Examining environmental variability in protected areas across Canada

Zoology Honours project

Rekha Marcus

(Marcus, Mount Revelstoke National Park, October 1, 2022)

Background

Protected areas

protect some resource or ecosystem
buffer against climate change (IUCN 2008)

Climate change refugia

Buffered Tree Population Changes in a Quaternary Refugium: Evolutionary Implications (Tzedakis et. al., 2002)

(Marcus, Pimachiowin Aki, June 2023)

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Refugia: identifying and understanding safe havens for biodiversity under climate change (Keppel et. al., 2011)

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Climate change refugia

Buffered Tree Population Changes in a Quaternary Refugium: Evolutionary Implications (Tzedakis et. al., 2002)

Refugia: identifying and understanding safe havens for biodiversity under climate change (Keppel et. al., 2011)

...but what about variability?

(Marcus, Pimachiowin Aki, June 2023)

(Marcus, Mount Revelstoke National Park, October 1, 2022)

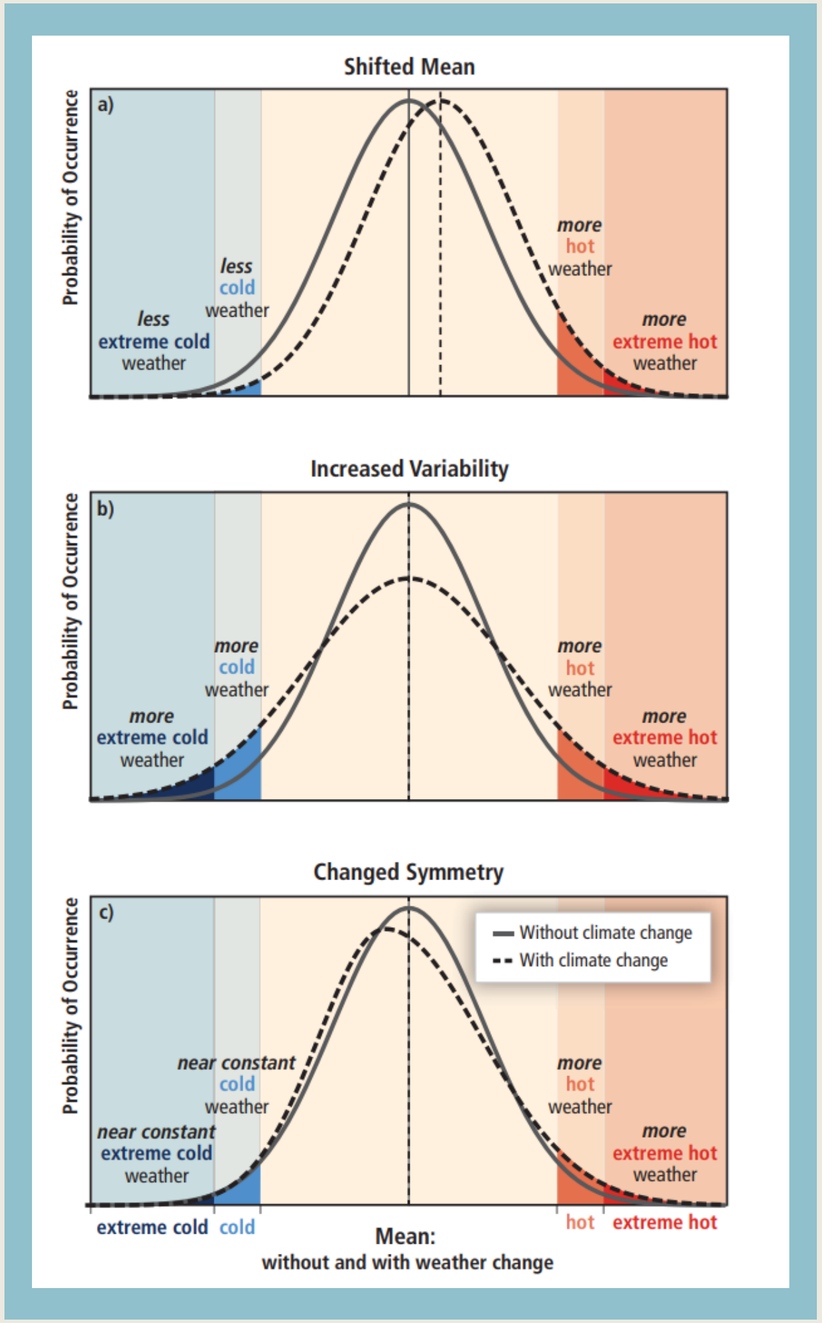
Background

Protected areas

protect some resource or ecosystem
buffer against climate change (IUCN 2008)

Environmental variability

changes in environmental conditions not explained by seasonal changes; extreme weather events



(IPCC 2012)

Background

Protected areas

protect some resource or ecosystem
buffer against climate change (IUCN 2008)

Environmental variability

changes in environmental conditions not explained by seasonal changes; extreme weather events

Climate change

will increase environmental variability (stochasticity) (IPCC 2012)

Environmental variability is not considered in climate change studies

Table 1. Review and classification into generations of community climate change experiments 2000–2012 (terrestrial and marine) and 1995–2012 (freshwater) which involved temperature manipulations (excluding other physical and chemical manipulations). For definitions of the 'generations' of studies, see the main text. A number of studies (with percentages of the total in brackets following) are shown. Individual papers are shown in Table S1

Generation	Effects on mean	Effects on variability	Incorporates extreme events?	Number of studies found		
				Terrestrial	Marine	Freshwater
Fixed mean	Increase	Large reduction	No	3 (4.5%)	15 (65.2%)	5 (23.8%)
Fixed minima	Increase	Small reduction	No	7 (10.6%)	0 (0%)	0 (0%)
Fixed increment	Increase	No effect	Some	52 (78.8%)	8 (34.8%)	15 (71.4%)
Extreme event studies	Increase	Increase	Yes	4 (6.1%)	0 (0%)	1(4.8%)

(Thompson 2013, Means and extremes: building variability into community-level climate change experiments)

