Climate-projected distributional shifts and refugia for North American ecoregions

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Climate model projections suggest major North American biome shifts in response to anthropogenic climate change (Rehfeldt et al. 2012). Such shifts could have profound influences on native flora and fauna, many of which would have to move long distances to track their climatic niches. To evaluate potential ecosystem changes at a somewhat finer scale, I projected the change in climate space for level III ecoregions (Commission for Environmental Cooperation 1997) as surrogates for multiple associated species and ecological communities. First, I developed a random forest model (Breiman 2001) to predict ecoregion class from bioclimatic variables (Table 1), using 1-km interpolated climate data for the 1969-1990 normal period (Hamann et al. 2013), available at http://adaptwest.databasin.org.

R Code for this portion follows:

```
library(randomForest)
library(raster)

#eco = project directory
setwd(eco)
datlcc = read.csv("CECEcoregionSampleLCC.csv")
cececo = read.csv("CECecoregions.csv")
LCC <- CRS("+proj=lcc +lat_1=49 +lat_2=77 +lat_0=0 +lon_0=-95 +x_0=0 +y_0=0 +
ellps=GRS80 +units=m +no_defs")

#cur = directory containing grids representing derived climate variables
setwd(cur)
clim <- list.files(cur, pattern =".asc$")
curclim<-stack(clim)
temp <- raster(clim[1])
ID <- as.data.frame(rasterToPoints(temp))
names(ID)[3] <- "ID4km"
ID$ID <- row.names(ID)
IDR <- raster(ncols=ncol(temp), nrows=nrow(temp), xmn=xmin(temp), xmx=xmax(te
mp), ymn=ymin(temp), ymx=ymax(temp))
IDRR <- rasterize(as.matrix(ID[,1:2]), IDR, as.numeric(ID[,4]))
curclim <- addLayer(curclim,IDRR)

setwd(eco)
sampleclim<-cbind(datlcc,extract(curclim,as.matrix(cbind(datlcc[,3],datlcc[,4
]))))
sc <- na.omit(sampleclim)
names(sc)[ncol(sc)] <- "IDgrid"
sc$NA_L3CODE <- as.factor(as.character(sc$NA_L3CODE))
lu <- as.data.frame(levels(sc$NA_L3CODE))
```

```
lu$level <- row.names(lu)
names(lu)[1] <- "NA_L3CODE"
write.csv(lu,file="ecoregionlu.csv",row.names=FALSE)

eco.rf <- randomForest(y=sc$NA_L3CODE, x=sc[,5:(ncol(sc)-1)],importance = TRU
E, proximity = TRUE, data=sc)
round(importance(eco.rf), 2)
varImpPlot(eco.rf)
ecocurr <- predict(curclim,eco.rf)
projection(ecocurr) <- LCC
writeRaster(ecocurr,filename="currentlcc.tif",datatype='INT4S',format="GTiff"
,overwrite=TRUE)
curfreq <- freq(ecocurr)
ecolu <- merge(lu,curfreq,by.x="level",by.y="value")
names(ecolu)[3] <- "curr"
```

Table 1: Bioclimatic variables used as inputs to random forest models (from Hamann et al. 2013)

MAT: mean annual temperature (°C)
MWMT: mean temperature of the warmest month (°C)
MCMT: mean temperature of the coldest month (°C)
TD: difference between MCMT and MWMT, as a measure of continentality (°C)
MAP: mean annual precipitation (mm)
MSP: mean summer (May to Sep) precipitation (mm)
AHM: annual heat moisture index, calculated as (MAT+10)/(MAP/1000)
SHM: summer heat moisture index, calculated as MWMT/(MSP/1000)
DD0: degree-days below 0°C (chilling degree days)
DD5: degree-days above 5°C (growing degree days)
DD18: degree-days below 18°C
DD18: degree-days above 18°C
NFFD: the number of frost-free days
bFFP: the julian date on which the frost-free period begins
eFFP: the julian date on which the frost-free period ends
FFP: frost-free period
PAS: precipitation as snow (mm)
EMT: extreme minimum temperature over 30 years
EXT: extreme maximum temperature over 30 years
Eref: Hargreave's reference evaporation
CMD: Hargreave's climatic moisture index
RH: mean annual relative humidity (%)
Tavewt: winter (Dec to Feb) mean temperature (°C)
Tavesm: summer (Jun to Aug) mean temperature (°C)
PPTwt: winter (Dec to Feb) precipitation (mm)
PPTsm: summer (Jun to Aug) precipitation (mm)

This model was then used to project ecoregions onto future mid-century (2041-2070) and end-of-century (2071-2100) climate conditions. Climate projections were based on 1-km downscaled climate anomalies (Wang et al. 2016) generated by an ensemble of 15 widely-used GCMs from the Coupled Model Intercomparison Project, Phase 5 (CMIP5, Taylor et al. 2012), available at http://adaptwest.databasin.org. I used representative concentration pathway (RCP) 8.5, to represent the 21st century conditions that are to be expected without dramatic reductions in greenhouse gas emissions or technological fixes (Fuss et al. 2014). I also evaluated RCP 4.5 to represent a future in which significant emissions reductions are achieved.

