

Supplementary Information: Supplementary Material 3

VERA vs. MESS Jurisdiction-Level Assessment for *Lynx canadensis*

This appendix summarizes the ecological interpretation of discordant VERA and MESS outputs across 49 jurisdictions where the two methods identified different dominant limiting variables for *Lynx canadensis*. For each jurisdiction, the ecologically more interpretable method was identified based on published field evidence and regional climatic context. Variable abbreviations used throughout: PET Seasonality (PETs), PET of the Driest Quarter (PETDrQ), PET of the Coldest Quarter (PETCoQ), PET of the Warmest Quarter (PETWaQ), Minimum Temperature of the Warmest Month (MTWM), Isothermality (Bio3), Mean Temperature of the Wettest Quarter (Bio8), Temperature Annual Range (Bio7), Precipitation of the Coldest Quarter (Bio19), and Precipitation of the Wettest Month (Bio13).

VERA-favored jurisdictions (n = 19)

Nunavut: VERA = PETs (76.07%); MESS = Bio3 (55.98%). Arctic–subarctic territory. PETs captures the extreme seasonal energy amplitude defining the northern treeline more directly than Bio3 (Krebs et al. 2001; Peers et al. 2014).

Québec: VERA = PETs (47.76%); MESS = Bio3 (31.72%). Extensive boreal lynx range with documented population cycles. PETs is more ecologically specific to hare–lynx cycle synchrony; Bio3 shows poor discrimination at 31.72% (Stenseth et al. 1997; Krebs et al. 2001; Koen et al. 2014; Peers et al. 2014).

Northwest Territories: VERA = PETs; MESS = Bio3. Northern boreal–subarctic core. The annual energy pulse is captured more directly by PETs than by Bio3 (Stenseth et al. 1997; Krebs et al. 2001; USFWS 2023).

Alaska: VERA = PETs; MESS = Bio3. High-latitude core range. Extreme seasonal energy oscillation is the defining environmental feature, captured more directly by PETs (Stenseth et al. 1997; Krebs et al. 2001; Kynoch 2025).

California: VERA = PETDrQ (89.92%); MESS = Bio3 (47.41%). No current populations. Mediterranean summer drought is the dominant constraint; PETDrQ captures this at very high confidence (Vanbianchi et al. 2017; USFWS 2023).

Montana: VERA = Bio3 (50.4%); MESS = PETs (62.43%). Breeding populations in the Northern Rockies. Bio3 aligns with the USFWS narrow thermal envelope framework for western mountain units (Squires et al. 2010; Squires et al. 2013; Vanbianchi et al. 2017; USFWS 2023).

New Mexico: VERA = PETCoQ; MESS = Bio3. Receives dispersing lynx from Colorado but lacks a breeding population. PETCoQ is more directly interpretable for winter energetic constraint at the southern montane margin (Hoving et al. 2005; USFWS 2023).

Arizona: VERA = PETDrQ (98.42%); MESS = MTWM (49.89%). Arid, no lynx habitat. Near-absolute PETDrQ dominance captures the primary moisture-limitation constraint (Roberts and Crimmins 2010; Tourani et al. 2023; USFWS 2023).

Nevada: VERA = PETDrQ (73.77%); MESS = PETs (42.02%). Highly arid. PETDrQ captures the evaporative demand preventing boreal habitat persistence more directly than PETs (Roberts and Crimmins 2010).

Colorado: VERA = PETCoQ; MESS = Bio3. Reintroduced Southern Rockies population. PETCoQ is more directly linked to winter energetic constraint and snow-supported habitat function (Devineau et al. 2010; USFWS 2023).

Oregon: VERA = PETDrQ (93.72%); MESS = Bio3 (65.66%). Marginal/historical presence. Summer drought under Mediterranean influence is the defining constraint, captured by PETDrQ at very high confidence (Vanbianchi et al. 2017; USFWS 2023).