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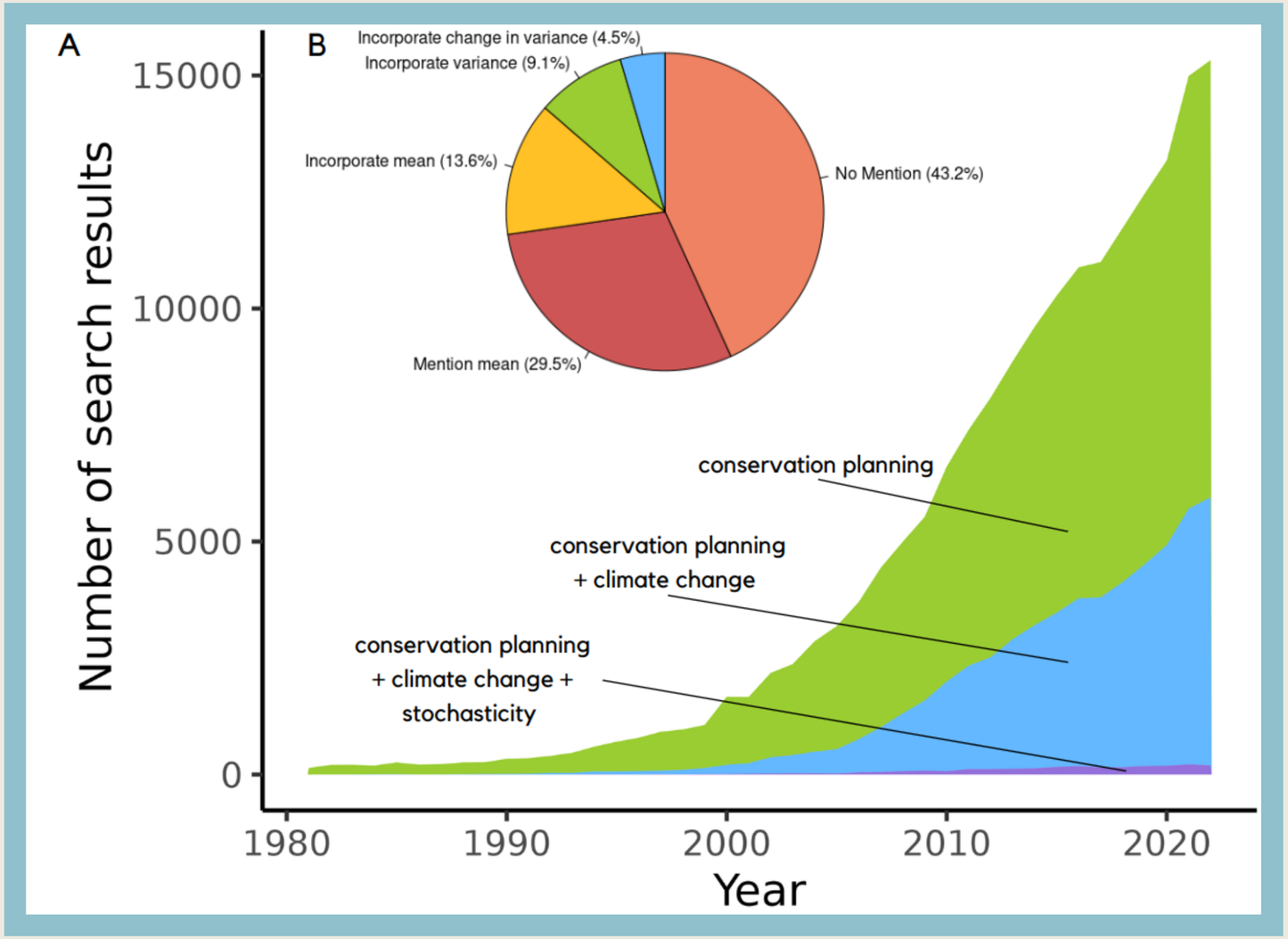
Environmental variability is an often overlooked aspect of protected area planning



(Marcus, Predicting the Unpredictable: Incorporating changing conditions into protected area planning, September 2023)

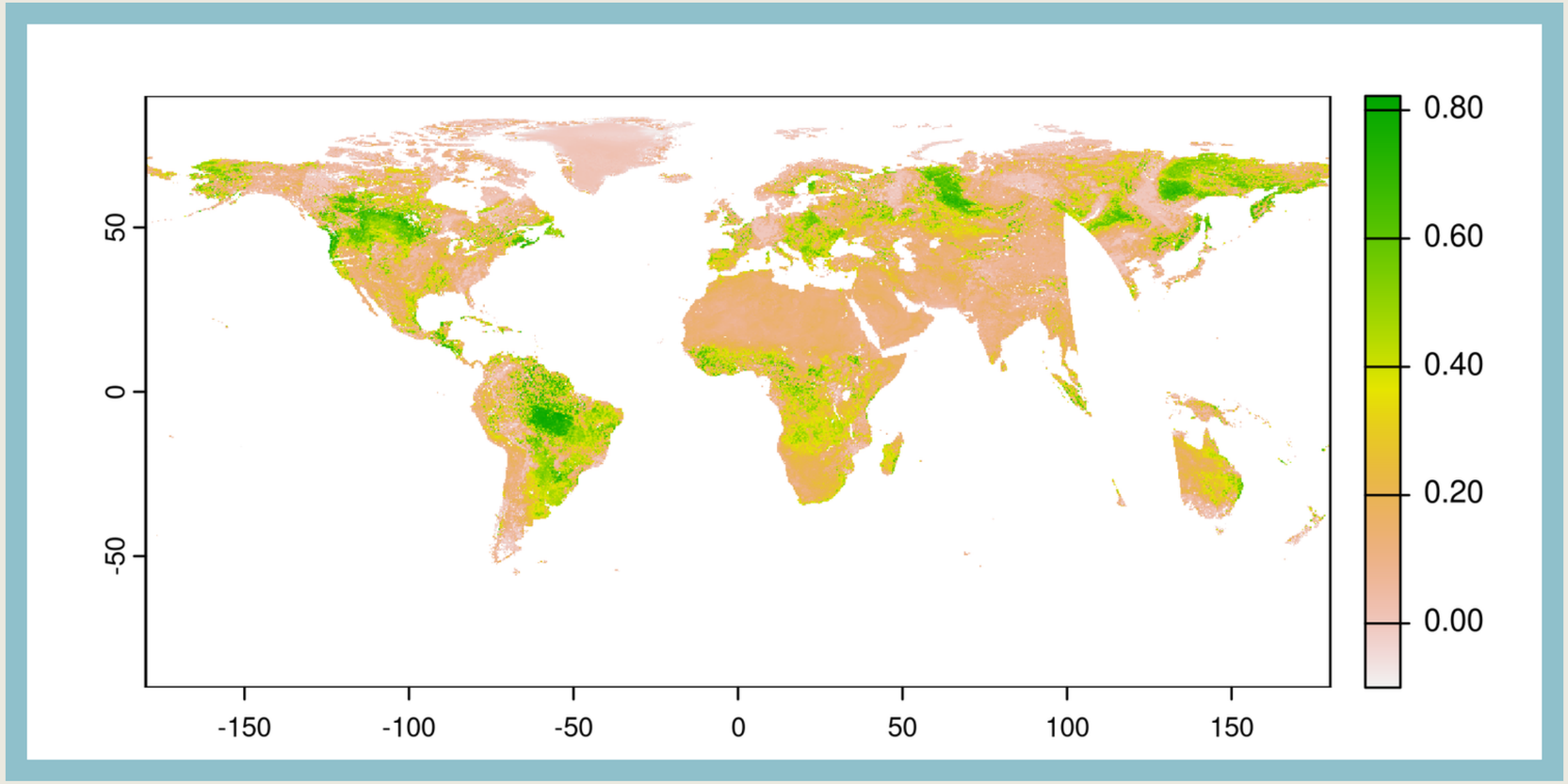
Aims

1) create a method by which the environmental variability of an area across time can be determined
2) assess the environmental variability of currently established protected areas around Canada to determine their ability to buffer against climate change