The following code generates projections for each representative and time period:

```
fut = directory containing grids representing derived future climate variable
s
rcp <- c("rcp45","rcp85")
time <- c("2050s","2080s")
for (j in rcp) {
    for (k in time) {
            w  <- paste(fut,"NA_ENSEMBLE_",j,"_",k,"_Bioclim_ASCII/",sep="")
            setwd(w)
            futclim <- list.files(w,pattern=".asc$")
            s <-stack(futclim)
            p <- predict(s,eco.rf)
            projection(p) <- LCC
            futfreq <- as.data.frame(freq(p))
        names(futfreq)[2] <- paste(i,j,sep="_")
        ecolu <- merge(ecolu,futfreq,by.x="level",by.y="value")
            writeRaster(p, filename=paste(eco,"pred",j,k,sep="_"),datatype='I
NT4S',format="GTiff", overwrite=TRUE)
            }
    }
```

Results for RCP 4.5 and RCP 8.5 are shown in Figures 1 and 2, respectively:

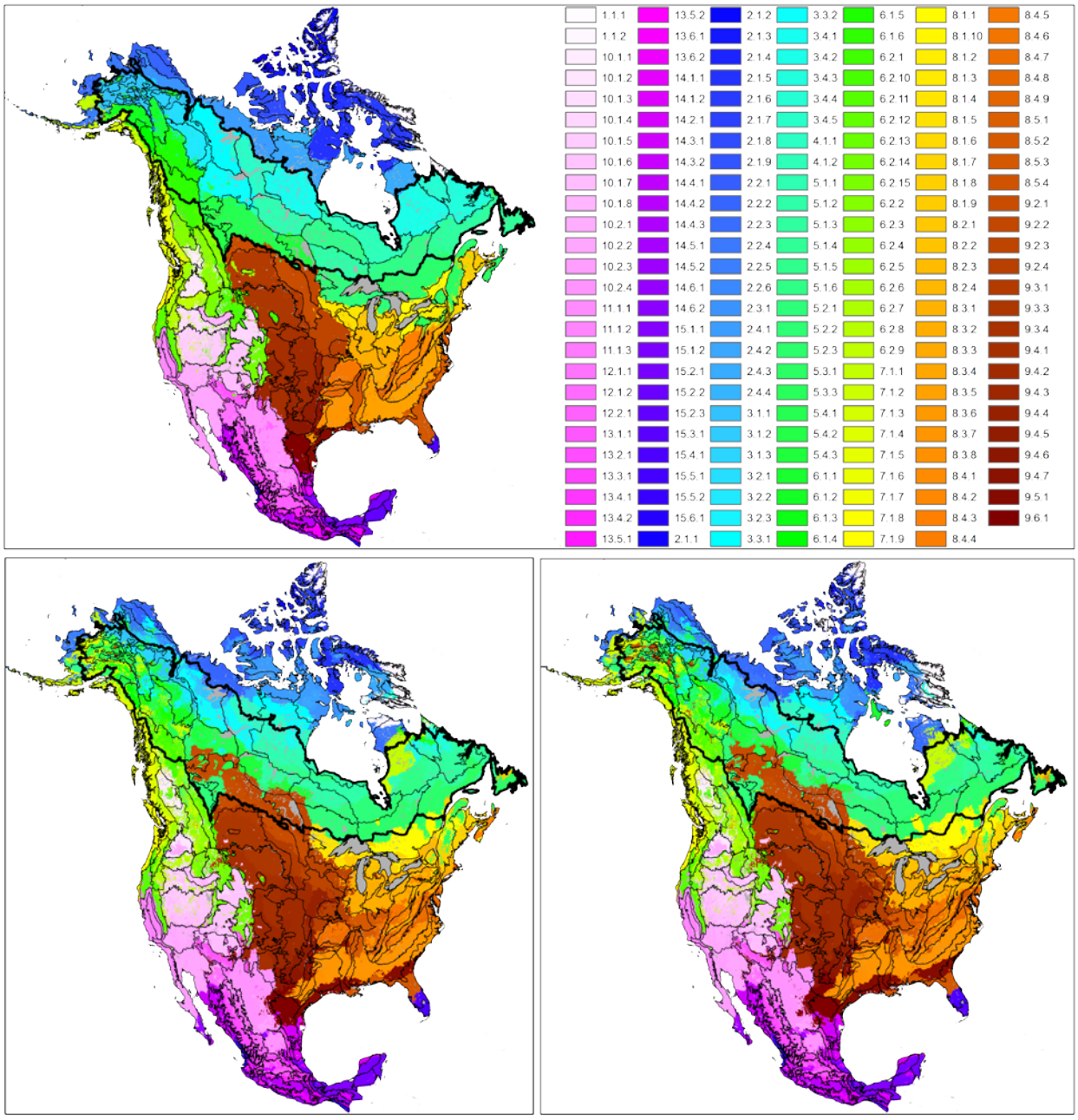

Figure 1. *Model-predicted (a) baseline, (b) mid-century, and (c) end-of-century changes in North American ecoregions for RCP 4.5. Boreal, hemi-boreal, and western forested regions are shown in green and blue-green shades; arctic ecoregions are in blue shades; prairie/parkland ecoregions are in brown shades; and temperate forest ecoregions are in yellow and orange shades (see Table 1 for full list of ecoregions). Boreal ecoregions are also outlined in black.*