Wyoming: VERA = Bio3 (64.07%); MESS = PETs (63.22%). Breeding populations in Greater Yellowstone. Nearly identical dominance values; Bio3 aligns with the USFWS thermal envelope framework. Marginally favored (Squires et al. 2010; Squires et al. 2013; USFWS 2023).

Minnesota: VERA = MTWM (72.07%); MESS = Bio8 (57.5%). Southern boreal population. MTWM more directly reflects the nocturnal thermal floor influencing boreal

habitat quality at the southern range margin (Moen et al. 2008; Peers et al. 2013; Peers et al. 2014).

Utah: VERA = PETDrQ (50.95%); MESS = PETs (50.1%). Semi-arid, limited high-elevation boreal potential. Near-equal confidence; PETDrQ marginally favored for consistency with the interior western moisture-limitation pattern (Roberts and Crimmins 2010; USFWS 2023).

Washington: VERA = PETDrQ; MESS = Bio3. Pacific trailing edge. Summer moisture deficit is the more ecologically interpretable limiting mechanism for boreal refugia in the Cascades (Vanbianchi et al. 2017; Scully et al. 2018; USFWS 2023).

Idaho: VERA = PETDrQ; MESS = Bio3. Northern Rockies and inland Pacific Northwest transition. Dry-season evaporative stress is more directly interpretable than Bio3 alone (Vanbianchi et al. 2017; Scully et al. 2018; USFWS 2023).

Sonora: VERA = PETDrQ (51.41%); MESS = MTWM (40.77%). Hot, arid, no lynx habitat. Evaporative demand captures the primary landscape-level constraint more directly than summer temperature (Espinosa-Flores et al. 2017; Tourani et al. 2023).

Baja California: VERA = PETDrQ (49.88%); MESS = Bio3 (71.17%). Extremely arid. PETDrQ captures aridity constraint more specifically, though MESS shows higher confidence. Marginally favored on ecological grounds (Espinosa-Flores et al. 2017).

Baja California Sur: VERA = PETDrQ; MESS = MTWM. Hyper-arid, outside any realistic climatic envelope for lynx. Dry-season evaporative demand is the more directly interpretable exclusion mechanism (Tourani et al. 2023; USFWS 2023).

MESS-favored jurisdictions (n = 28)

A consistent pattern emerged across 24 warm-temperate and subtropical jurisdictions where VERA identified PETCoQ as the dominant variable, whereas MESS identified MTWM. In each case, warm-season thermal stress was judged to be the more ecologically interpretable exclusion mechanism for a boreal specialist, because summer warmth—rather than insufficient winter cold—is the proximate constraint preventing the persistence of boreal vegetation and snowshoe hare habitat (Hoving et al. 2005; Roberts

and Crimmins 2010). Listed from largest to smallest, these jurisdictions are Texas (Hoving et al. 2005; Farrell et al. 2018; Tourani et al. 2023), Kansas (MTWM = 100%), South Dakota, Nebraska, Oklahoma (Parren et al. 2022), Missouri (MTWM = 100%), Wisconsin (transitional; marginally favored based on Peers et al. 2014 and Marrotte et al. 2020), Illinois (MTWM = 100%), New York, Arkansas (MTWM = 99.94%; Thornton et al. 2004; Thornton and Pekins 2015), Louisiana, Mississippi, Pennsylvania, Ohio (MTWM = 96.47%), Tennessee, Kentucky, Indiana (MTWM = 100%), Maryland, Massachusetts, New Jersey, Connecticut (Litvaitis et al. 2015), Delaware, Rhode Island (VERA = PETDrQ, but this is ecologically implausible in humid maritime New England), and the District of Columbia (both methods identified a single dominant variable with 100% support, but too small for meaningful ecological interpretation).