NDVI

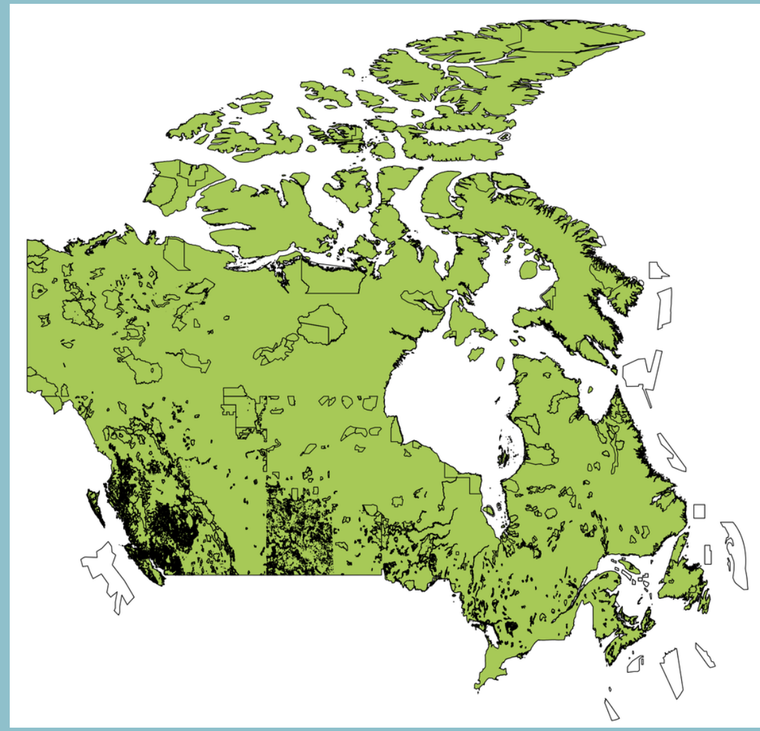
well-established measure of ecosystem health (Petorelli et. al., 2005, 2013)

daily 5km NOAA AVHRR climate data, 1981 - 2023



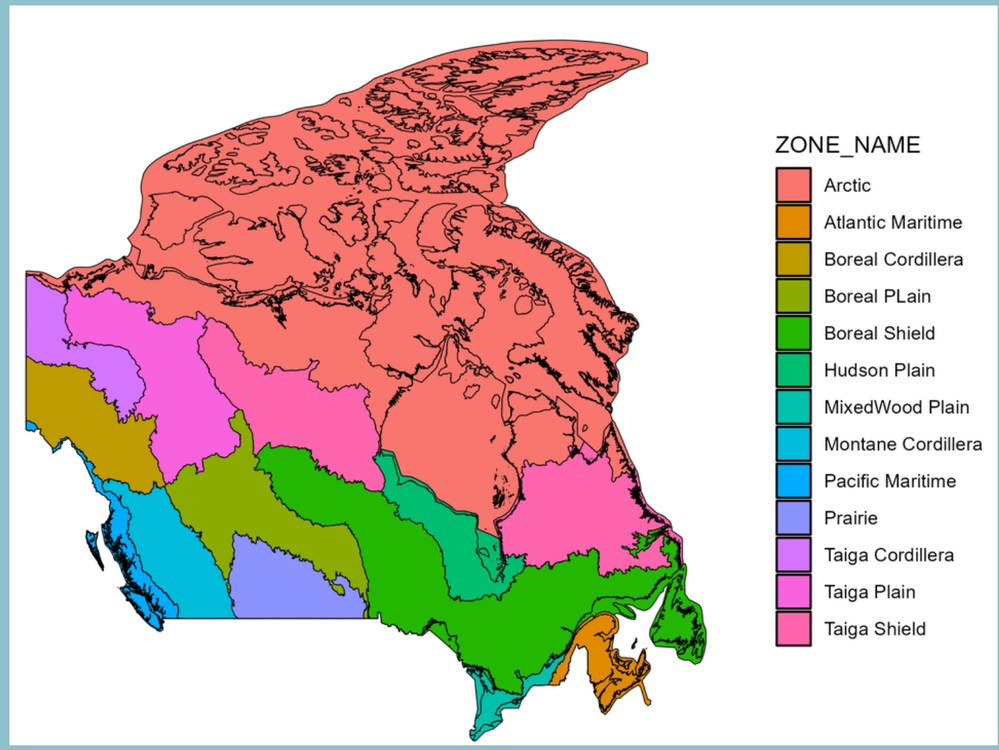
(Vermote, NOAA Climate Data Record (CDR) of AVHRR Normalized Difference Vegetation Index (NDVI), Version 5, accessed October 2023)

Protected Areas



(Canada Protected and Conserved Areas Database, accessed July 2023)

Ecozones



(Ecological Framework of Canada, accessed October 2023)

Sample Data

	NDVI	QA	park	date	dec_date	year	doy	long	lat	ecozone
7328	0.1678915	-16223.455	FALSE	1981-06-25	1981.479	1981	176	-125.025	69.425	ARC
7490	0.2990468	-15014.662	TRUE	1981-06-25	1981.479	1981	176	-124.125	72.125	ARC
7591	0.2931518	-12492.127	TRUE	1981-06-25	1981.479	1981	176	-123.675	73.025	ARC
7683	0.2491507	-9772.882	TRUE	1981-06-25	1981.479	1981	176	-123.225	73.025	ARC
7773	0.2030284	-12288.846	TRUE	1981-06-25	1981.479	1981	176	-122.775	72.575	ARC

Modelling the data

generalized additive modelling (mgcv package)

