL2000 | 5,394,980 | 97.7 | 4,029,533 | 74.7 |  |  |  |  |
| CIFL2013 | 5,394,980 | 97.7 | 3,837,668 | 71.1 |  |  |  |  |
| GIFL2000 | 4,746,030 | 86.0 | 2,780,919 | 58.6 | 475,765 | 64.6 | 379,475 | 79.8 |
| GIFL2013 | 4,746,030 | 86.0 | 2,652,463 | 55.9 | 475,765 | 64.6 | 355,012 | 74.6 |
| GIFL2016 | 4,746,030 | 86.0 | 2,619,094 | 55.2 | 475,765 | 64.6 | 350,983 | 73.8 |
| HF1993 | 5,519,764 | 100.0 | 3,867,998 | 70.1 | 737,008 | 100 | 456,736 | 62.0 |
| HF2009 | 5,519,764 | 100.0 | 3,805,526 | 68.9 | 737,008 | 100 | 455,329 | 61.8 |
| AB2000 | 5,519,764 | 100.0 | 4,752,600 | 86.1 | 737,008 | 100 | 671,113 | 91.1 |
| GHM2015 | 5,519,764 | 100.0 | 1,977,361 | 35.8 | 737,008 | 100 | 165,600 | 22.5 |
| VLIA2015 | 5,519,764 | 100.0 | 4,166,590 | 75.5 | 737,008 | 100 | 452,638 | 61.4 |
| FF1996 | 5,519,764 | 100.0 | 3,324,371 | 60.2 | 737,008 | 100 | 237,657 | 32.2 |

1 Created by erasing polygonal (231,711 km2) and 5-m buffered linear disturbances (5,894 km2).

**Table 3.** Proportional agreement between each pair-wise map comparisons within Canadian boreal region. Each entry represents the proportion of intact area in Map A (shown in the rows) that is also mapped as intact in Map B (shown in the columns). Comparisons were restricted to the area of intersection among the 9 intactness maps (3,804,654 km2).

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Map 1** | | | **Map 2** | | | **Overlap** | |
| **Name** | **Intact km2** | **Unique %** | **Name** | **Intact km2** | **Unique %** | **Overlap km2** | **Overlap %** |
| bead2010 | 3,568,250 | 16.7 | ha2010 | 2,997,778 | 0.9 | 2,965,974 | 82.4 |
| bead2010 | 3,568,250 | 27.9 | cifl2013 | 2,573,061 | 0.1 | 2,571,254 | 72.0 |
| bead2010 | 3,568,250 | 43.6 | gifl2013 | 2,013,600 | 0.1 | 2,009,966 | 56.3 |
| bead2010 | 3,568,250 | 29.1 | hfp2009 | 2,590,171 | 2.3 | 2,507,207 | 68.7 |
| bead2010 | 3,568,250 | 9.2 | ab2000 | 3,392,324 | 4.5 | 3,225,463 | 86.4 |
| bead2010 | 3,568,250 | 59.9 | ghm2015 | 1,440,832 | 0.7 | 1,416,583 | 39.4 |
| bead2010 | 3,568,250 | 21.2 | vlia2015 | 2,877,688 | 2.3 | 2,792,102 | 76.4 |
| bead2010 | 3,568,250 | 25.0 | ff1996 | 2,715,152 | 1.5 | 2,660,976 | 73.5 |
| ha2010 | 2,997,778 | 15.8 | cifl2013 | 2,573,061 | 1.9 | 2,513,843 | 82.2 |
| ha2010 | 2,997,778 | 33.6 | gifl2013 | 2,013,600 | 1.2 | 1,977,164 | 65.2 |
| ha2010 | 2,997,778 | 22.9 | hfp2009 | 2,590,171 | 10.8 | 2,228,992 | 66.4 |
| ha2010 | 2,997,778 | 6.5 | ab2000 | 3,392,324 | 17.4 | 2,762,272 | 76.1 |
| ha2010 | 2,997,778 | 53.5 | ghm2015 | 1,440,832 | 3.2 | 1,342,443 | 43.4 |
| ha2010 | 2,997,778 | 16.5 | vlia2015 | 2,877,688 | 13.0 | 2,428,314 | 70.4 |
| ha2010 | 2,997,778 | 17.4 | ff1996 | 2,715,152 | 8.8 | 2,427,263 | 73.9 |
| cifl2013 | 2,573,061 | 22.8 | gifl2013 | 2,013,600 | 1.4 | 1,976,880 | 75.7 |
| cifl2013 | 2,573,061 | 16.3 | hfp2009 | 2,590,171 | 16.8 | 2,069,830 | 66.9 |
| cifl2013 | 2,573,061 | 3.6 | ab2000 | 3,392,324 | 26.9 | 2,446,047 | 69.5 |
| cifl2013 | 2,573,061 | 46.9 | ghm2015 | 1,440,832 | 5.1 | 1,302,198 | 48.0 |
| cifl2013 | 2,573,061 | 11.5 | vlia2015 | 2,877,688 | 20.9 | 2,199,395 | 67.6 |
| cifl2013 | 2,573,061 | 8.0 | ff1996 | 2,715,152 | 12.8 | 2,336,362 | 79.1 |
| gifl2013 | 2,013,600 | 10.9 | hfp2009 | 2,590,171 | 30.7 | 1,698,231 | 58.4 |
| gifl2013 | 2,013,600 | 2.2 | ab2000 | 3,392,324 | 41.9 | 1,938,490 | 55.9 |
| gifl2013 | 2,013,600 | 40.3 | ghm2015 | 1,440,832 | 16.6 | 1,039,153 | 43.0 |
| gifl2013 | 2,013,600 | 8.9 | vlia2015 | 2,877,688 | 36.2 | 1,734,176 | 54.9 |
| gifl2013 | 2,013,600 | 5.0 | ff1996 | 2,715,152 | 29.5 | 1,870,605 | 65.4 |
| hfp2009 | 2,590,171 | 3.8 | ab2000 | 3,392,324 | 26.5 | 2,457,568 | 69.7 |
| hfp2009 | 2,590,171 | 50.0 | ghm2015 | 1,440,832 | 10.1 | 1,150,103 | 39.9 |
| hfp2009 | 2,590,171 | 14.2 | vlia2015 | 2,877,688 | 22.8 | 2,113,308 | 63.0 |
| hfp2009 | 2,590,171 | 14.9 | ff1996 | 2,715,152 | 18.8 | 2,115,571 | 66.3 |
| ab2000 | 3,392,324 | 58.4 | ghm2015 | 1,440,832 | 2.0 | 1,371,110 | 39.6 |
| ab2000 | 3,392,324 | 19.9 | vlia2015 | 2,877,688 | 5.6 | 2,676,266 | 74.5 |
| ab2000 | 3,392,324 | 23.3 | ff1996 | 2,715,152 | 4.1 | 2,568,722 | 72.6 |
| ghm2015 | 1,440,832 | 7.3 | vlia2015 | 2,877,688 | 53.6 | 1,214,780 | 39.1 |
| ghm2015 | 1,440,832 | 5.4 | ff1996 | 2,715,152 | 49.8 | 1,287,070 | 44.9 |
| vlia2015 | 2,877,688 | 17.2 | ff1996 | 2,715,152 | 12.3 | 2,311,793 | 70.5 |