The remaining four MESS-favored jurisdictions involved variable pairs other than PETCoQ vs. MTWM:

Manitoba: VERA = MTWM (34.96%); MESS = PETDrQ (57.59%). Boreal–prairie ecotone. PETDrQ captures the moisture-energy limitation at the southern boreal boundary more effectively; VERA shows poor discrimination at 34.96% (Koen et al. 2014; Peers et al. 2014; Dyck et al. 2022).

Michigan: VERA = PETCoQ; MESS = MTWM. Great Lakes transition zone with only sporadic lynx detections. MTWM is more plausible as the broad-scale exclusion mechanism across the predominantly temperate landscape (Hoving et al. 2005; Marrotte et al. 2020; USFWS 2023).

Nova Scotia: VERA = PETDrQ (56.95%); MESS = PETCoQ (78.3%). Maritime province with lynx in Cape Breton Highlands. PETDrQ is ecologically implausible given abundant year-round precipitation; PETCoQ is far more appropriate for this region where winter warming threatens snowpack (Peers et al. 2013; Peers et al. 2014; Koen et al. 2015).

Prince Edward Island: VERA = PETDrQ; MESS = PETCoQ. Humid maritime province. Dry-quarter stress is unlikely as the primary constraint; winter energy and snow conditions are more plausible (Hoving et al. 2005; Peers et al. 2014).

Ambiguous jurisdictions (n = 2)

Ontario: VERA = PETs (23.54%); MESS = PETDrQ (31.48%). Both methods show very weak dominance (<35%), confirming distributed multivariate restriction across a vast boreal-to-temperate gradient. Both mechanisms are ecologically defensible (Koen et al. 2014; Peers et al. 2014; Koen et al. 2015; Marrotte et al. 2020).

Vermont: VERA = PETCoQ (100%); MESS = Bio8 (43.75%). VERA's absolute dominance warrants methodological caution. Bio8 is also weak. Winter warming and summer conditions both contribute; neither method provides a fully convincing signal (Hoving et al. 2005; Peers et al. 2014; Litvaitis et al. 2015).

VERA vs. MESS Jurisdiction-Level Assessment for *Lynx rufus*

This appendix summarizes the ecological interpretation of VERA and MESS outputs across 20 jurisdictions evaluated for *Lynx rufus*. Variable abbreviations: PET of the Warmest Quarter (PETWaQ), PET of the Coldest Quarter (PETCoQ), Minimum Temperature of the Warmest Month (MTWM), Temperature Annual Range (Bio7), Precipitation of the Wettest Month (Bio13), and Precipitation of the Coldest Quarter (Bio19).

Concordant jurisdictions (n = 7)

Seven jurisdictions showed agreement between VERA and MESS on the dominant limiting variable. In central Mexico, three highland states identified PETCoQ as the concordant variable: Guanajuato (VERA 59.16%, MESS 52.86%), Zacatecas (VERA 64.03%, MESS 50.14%), and Nuevo León (VERA 43.55%, MESS 61.43%), consistent with winter energy constraints at elevation (Espinosa-Flores et al. 2017). Similarly, Tamaulipas showed PETCoQ concordance (VERA 47.48%, MESS 54.64%), plausible given cold-front dynamics in northeastern Mexico (Arias-Alzate et al. 2017; Espinosa-Flores et al. 2017). Pennsylvania showed PETWaQ concordance (VERA 67.23%, MESS 49.63%), consistent with growing-season energy influencing habitat productivity in Appalachian terrain (Roberts and Crimmins 2010; Loveless et al. 2016). West Virginia showed Bio13 concordance (VERA 44.33%, MESS 58.97%), reflecting warm-season precipitation effects in a humid montane setting (Loveless et al. 2016). New Jersey

showed Bio19 concordance (VERA 50.57%, MESS 27.9%), reflecting winter precipitation dynamics in a transitional Mid-Atlantic climate (Roberts and Crimmins 2010).