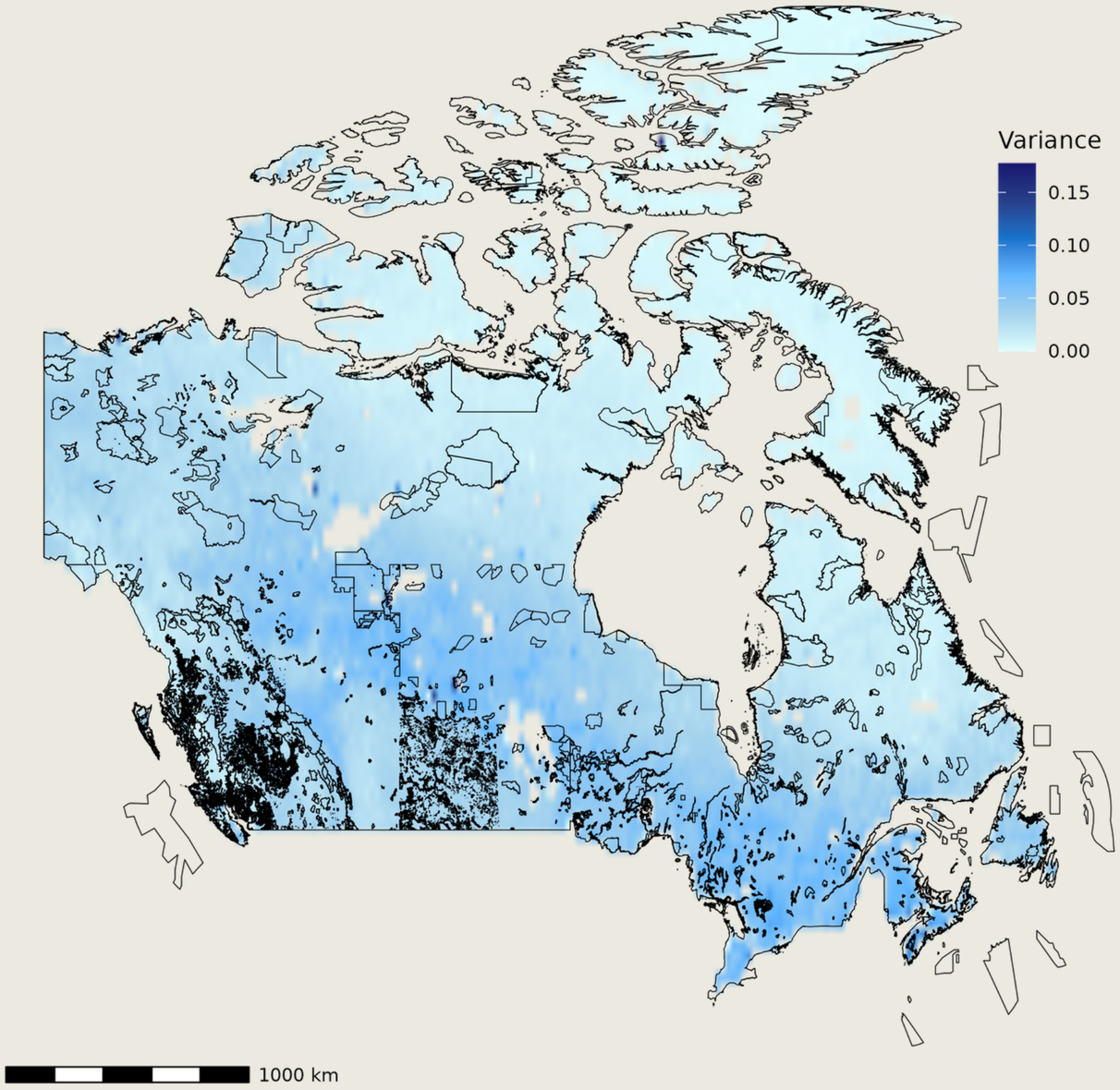
`bam()` - used for large datasets

beta distribution (NDVI was scaled between 0 and 1)

```
mean_ndvi <-
  bam(
    NDVI_scaled ~
      # fixed effects
      park + ecozone +
      # global smooths
      s(long, lat, bs = 'ds', k = 700) + #area effect
      s(year, bs = 'tp', k = 17) + #year effect
      s(doy, bs = 'cc', k = 10) + #seasonal/day of year effect
      # in/out level smooths
      s(year, park, bs = 'fs', k = 15) + #yearly trends in parks
      s(doy, park, bs = 'fs', k = 12, xt = list(bs = 'cc')) + #seasonal trends in parks
      # tensor interaction terms
      ti(year, doy, bs = c('cr', 'cc'), k = c(15, 20)) + #yearly trends over time
      ti(long, lat, year, bs = c('ds', 'cr'), d = c(2, 1), k = c(20, 10)) +
      ti(long, lat, doy, bs = c('ds', 'cc'), d = c(2, 1), k = c(20, 15)),
    family = betar(), #beta location scale distribution for the data
    data = d,
    method = 'fREML',
    discrete = TRUE,
    knots = list(doy = c(0.5, 366.5)),
    control = gam.control(nthreads = 1, trace = TRUE))
```