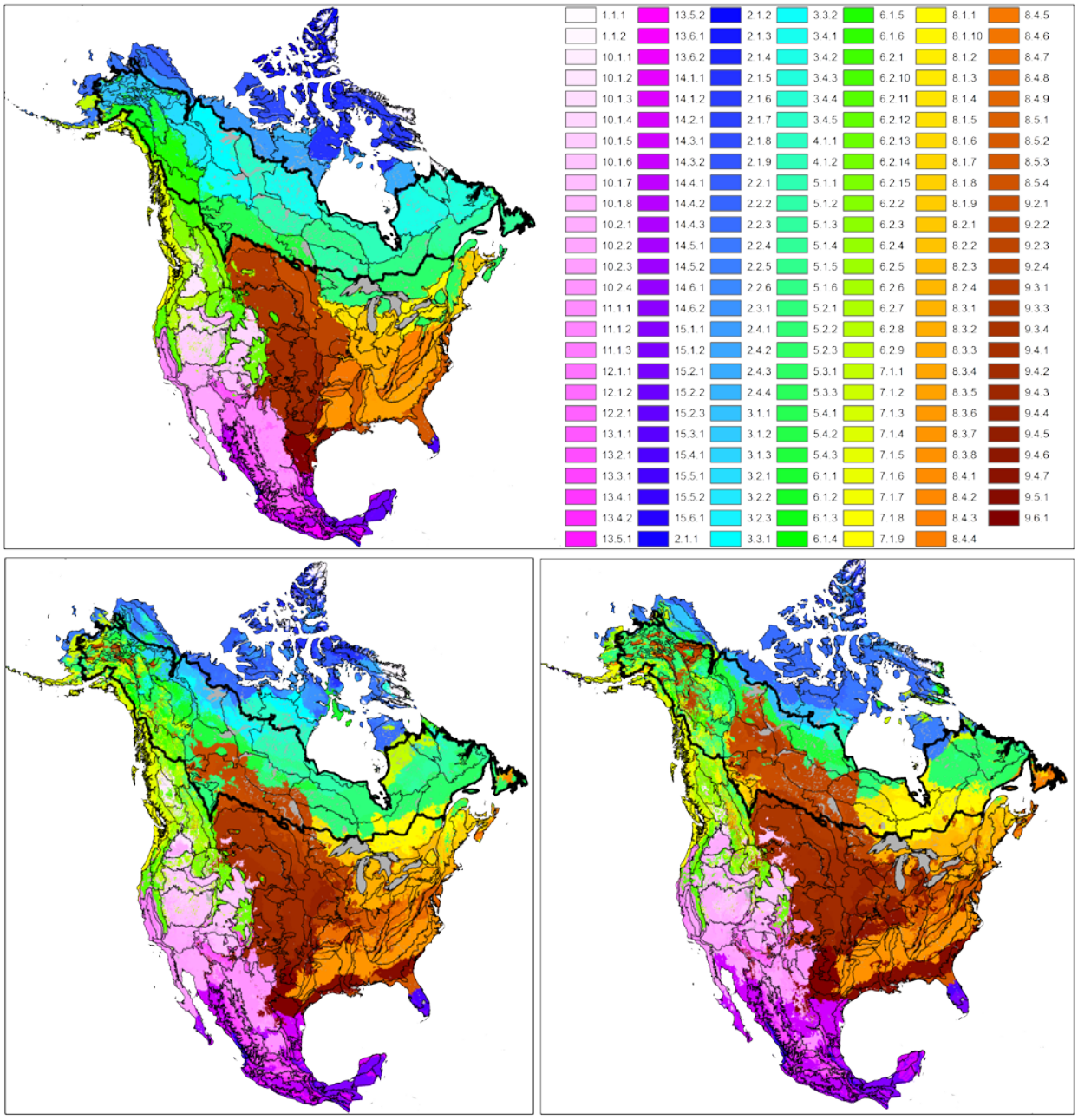

Figure 2. *Model-predicted (a) baseline, (b) mid-century, and (c) end-of-century changes in North American ecoregions for RCP 8.5. Boreal, hemi-boreal, and western forested regions are shown in green and blue-green shades; arctic ecoregions are in blue shades; prairie/parkland ecoregions are in brown shades; and temperate forest ecoregions are in yellow and orange shades (see Table 1 for full list of ecoregions). Boreal ecoregions are also outlined in black.*

Next, I used the following code to calculate the change in area (16 km2 pixels) for each Level III ecoregion (Table 2):

```
groups <- c("rcp45_2050s","rcp45_2080s","rcp85_2050s","rcp85_2080s")
setwd(eco)
for (i in groups) {
```

```
    g <- list.files(eco,pattern=i)
    g1 <- grep(pattern=".tif$",g,value=TRUE)
    m <- raster(g1)
    futfreq <- as.data.frame(freq(m))
    names(futfreq)[2] <- i
    ecolu <- merge(ecolu,futfreq,by.x="level",by.y="value")
    }
ecolu1 <- merge(unique(cececo[,c(2:4)]),ecolu[,2:7],by="NA_L3CODE")
write.csv(ecolu1,file="ecoregion_changesummary.csv",row.names=FALSE)
```

Table 2. Model-projected changes by ecoregion (sq km):

NA_L3CODE	NA_L3NAME	curr	rcp45_2050s	rcp45_2080s	rcp85_2050s	rcp85_2080s
1.1.2	Baffin and Torngat Mountains	147,147	256,752	278,424	235,507	106,740
10.1.1	Thompson-Okanogan Plateau	79,481	128,181	102,991	93,853	17,523