**Table 4.** Harvested cutblocks wrongly classified as intact in northeast British Columbia. Only cutblocks within 30 years of map production were considered for each dataset.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Intactness Map** | **Study area (km2)** | **Intact area (km2)** | **Intact area (%)** | **Disturbed area (km2)** | **Misclassified as intact (km2)** | **Misclassified as intact (%)** |
| BEAD2010 | 69,956.3 | 67,561.7 | 96.6 | 1,190.4 | 295.6 | 24.8 |
| HA2010 | 100,974.7 | 55,696.3 | 55.2 | 1,190.4 | 239.4 | 20.1 |
| CIFL2000 | 100,974.7 | 41,861.6 | 41.5 | 930.5 | 43.9 | 4.7 |
| CIFL2013 | 100,974.7 | 33,319.6 | 33.0 | 1,118.7 | 3.5 | 0.3 |
| GIFL2000 | 100,974.7 | 23,016.0 | 22.8 | 930.5 | 0.0 | 0.0 |
| GIFL2013 | 100,974.7 | 22,965.3 | 22.7 | 1,118.7 | 0.0 | 0.0 |
| GIFL2016 | 100,974.7 | 22,963.1 | 22.7 | 1,008.2 | 0.0 | 0.0 |
| HFP1993 | 100,974.7 | 70,818.0 | 70.1 | 608.3 | 114.1 | 18.8 |
| HFP2009 | 100,974.7 | 68,874.3 | 68.2 | 1,215.4 | 326.6 | 26.9 |
| AB2000 | 100,974.7 | 96,519.9 | 95.6 | 930.5 | 816.2 | 87.7 |
| VLIA2015 | 100,974.7 | 83,533.9 | 82.7 | 1,047.8 | 634.3 | 60.5 |
| GHM2015 | 100974.7 | 3855.6 | 3.8 | 1,047.8 | 4.6 | 0.4 |