Mean

mean of predicted NDVI values based on model results

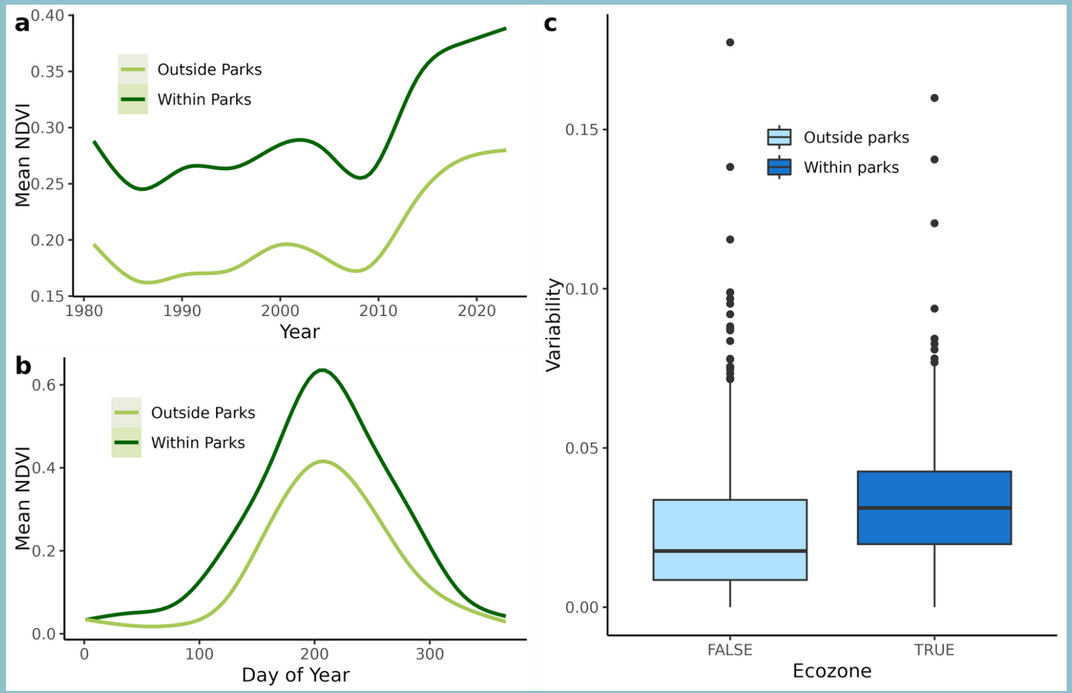


Variance

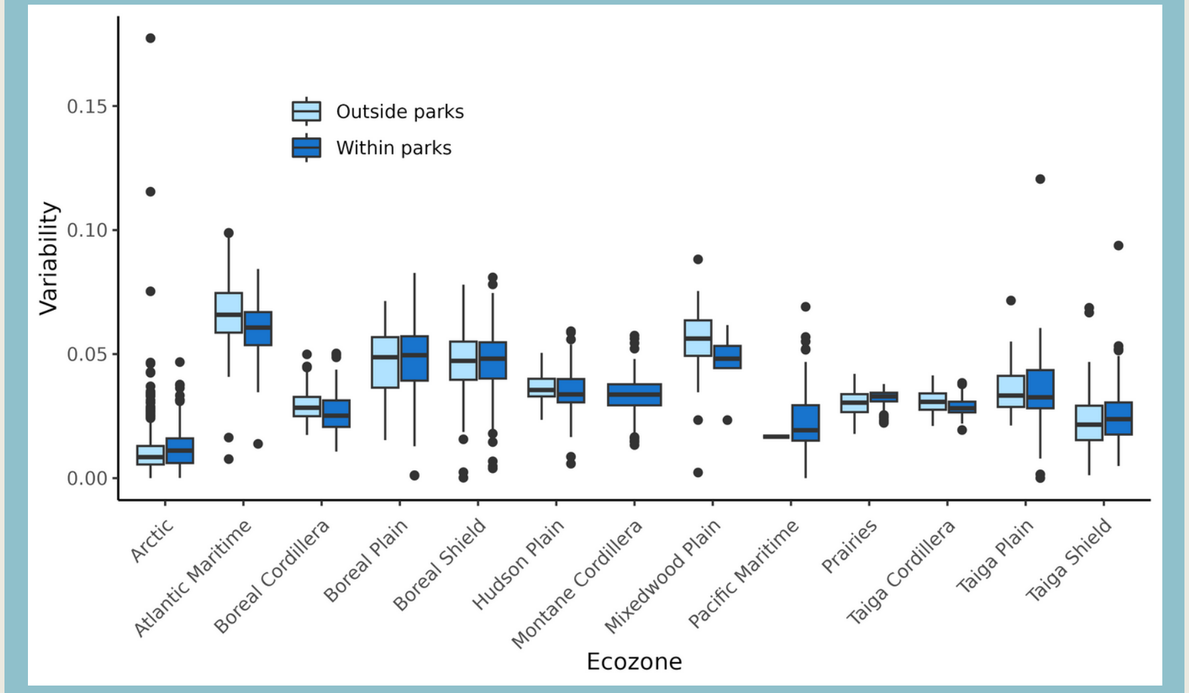
residuals extracted from model (unexplained variance)

variance taken of all residuals for each point to construct map of variance across Canada

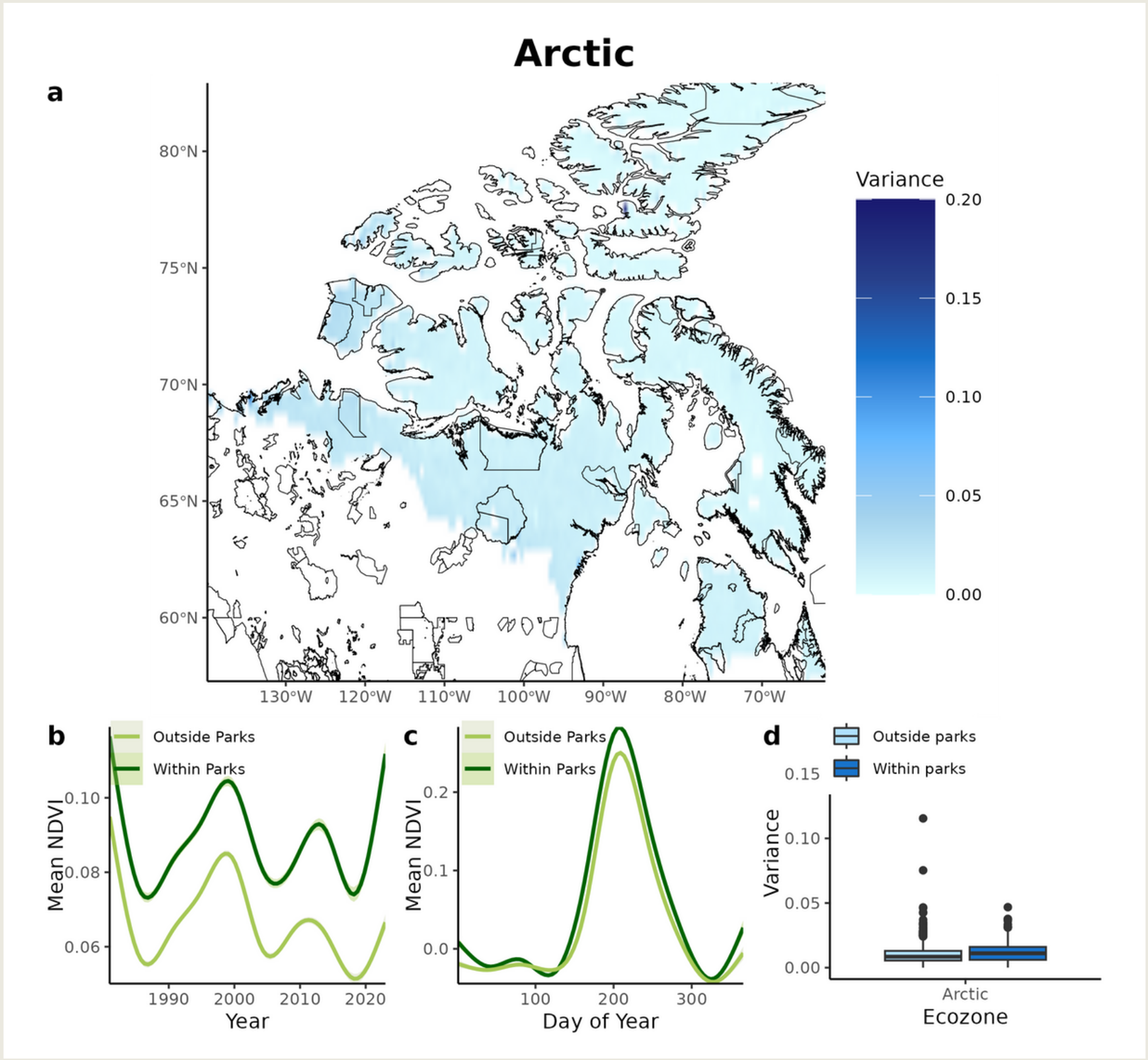
Protected Areas



a) trends in mean NDVI from 1981 to 2023, both within and outside protected areas (referred to as parks). b) trends in mean NDVI by day of year, both within and outside of protected areas. c) variance of residuals within vs outside of protected areas.



variance within and outside of protected areas in the different ecozones assessed