VERA-favored jurisdictions (n = 5)

Saskatchewan: VERA = Bio7 (82.69%); MESS = PETCoQ (54.59%). Extremely continental climate. Bio7 captures the defining thermal amplitude more precisely than a single cold-season metric; VERA's much stronger dominance suggests a cleaner signal (Koen et al. 2014; Marrotte et al. 2020).

Newfoundland and Labrador: VERA = PETWaQ (97.33%); MESS = PETCoQ (50.37%). Limited bobcat occurrence. At this extreme northern maritime location, short growing seasons and low summer warmth accumulation may constrain prey productivity more than ocean-moderated winter cold. VERA's near-absolute dominance supports this interpretation (Litvaitis et al. 2015; Marrotte et al. 2020).

Hidalgo: VERA = Bio7 (41.14%); MESS = PETCoQ (30.46%). Diverse topography from arid valleys to humid mountains. Bio7 captures the elevational-climatic heterogeneity; MESS shows poor discrimination at 30.46% (Arias-Alzate et al. 2017; Espinosa-Flores et al. 2017).

Querétaro: VERA = PETCoQ (44.18%); MESS = Bio19 (32%). Semi-arid to humid highland gradient. PETCoQ is regionally coherent with the broader central Mexican highland pattern; MESS shows weak discrimination (Espinosa-Flores et al. 2017).

Tlaxcala: VERA = PETCoQ (49.54%); MESS = Bio19 (39.86%). Small highland state (>2,000 m). PETCoQ maintains coherence with the central Mexican highland pattern; MESS's Bio19 breaks this pattern without ecological justification (Espinosa-Flores et al. 2017).

MESS-favored jurisdictions (n = 3)

British Columbia: VERA = PETWaQ; MESS = PETCoQ. Northern range limit. Cold-season energy constraints are consistently identified in the literature as the dominant filter at high latitudes. VERA's warm-season signal may reflect a secondary prey-productivity limitation (Koen et al. 2014; Litvaitis et al. 2015; Marrotte et al. 2020; Dyck et al. 2022).

Yukon: VERA = PETWaQ (41.95%); MESS = PETCoQ (65.11%). Extreme northwestern range margin. PETCoQ aligns with documented winter-severity constraints; VERA's weaker signal may reflect secondary growing-season limitations (Litvaitis et al. 2015; Marrotte et al. 2020; Dyck et al. 2022).

Oklahoma: VERA = MTWM (34.7%); MESS = Bio13 (43.96%). Strong west-to-east moisture gradient. Bio13 is more consistent with literature indicating drought and precipitation dynamics shape mesopredator responses in the southern Great Plains (Roberts and Crimmins 2010; Little et al. 2018; Parren et al. 2022).

Ambiguous jurisdictions (n = 5)

Alaska: VERA = PETWaQ (71.79%); MESS = PETCoQ (52.68%). Beyond normal bobcat range. Warm-season productivity limitation and cold-season survival cost likely represent two facets of the same high-latitude barrier (Litvaitis et al. 2015; Marrotte et al. 2020).

Québec: VERA = PETWaQ (54.46%); MESS = PETCoQ (60.61%). Maritime-to-continental gradient. Winter constraints may dominate in the south, growing-season limitations in the north. Moderate dominance in both suggests genuine co-limitation (Koen et al. 2014; Litvaitis et al. 2015; Marrotte et al. 2020).

Coahuila: VERA = Bio13 (39.9%); MESS = Bio19 (47.19%). Both methods identify precipitation but differ on seasonality. Low dominance reflects multi-factor limitation in this semi-arid Chihuahuan Desert–Sierra Madre transition (Arias-Alzate et al. 2017; Espinosa-Flores et al. 2017).

Arkansas: VERA = Bio13 (38.23%); MESS = Bio19 (48.95%). Both methods identify precipitation; low dominance suggests multivariable limitation in the Ozark–Mississippi transition (Thornton et al. 2004; Roberts and Crimmins 2010).