10.1.2	Columbia Plateau	87,319	128,349	130,511	133,438	92,006
10.1.3	Northern Basin and Range	163,503	52,087	28,000	26,510	2,500
10.1.4	Wyoming Basin	142,375	20,672	10,308	8,748	317
10.1.5	Central Basin and Range	248,329	178,117	161,763	171,074	44,943
10.1.6	Colorado Plateaus	148,135	410,063	445,829	458,570	479,993
10.1.7	Arizona/New Mexico Plateau	170,714	215,623	216,068	215,201	137,227
10.1.8	Snake River Plain	71,248	34,098	22,125	20,400	1,620
10.2.1	Mojave Basin and Range	145,279	178,168	214,764	239,676	559,531
10.2.2	Sonoran Desert	249,917	313,014	308,390	333,780	477,826
10.2.3	Baja Californian Desert	125,247	108,494	133,306	143,065	130,262
10.2.4	Chihuahuan Desert	560,769	634,266	615,488	614,688	512,968
11.1.1	California Coastal Sage, Chaparral, and Oak Woodlands	118,844	119,971	124,429	124,621	148,146
11.1.2	Central California Valley	59,912	55,961	47,599	41,428	920
11.1.3	Southern and Baja California Pine-Oak Mountains	40,794	52,147	49,068	48,033	34,558
12.1.1	Madrean Archipelago	119,798	120,764	113,420	110,430	109,247
12.1.2	Piedmonts and Plains with Grasslands, Xeric Shrub, and Oak and Conifer Forests	225,107	159,305	140,803	136,965	67,801
12.2.1	Hills and Interior Plains with Xeric Shrub and Mesquite Low Forest	117,722	115,409	104,551	100,841	60,874
13.1.1	Arizona/New Mexico	119,795	121,932	125,652	120,830	138,375