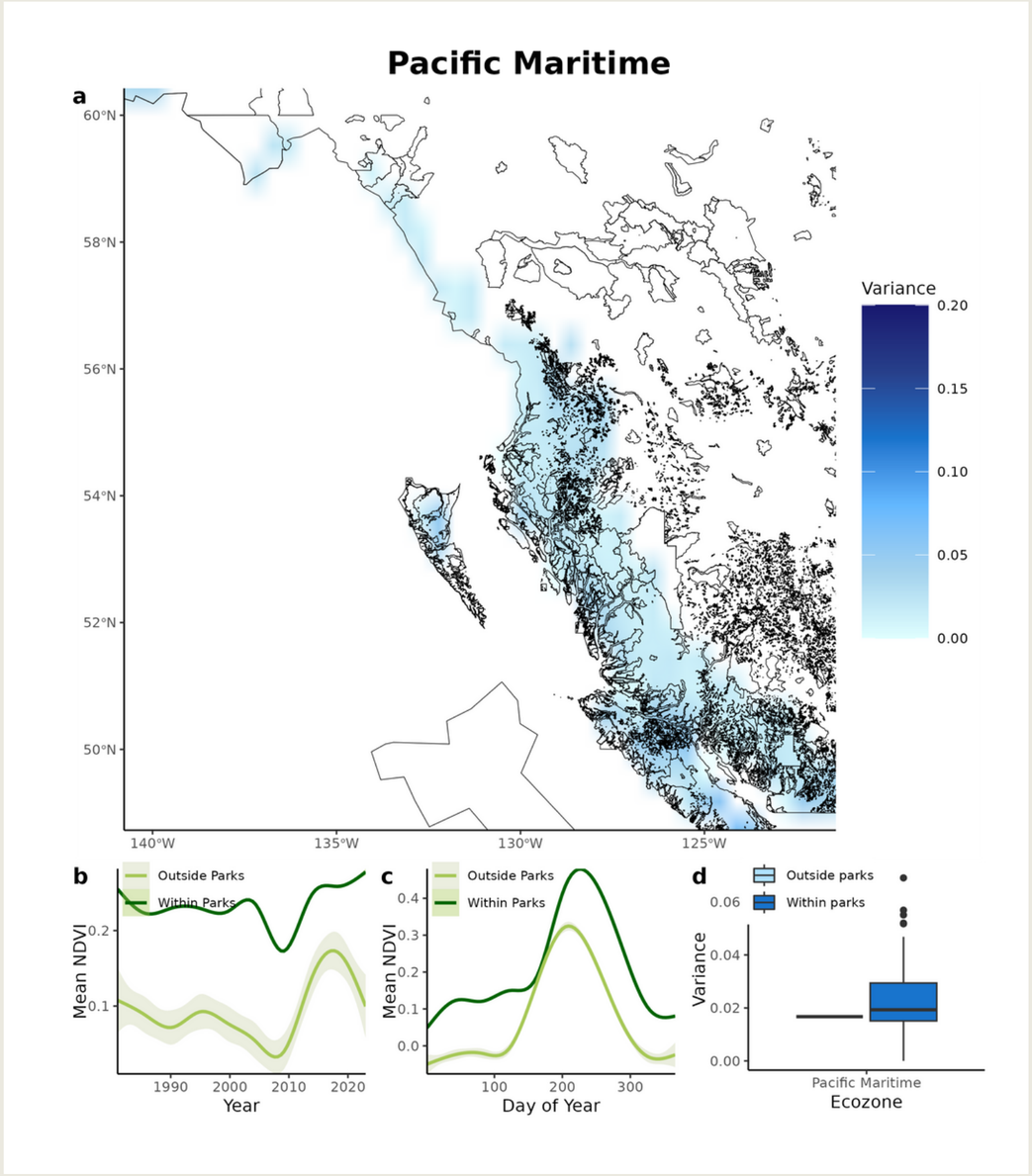


Arctic Ecozone

higher productivity within parks

variance is low (to be expected), but increases as latitude decreases

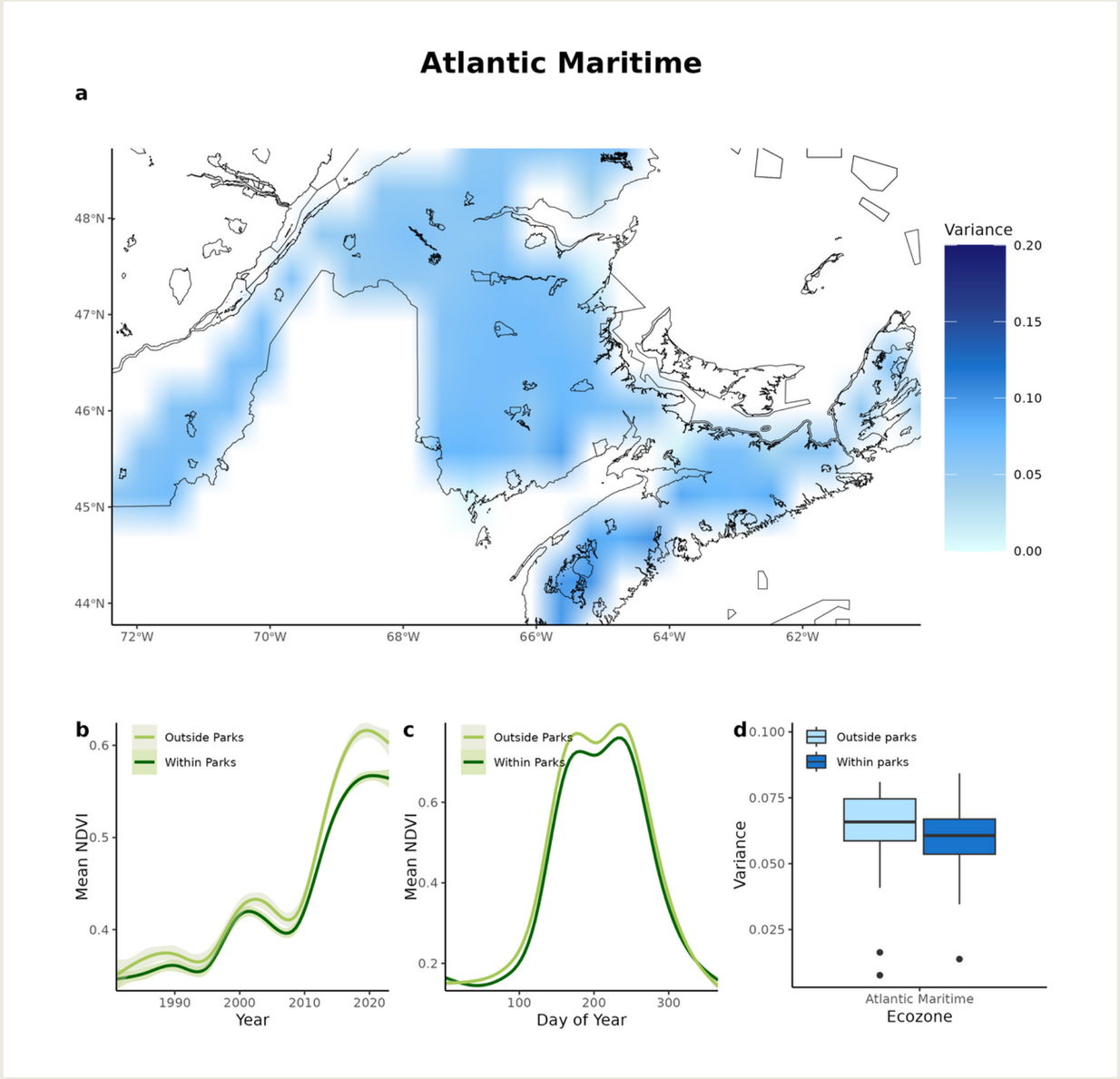
variance is higher within parks (protected area bias)