Durango: VERA = Bio13 (44.5%); MESS = Bio19 (47.57%). Sierra Madre Occidental and semi-arid lowlands. Both wet-season and winter precipitation are plausible constraints; neither method is clearly superior (Espinosa-Flores et al. 2017).

References

Arias-Alzate A, González-Maya JF, Arroyo-Cabrales J, Medellín RA, Martínez-Meyer E (2017) Wild felid range shift due to climatic constraints in the Americas: a bottleneck explanation for extinct felids? *J Mammal Evol* 24:427–438. <https://doi.org/10.1007/s10914-016-9350-0>

Devineau O, Shenk TM, White GC, Doherty PF Jr, Lukacs PM, Kahn RH (2010) Evaluating the Canada lynx reintroduction programme in Colorado: patterns in mortality. *J Appl Ecol* 47:524–531. <https://doi.org/10.1111/j.1365-2664.2010.01807.x>

Dyck MA, Wyza E, Popescu VD (2022) When carnivores collide: a review of studies exploring the competitive interactions between bobcats (*Lynx rufus*) and coyotes (*Canis latrans*). *Mammal Review* 52:52–66. <https://doi.org/10.1111/mam.12260>

Espinosa-Flores ME, López-González CA, Morales-Domínguez JF (2017) Distribución potencial del lince rojo (*Lynx rufus*) en México: implicaciones para su conservación. *Therya* 8:223–229. <https://doi.org/10.12933/therya-17-490>

Koen EL, Bowman J, Wilson PJ (2015) Isolation of peripheral populations of Canada lynx (*Lynx canadensis*). *Can J Zool* 93:521–530. <https://doi.org/10.1139/cjz-2014-0227>

Kynoch MC, Williams CT, Breed GA, Kielland K (2025) Seasonal changes in the movement rates and activity patterns of Canada lynx. *Canadian Journal of Zoology* 103:1–14. <https://doi.org/10.1139/cjz-2023-0194>

Little AR, Chamberlain MJ, Conner LM, Warren RJ (2018) Abiotic variables influencing the nocturnal movements of bobcats and cottontail rabbits. *J Wildl Manag* 82:803–809. <https://doi.org/10.1002/jwmg.21430>

Loveless AM, Reding DM, Kapfer PM, Papeş M (2016) Combining ecological niche modelling and morphology to assess the range-wide population genetic structure of bobcats (*Lynx rufus*). *Biol J Linn Soc* 117:842–857. <https://doi.org/10.1111/bij.12718>

Moen R, Burdett CL, Niemi GJ (2008) Movement and habitat use of Canada lynx during denning in Minnesota. *J Wildl Manag* 72:1507–1513. <https://doi.org/10.2193/2008-072>

Parren MK, Furnas BJ, Barton DC (2022) Drought and coyotes mediate mesopredator response to human disturbance. *Ecosphere* 13:e4108. <https://doi.org/10.1002/ecs2.4108>

Squires JR, DeCesare NJ, Kolbe JA, Ruggiero LF (2010) Seasonal resource selection of Canada lynx in managed forests of the northern Rocky Mountains. *J Wildl Manag* 74:1648–1660. <https://doi.org/10.2193/2009-184>

Thornton DH, Pekins CE (2015) Spatially explicit capture–recapture analysis of bobcat (*Lynx rufus*) density: implications for mesocarnivore monitoring. *Wildl Res* 42:394–404. <https://doi.org/10.1071/WR15092>

Thornton DH, Sunquist ME, Main MB (2004) Ecological separation within newly sympatric populations of coyotes and bobcats in south-central Florida. *J Mammal* 85:973–982. <https://doi.org/10.1644/BEH-020>

Tourani M, Sollmann R, Kays R, Ahumada J, Fegraus E, Karp DS (2023) Maximum temperatures determine the habitat affiliations of North American mammals. *Proc Natl Acad Sci USA* 120:e2304411120. <https://doi.org/10.1073/pnas.2304411120>