NA_L3CODE	NA_L3NAME	curr	rcp45_2050s	rcp45_2080s	rcp85_2050s	rcp85_2080s
	Mountains					
13.2.1	Sierra Madre Occidental with Conifer, Oak, and Mixed Forests	203,850	129,997	119,021	106,488	64,358
13.3.1	Sierra Madre Oriental with Conifer, Oak, and Mixed Forests	99,879	112,527	125,093	125,837	102,492
13.4.1	Interior Plains and Piedmonts with Grasslands and Xeric Shrub	30,155	13,136	9,148	8,526	1,347
13.4.2	Hills and Sierras with Conifer, Oak, and Mixed Forests	90,230	56,118	46,624	41,800	21,474
13.5.1	Sierras of Jalisco and Michoacan with Conifer, Oak, and Mixed Forests	45,189	29,437	30,622	27,347	19,195
13.5.2	Sierras of Guerrero and Oaxaca with Conifer, Oak, and Mixed Forests	93,219	56,589	51,279	46,021	21,458
13.6.1	Central American Sierra Madre with Conifer, Oak, and Mixed Forests	24,543	10,157	8,224	8,785	2,653
13.6.2	Chiapas Highlands with Conifer, Oak, and Mixed Forest	47,734	30,717	26,910	25,142	11,528
14.1.1	Coastal Plain with Low Tropical Deciduous Forest	45,021	67,157	58,930	52,306	26,294
14.1.2	Hills and Sierra with Low Tropical Deciduous Forest and Oak Forest	32,934	27,023	22,562	21,273	9,515
14.2.1	Northwestern Yucatan Plain with Low Tropical Deciduous Forest	21,348	31,181	43,435	42,619	120,368
14.3.1	Sinaloa Coastal Plain with Low Thorn Tropical Forest and Wetlands	55,351	184,089	253,772	303,349	693,883
14.3.2	Sinaloa and Sonora Hills and Canyons with Xeric Shrub and Low Tropical Deciduous Forest	116,252	161,186	188,683	190,719	386,533
14.4.1	Balsas Depression with Low Tropical Deciduous Forest and Xerophytic Shrub	94,443	142,241	155,449	167,393	217,971
14.4.2	Chiapas Depression with Low Deciduous and Medium Semi-Deciduous Tropical Forest	27,227	13,295	11,191	10,296	9,580

NA_L3CODE	NA_L3NAME	curr	rcp45_2050s	rcp45_2080s	rcp85_2050s	rcp85_2080s
14.4.3	Valleys and Depressions with Xeric Shrub and Low Tropical Deciduous Forest	27,146	38,202	36,891	37,294	35,815
14.5.1	Tehuantepec Canyon and Plain with Low Tropical Deciduous Forest and Low Thorn Tropical Forest	19,737	41,575	43,559	41,086	52,429
14.5.2	South Pacific Hills and Piedmonts with Low Tropical Deciduous Forest	66,703	85,395	99,426	102,297	119,513
14.6.1	Los Cabos Plains and Hills with Low Tropical Deciduous Forest and Xeric Shrub	16,353	42,909	43,769	41,573	23,672
14.6.2	La Laguna Mountains with Oak and Conifer Forest	2,570	1,344	1,185	1,126	501
15.1.1	Gulf of Mexico Coastal Plain with Wetlands and High Tropical Rain Forest	92,436	160,749	153,390	154,527	136,595
15.1.2	Hills with Medium and High Evergreen Tropical Forest	106,764	75,092	81,041	90,784	119,204
15.2.1	Plain with Low and Medium Deciduous Tropical Forest	63,136	123,240	125,750	130,375	93,831
15.2.2	Plain with Medium and High Semi-Evergreen Tropical Forest	46,630	34,045	29,748	22,123	2,786
15.2.3	Hills with High and Medium Semi-Evergreen Tropical Forest	78,883	5,709	6,137	5,979	6,417
15.3.1	Los Tuxtlas Sierra with High Evergreen Tropical Forest	10,762	2,087	1,633	1,416	13,724
15.4.1	Southern Florida Coastal Plain	38,967	74,884	83,614	78,635	40,314
15.5.1	Nayarit and Sinaloa Plain with Low Thorn Tropical Forest	9,738	2,650	1,532	1,425	1,651
15.5.2	Jalisco and Nayarit Hills and Plains with Medium Semi-Evergreen Tropical Forest	20,266	42,203	49,771	52,308	75,866
15.6.1	Coastal Plain and Hills with High and Medium-High Evergreen Tropical	20,201	25,035	18,554	17,797	7,691