Pacific Maritime Ecozone

most of the region is protected (very little data outside of protected areas)

higher productivity and variance within parks



Atlantic Maritime Ecozone

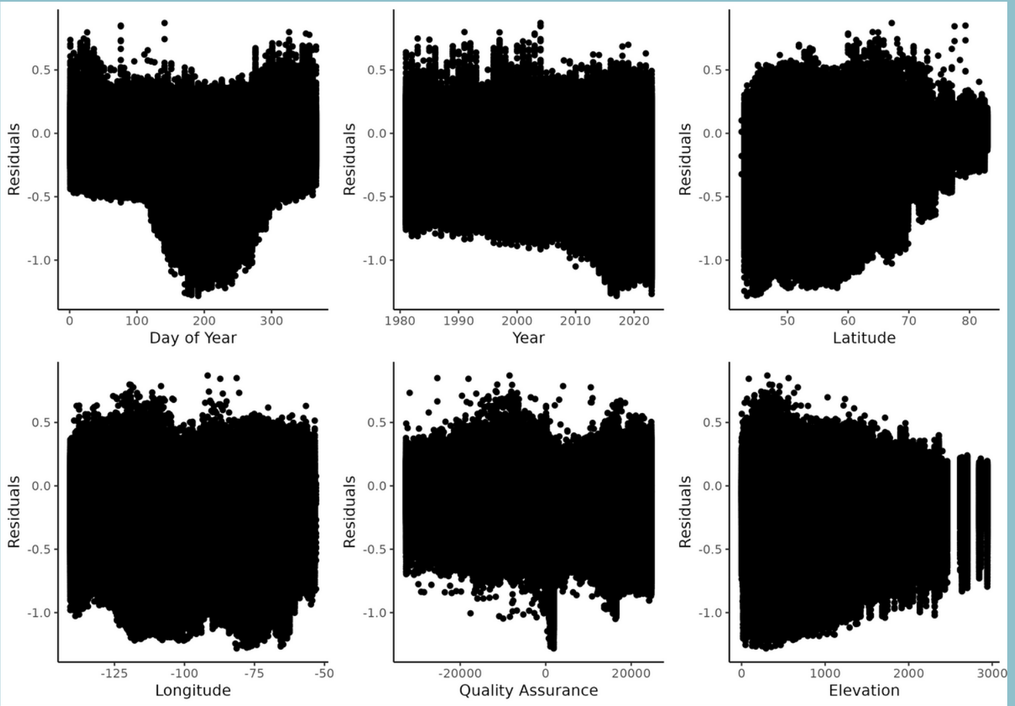
higher productivity outside parks

higher variance overall compared to rest of Canada

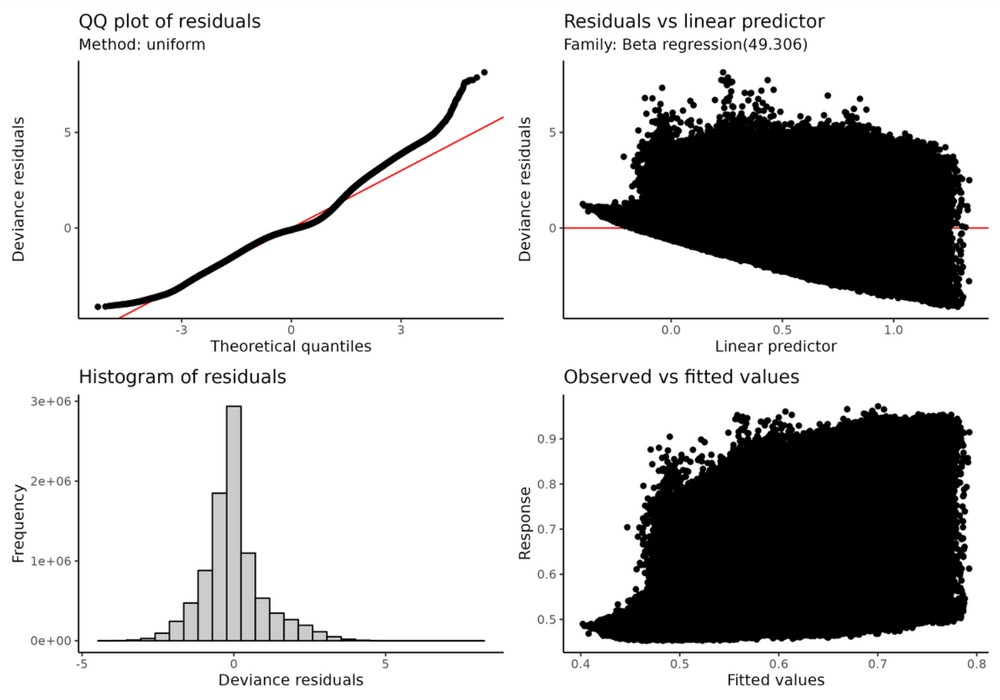
trends are different from the Pacific Maritime ecozone, suggesting it's not just a coastal effect

more variance outside parks

modelled residuals

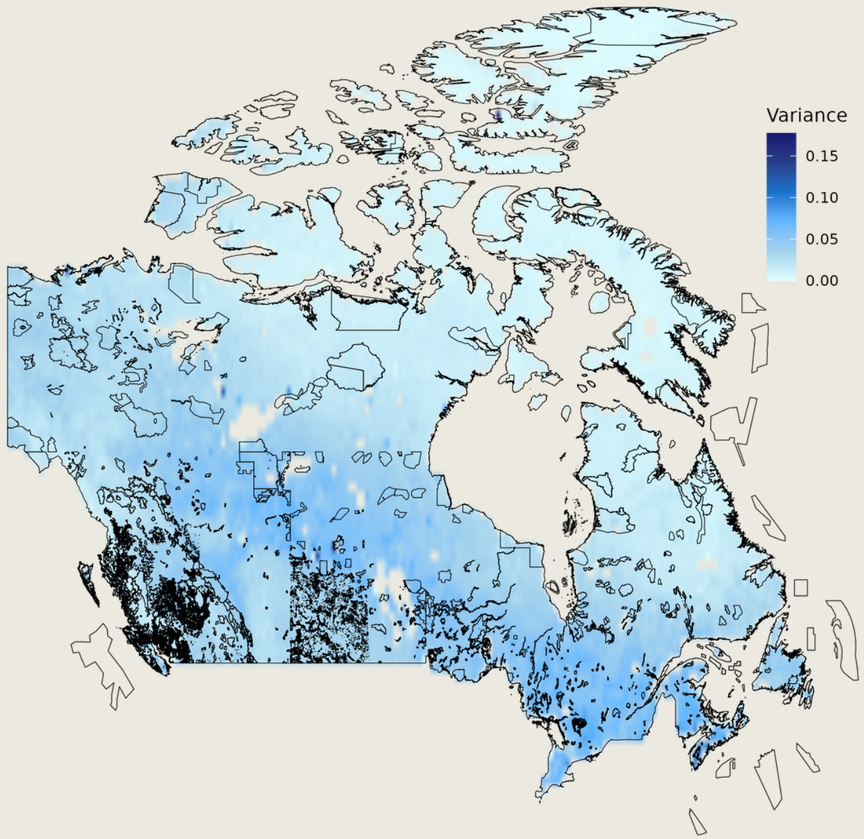


`appraise()`



Aim 1 - achieved

create a method by which the environmental variability of an area across time can be determined