**Table 5.** Area of seismic cutlines and 500-m buffered seismic cutlines that are wrongly classified as intact in Alberta study region (28,148.2 km2). Only cutlines that were established before map production were considered for each dataset. ABMI seismic lines are mostly polygonal features (3-m or 6-m buffer); exceptions include ABMI2016, where we added a 4.5-m buffer to create polygonal features).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | **Unbuffered cutlines** | | | **Buffered (500-m) cutlines** | | |
| **Intactness Map** | **Intact area (km2)** | **Intact area (%)** | **Disturbed area (km2)** | **Error (km2)** | **Error (%)** | **Disturbed area (km2)** | **Error (km2)** | **Error (%)** |
| bead2010 | 27969.3 | 99.4 | 168.8 | 116.8 | 69.2 | 47938.5 | 45833.4 | 95.6 |
| ha2010 | 23441.7 | 83.3 | 168.8 | 66.2 | 39.2 | 47938.5 | 17232.2 | 35.9 |
| cifl2013 | 20430.2 | 72.6 | 200.3 | 37.5 | 18.7 | 28718.4 | 6107.5 | 21.3 |
| gifl2013 | 14238.1 | 50.6 | 200.3 | 7.9 | 3.9 | 28718.4 | 2065.6 | 7.2 |
| gifl2016 | 13909.5 | 49.4 | 129.4 | 8.9 | 6.9 | 29613.8 | 1704.7 | 5.8 |
| hfp2009 | 23745.8 | 84.4 | 168.7 | 118 | 69.9 | 58257.2 | 50235.9 | 86.2 |
| ghm2015 | 25568.3 | 90.8 | 236.5 | 228.4 | 96.6 | 22349.1 | 20927.9 | 93.6 |
| vlia2015 | 23870.0 | 84.8 | 236.5 | 141.0 | 59.6 | 22349.1 | 17294.4 | 77.4 |

**Table 6.** Polygonal (placer mining) and linear (mostly roads) disturbances wrongly classified as intact in the Indian River watershed, Yukon (2,257.4 km2).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | **Mining disturbances** | | | **Linear disturbances** | | |
| **Intactness Map** | **Intact area (km2)** | **Intact area (%)** | **Disturbed area (km2)** | **Error (km2)** | **Error (%)** | **Disturbed length (km)** | **Error (km)** | **Error (%)** |
| HA2010 | 1,723.7 | 76.4 | 64.3 | 14 | 21.8 | 1,230.1 | 467.1 | 38.0 |
| CIFL2013 | 1,095.0 | 48.5 | 64.3 | 7.7 | 12 | 1,230.1 | 261.7 | 21.3 |
| GIFL2016 | 276.8 | 12.3 | 72.2 | 0.0 | 0.0 | 1,043.8 | 19.9 | 1.9 |
| HFP2009 | 1,713.0 | 75.9 | 64.3 | 58.2 | 90.5 | 1,230.1 | 1,051.1 | 85.4 |
| VLIA2015 | 2,180.6 | 96.6 | 72.2 | 71.3 | 98.8 | 1,043.8 | 1,022.5 | 98.0 |
| GHM2015 | 110.0 | 4.9 | 72.2 | 0.1 | 0.1 | 1,043.8 | 68.2 | 6.5 |
| AB2000 | 1,861.2 | 82.4 | 64.3 | 35.3 | 54.9 | 1,230.1 | 921.7 | 74.9 |

**Table 8.** Which datasets are best for conservation planning in the boreal region of Canada?

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Map Type** | **Extent** | **Map Name** | **Years** | **Discontinued** | **Format** | **Scale/Res** | **MMU (ha)** | **Buffer (km)** | **Harvesting** | **Oil & Gas** | **Mining** | **Roads** | **Agriculture** | **Built-up** |
| Wilderness & intact areas | Global | Global IFL | 2000, 2013, 2016 |  | Vector | 1:1,000,000 | 50,000 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
|  |  | Forest Frontiers | 1996 | yes | Vector | 1:8,000,000 | 50,000 |  | 0 | 0 | 0 | 0 | 0 | 0 |
|  | Regional | Canada IFL | 2000, 2013 | yes | Vector | 1:1,000,000 | 1,000; 5,000 | 0.5-1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Cumulative disturbances | Global | Human Footprint | 1993, 2009 |  | Raster | 1 km2 | 50,000 | 0-2; 2-15 | 0 | 0 | 0 | 1 | 1 | 1 |
|  |  | Human Modification | 2015 |  | Raster | 1 km2 |  |  | 0 | 1 | 1 | 1 | 1 | 1 |
|  |  | Low Impact Area | 2015 |  | Raster | 1 km2 |  |  | 1 | 0 | 0 | 1 | 1 | 1 |
|  | Regional | Human Access | 2010 | yes | Vector | 1:1,000,000 |  | 0.5 | 0 | 0 | 1 | 1 | 1 | 0 |
|  |  | BEAD | 2000, 2013 |  | Vector | 1:50,000 | 2 |  | 1 | 1 | 1 | 0 | 1 | 1 |
| Regionalizations | Global | Anthromes | 2000 |  | Raster | ~ 5 km2 |  |  | 0 | 0 | 0 | 0 | 1 | 1 |

1. <https://catalogue.data.gov.bc.ca/dataset/harvested-areas-of-bc-consolidated-cutblocks-> [↑](#footnote-ref-1)
2. Mammoth Mapping. 2010. Final Report: Mapping of surface disturbance and linear features in the Dawson Land Use Planning Region. Prepared for Environment Yukon. 7 pages. [↑](#footnote-ref-2)
3. Drift Geomatics. 2017. Review and Update Surface Disturbance Indian River Study Areas, Yukon. Submitted to Department of Environment, Government of Yukon. [↑](#footnote-ref-3)