NA_L3CODE	NA_L3NAME	curr	rcp45_2050s	rcp45_2080s	rcp85_2050s	rcp85_2080s
	Forest and Wetlands					
2.1.4	Lancaster and Borden Peninsula Plateaus	153,401	100,458	57,518	52,380	2
2.1.5	Foxe Uplands	359,792	172,936	212,147	159,876	76,162
2.1.6	Baffin Uplands	148,664	39,067	32,090	28,237	22,447
2.1.7	Gulf of Boothia and Foxe Basin Plains	147,691	94,997	44,196	30,062	4,356
2.1.9	Banks Island and Amundsen Gulf Lowlands	160,336	239,188	224,215	194,489	15,065
2.2.1	Arctic Coastal Plain	58,756	95	2,266	5,255	22,959
2.2.2	Arctic Foothills	123,434	235,933	305,118	459,436	119,091
2.2.3	Subarctic Coastal Plains	100,808	229,447	323,128	388,110	1,281,925
2.2.4	Seward Peninsula	59,337	156,920	256,979	281,469	286,106
2.2.5	Bristol Bay-Nushagak Lowlands	63,649	106,118	103,595	106,972	389,553
2.2.6	Aleution Islands	12,993	4,767	2,467	2,058	1,132
2.4.1	Amundsen Plains	285,721	491,512	345,481	217,998	44,812
2.4.3	Central Ungava Peninsula and Ottawa and Belcher Islands	168,795	136,014	90,049	83,728	57,559
3.1.1	Interior Forested Lowlands and Uplands	154,744	214,494	244,642	302,972	397,504
3.1.2	Interior Bottomlands	147,095	104,970	89,188	60,760	24,020
3.1.3	Yukon Flats	43,564	57,030	38,887	47,545	20,218
3.2.1	Ogilvie Mountains	78,032	84,458	80,561	67,101	40,699
3.3.2	Hay and Slave River Lowlands	273,770	329,298	260,311	228,498	88,246
3.4.3	Smallwood Uplands	260,456	72,043	45,379	31,847	8,018
3.4.4	Ungava Bay Basin and George Plateau	124,658	16,561	15,184	14,273	175
3.4.5	Coppermine River and Tazin Lake Uplands	247,484	278,724	261,461	289,089	3,376
4.1.2	Hudson Bay and James Bay Lowlands	277,767	56,692	24,743	18,601	4,711
5.1.1	Athabasca Plain and Churchill River Upland	261,634	180,539	172,825	169,140	61,254
5.1.2	Lake Nipigon and Lac Seul Upland	217,842	383,191	334,585	292,786	77,691
5.1.3	Central Laurentians and Mecatina Plateau	302,052	319,010	262,655	245,088	61,726
5.1.4	Newfoundland Island	125,291	159,633	150,097	145,165	141,949
5.1.5	Hayes River Upland and Big Trout Lake	264,910	99,563	68,160	60,244	1,195
5.1.6	Abitibi Plains and Riviere Rupert Plateau	287,990	145,527	142,434	111,390	15,384

NA_L3CODE	NA_L3NAME	curr	rcp45_2050s	rcp45_2080s	rcp85_2050s	rcp85_2080s
5.2.1	Northern Lakes and Forests	297,661	550,438	693,642	770,212	567,791
5.2.3	Algonquin/Southern Laurentians	350,698	443,628	423,668	436,081	460,129
5.3.1	Northern Appalachian and Atlantic Maritime Highlands	213,235	297,005	324,996	338,882	484,216
5.3.3	North Central Appalachians	40,906	5,581	6,484	7,114	15,510
5.4.1	Mid-Boreal Uplands and Peace-Wabaska Lowlands	384,861	384,235	311,499	240,506	112,622
5.4.2	Clear Hills and Western Alberta Upland	147,911	76,236	63,250	52,958	8,624
5.4.3	Mid-Boreal Lowland and Interlake Plain	137,275	232,935	277,233	324,472	401,337
6.1.1	Interior Highlands and Klondike Plateau	125,183	86,212	115,739	128,553	19,129
6.1.2	Alaska Range	101,281	86,438	91,774	95,471	35,952
6.1.3	Copper Plateau	25,317	7,840	1,044	376	21
6.1.4	Wrangell and St. Elias Mountains	58,813	35,893	27,452	23,311	14,394
6.1.5	Watson Highlands	215,821	109,456	57,769	43,653	6,952
6.1.6	Yukon-Stikine Highlands/Boreal Mountains and Plateaus	162,769	50,965	43,275	34,939	23,134
6.2.1	Skeena-Omineca-Central Canadian Rocky Mountains	146,470	160,853	135,239	120,210	50,879
6.2.10	Middle Rockies	161,078	55,926	45,646	40,694	18,262
6.2.11	Klamath Mountains	59,290	100,615	113,637	116,533	190,016
6.2.12	Sierra Nevada	56,436	44,004	41,467	40,535	22,943
6.2.13	Wasatch and Uinta Mountains	95,639	85,060	84,545	82,247	40,683
6.2.14	Southern Rockies	146,075	79,895	64,838	51,395	25,539
6.2.15	Idaho Batholith	74,737	76,608	70,690	73,617	53,969
6.2.2	Chilcotin Ranges and Fraser Plateau	113,621	7,374	2,090	1,782	122
6.2.3	Columbia Mountains/Northern Rockies	161,058	252,240	264,915	271,050	274,785
6.2.4	Canadian Rockies	106,010	53,214	33,347	23,701	3,133
6.2.5	North Cascades	41,160	35,151	31,590	30,225	19,980
6.2.6	Cypress Upland	22,463	925	2,326	3,179	3,527
6.2.7	Cascades	48,106	30,917	32,153	30,980	24,273
6.2.8	Eastern Cascades Slopes and Foothills	76,924	50,858	39,265	37,516	10,082