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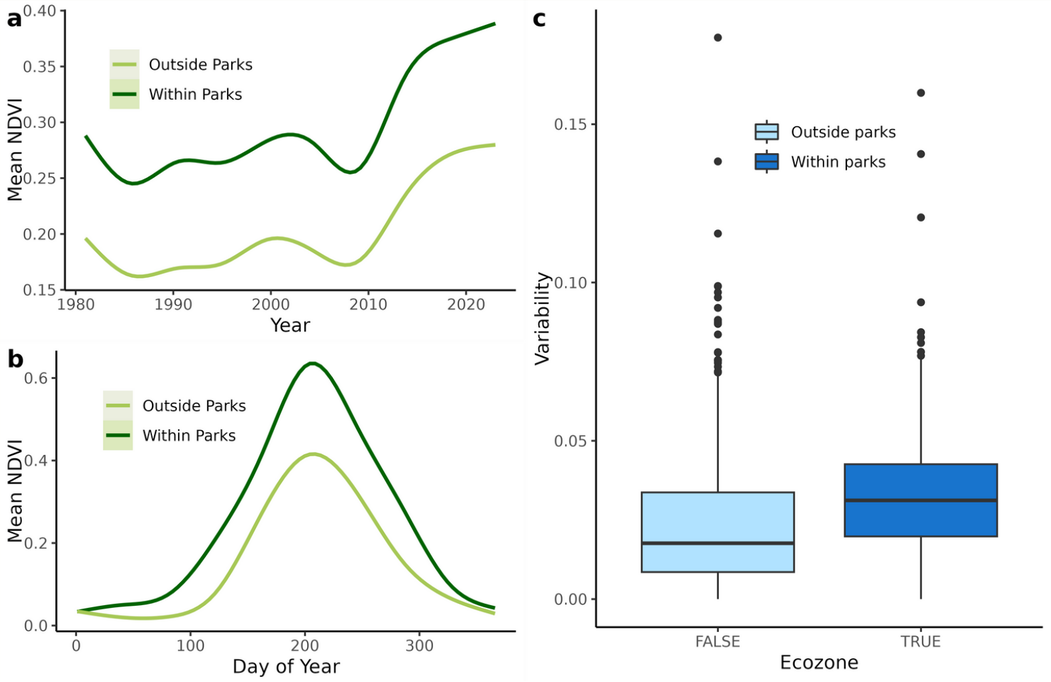
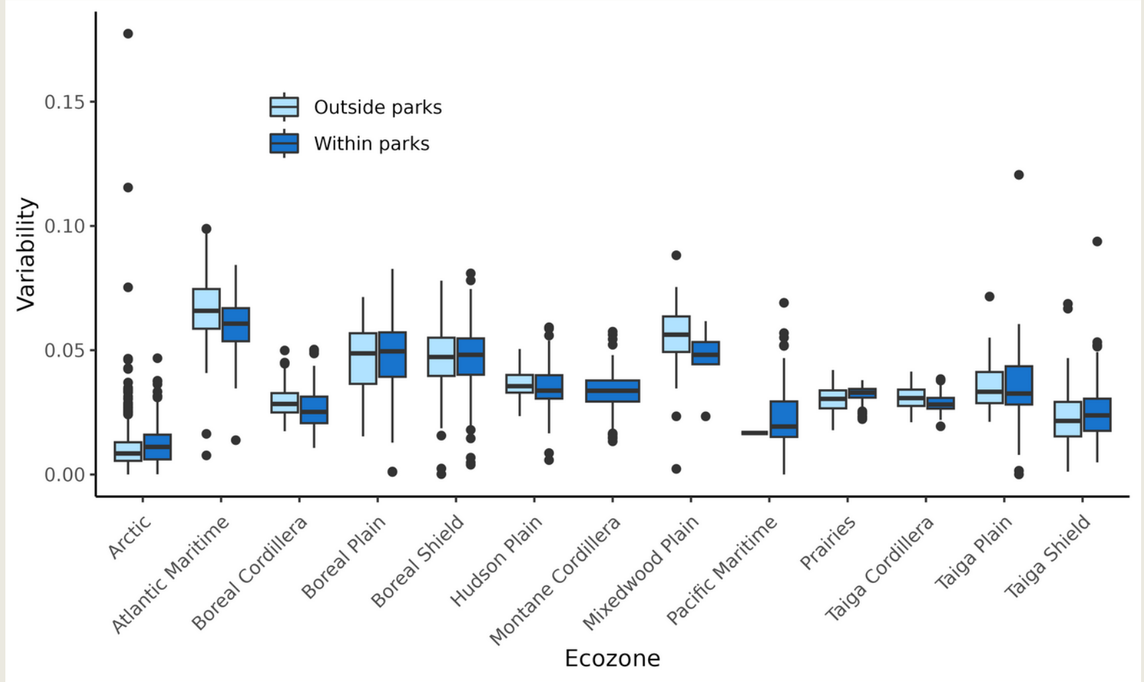
Aim 2 - achieved

assess the environmental variability of currently established protected areas around Canada to determine their ability to buffer against climate change





Conclusion

using our methodology, it is possible to determine the average variability of a region

protected areas are not made with consideration for variability, and often protect less stable habitat

in order to meet Canada’s conservation goals, consideration of variability is essential

(Marcus, Kootenay National Park, July 10, 2023)

thank you <3

References

Tzedakis et. al. (2002). Buffered Tree Population Changes in a Quaternary Refugium: Evolutionary Implications.

Thompson, R. M., Beardall, J., Beringer, J., Grace, M., & Sardina, P. (2013). Means and extremes: building variability into community-level climate change experiments. Ecology Letters, 16(6), 799–806.

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Pettorelli, N., Ryan, S., Mueller, T., Bunnefeld, N., Jedrzejewska, B., Lima, M., & Kausrud, K. (2011). The Normalized Difference Vegetation Index (NDVI): unforeseen successes in animal ecology. Climate Research, 46(1), 15–27.

IPCC. (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.