NA_L3CODE	NA_L3NAME	curr	rcp45_2050s	rcp45_2080s	rcp85_2050s	rcp85_2080s
6.2.9	Blue Mountains	81,264	122,265	114,078	110,356	113,839
7.1.1	Ahklun and Kilbuck Mountains	62,628	210,151	224,034	200,959	32,945
7.1.2	Alaska Peninsula Mountains	54,947	28,924	27,208	26,629	22,337
7.1.3	Cook Inlet	31,714	258,308	325,196	360,731	204,427
7.1.4	Pacific Coastal Mountains	109,324	110,053	113,038	112,518	87,051
7.1.5	Coastal Western Hemlock-Sitka Spruce Forests	96,025	167,783	176,032	178,428	163,666
7.1.6	Pacific and Nass Ranges	99,230	133,991	150,169	153,362	154,938
7.1.7	Strait of Georgia/Puget Lowland	48,048	37,542	41,816	44,456	80,267
7.1.8	Coast Range	57,502	111,722	124,460	125,210	146,726
7.1.9	Willamette Valley	19,425	4,945	3,615	3,925	12,446
8.1.1	Eastern Great Lakes Lowlands	185,396	399,806	511,228	563,219	801,293
8.1.10	Erie Drift Plain	54,959	3,115	593	373	182
8.1.2	Lake Erie Lowland	71,512	71,944	50,905	53,404	21,297
8.1.3	Northern Allegheny Plateau	56,906	1,487	534	560	23,971
8.1.4	North Central Hardwood Forests	107,373	103,169	108,931	101,597	237,007
8.1.5	Driftless Area	56,904	27,122	6,541	9,722	56,230
8.1.6	Southern Michigan/Northern Indiana Drift Plains	81,430	23,829	17,145	13,253	417
8.1.7	Northeastern Coastal Zone	61,604	230,818	254,436	245,976	200,520
8.1.8	Acadian Plains and Hills	111,308	40,773	46,764	37,862	28,274
8.1.9	Maritime Lowlands	46,701	13,691	12,593	8,969	8,838
8.2.1	Southeastern Wisconsin Till Plains	41,043	42,756	43,861	32,257	90,658
8.2.2	Huron/Erie Lake Plains	54,469	85,966	67,329	61,276	28,067
8.2.3	Central Corn Belt Plains	92,678	73,997	100,504	140,394	250,957
8.2.4	Eastern Corn Belt Plains	87,010	39,615	33,682	36,241	8,857
8.3.1	Northern Piedmont	42,573	170,005	167,343	153,662	53,715
8.3.2	Interior River Valleys and Hills	131,437	373,661	383,500	408,178	433,738
8.3.3	Interior Plateau	145,391	60,581	57,552	55,578	50,507
8.3.4	Piedmont	199,405	24,230	20,990	15,243	2,166
8.3.5	Southeastern Plains	304,687	9,091	6,755	7,501	3,549
8.3.6	Mississippi Valley Loess Plains	85,927	13,701	11,629	9,952	22,612
8.3.7	South Central Plains	178,978	701,415	692,767	704,770	611,455

NA_L3CODE	NA_L3NAME	curr	rcp45_2050s	rcp45_2080s	rcp85_2050s	rcp85_2080s
8.3.8	East Central Texas Plains	62,055	166,974	215,681	249,240	433,078
8.4.1	Ridge and Valley	85,618	29,098	16,038	10,560	2,334
8.4.2	Central Appalachians	89,927	51,069	40,889	44,792	66,604
8.4.3	Western Allegheny Plateau	83,575	8,479	4,804	3,360	15
8.4.4	Blue Ridge	51,004	33,856	35,301	35,072	66,437
8.4.5	Ozark Highlands	109,761	76,718	42,713	26,546	1,981
8.4.6	Boston Mountains	24,203	60,902	63,537	39,483	5,440
8.4.7	Arkansas Valley	38,145	140,421	168,122	184,531	89,087
8.4.8	Ouachita Mountains	30,471	87,982	86,472	65,818	32,104
8.4.9	Southwestern Appalachians	61,141	14,531	10,304	8,422	5,821
8.5.1	Middle Atlantic Coastal Plain	114,545	16,124	25,858	17,272	22,159
8.5.2	Mississippi Alluvial Plain	149,150	337,261	334,998	319,597	370,833
8.5.3	Southern Coastal Plain	186,085	95,570	86,825	80,677	60,148
8.5.4	Atlantic Coastal Pine Barrens	20,263	22,794	35,426	36,084	99,628
9.2.1	Aspen Parkland/Northern Glaciated Plains	318,674	466,186	519,631	546,675	837,779
9.2.2	Lake Manitoba and Lake Agassiz Plain	106,437	403,991	440,897	460,192	452,954
9.2.3	Western Corn Belt Plains	218,212	262,681	224,934	223,667	209,025
9.2.4	Central Irregular Plains	134,204	204,341	223,959	238,121	321,836
9.3.1	Northwestern Glaciated Plains	366,518	251,564	231,664	245,870	563,860
9.3.3	Northwestern Great Plains	368,298	448,245	460,729	457,994	390,148
9.3.4	Nebraska Sand Hills	82,506	46	27	60	4,846
9.4.1	High Plains	292,621	434,924	488,715	495,241	467,915
9.4.2	Central Great Plains	272,514	356,382	397,340	404,906	632,890
9.4.3	Southwestern Tablelands	239,595	364,196	362,126	335,141	293,115
9.4.4	Flint Hills	48,028	113,851	146,532	151,212	154,204
9.4.5	Cross Timbers	108,973	104,547	117,198	141,406	379,103
9.4.6	Edwards Plateau	111,195	113,999	97,552	80,404	27,236
9.4.7	Texas Blackland Prairies	65,484	90,892	78,487	87,808	204,468
9.5.1	Western Gulf Coastal Plain	115,252	270,442	323,841	345,851	502,966
9.6.1	Southern Texas Plains/Interior Plains and Hills with Xerophytic Shrub and Oak Forest	192,562	253,019	291,794	296,432	391,367

I also specifically summarized changes for boreal ecoregions (4.1, 5.4, 5.1, 3.4, 3.3, 3.2, 3.1, and 6.1) (Table 3):

Table 3. Model-projected changes by boreal ecoregion (sq km):

NA_L3CODE	NA_L3NAME	curr	rcp45_2050s	rcp45_2080s	rcp85_2050s	rcp85_2080s
3.1.1	Interior Forested Lowlands and Uplands	154,744	214,494	244,642	302,972	397,504
3.1.2	Interior Bottomlands	147,095	104,970	89,188	60,760	24,020
3.1.3	Yukon Flats	43,564	57,030	38,887	47,545	20,218
3.2.1	Ogilvie Mountains	78,032	84,458	80,561	67,101	40,699
3.3.2	Hay and Slave River Lowlands	273,770	329,298	260,311	228,498	88,246
3.4.3	Smallwood Uplands	260,456	72,043	45,379	31,847	8,018
3.4.4	Ungava Bay Basin and George Plateau	124,658	16,561	15,184	14,273	175
3.4.5	Coppermine River and Tazin Lake Uplands	247,484	278,724	261,461	289,089	3,376
4.1.2	Hudson Bay and James Bay Lowlands	277,767	56,692	24,743	18,601	4,711
5.1.1	Athabasca Plain and Churchill River Upland	261,634	180,539	172,825	169,140	61,254
5.1.2	Lake Nipigon and Lac Seul Upland	217,842	383,191	334,585	292,786	77,691
5.1.3	Central Laurentians and Mecatina Plateau	302,052	319,010	262,655	245,088	61,726
5.1.4	Newfoundland Island	125,291	159,633	150,097	145,165	141,949
5.1.5	Hayes River Upland and Big Trout Lake	264,910	99,563	68,160	60,244	1,195
5.1.6	Abitibi Plains and Riviere Rupert Plateau	287,990	145,527	142,434	111,390	15,384
5.4.1	Mid-Boreal Uplands and Peace-Wabaska Lowlands	384,861	384,235	311,499	240,506	112,622
5.4.2	Clear Hills and Western Alberta Upland	147,911	76,236	63,250	52,958	8,624
5.4.3	Mid-Boreal Lowland and Interlake Plain	137,275	232,935	277,233	324,472	401,337
6.1.1	Interior Highlands and Klondike Plateau	125,183	86,212	115,739	128,553	19,129
6.1.2	Alaska Range	101,281	86,438	91,774	95,471	35,952
6.1.3	Copper Plateau	25,317	7,840	1,044	376	21
6.1.4	Wrangell and St. Elias Mountains	58,813	35,893	27,452	23,311	14,394
6.1.5	Watson Highlands	215,821	109,456	57,769	43,653	6,952
6.1.6	Yukon-Stikine Highlands/Boreal Mountains and Plateaus	162,769	50,965	43,275	34,939	23,134

This translates into 14% and 42% losses of boreal climate space by 2041-2070 and 2071-2100, respectively, based on RCP 8.5; or 9% and 13% losses based on RCP 4.5

Change projections can be found at http://adaptwest.databasin.org.

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