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Outpacing the Math: Why Range-Shifting Species Are in Greater Danger Than We Think

Biology * Environment * Climate Change

Introduction: Climate Velocity and the Limits of Extinction Forecasting

Accelerating anthropogenic climate change is forcing global biodiversity into an urgent adapt-or-migrate dilemma[1]. While early macroecological forecasts relied on static species-area power laws to project that 15-37% of terrestrial species could face extinction by 2050[2][3], multi-decadal resurveys show that local extinctions are driven primarily by summer maximum daily temperatures rather than mean annual anomalies[4]. Because in-situ thermal niche evolution proceeds at roughly 0.02 deg C per year -- three to four times slower than anthropogenic warming -- 16-30% of terrestrial species remain threatened over the next half-century unless they actively shift their geographic ranges[4].

Translating these ecological trajectories into species-specific warnings relies on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species[1][5]. However, a landmark 2026 study in Nature Ecology & Evolution demonstrates that the standard correlative models used in Red List assessments systematically underestimate extinction risk for range-shifting species by relying on a flawed linear assumption between suitable habitat area and population abundance[1].

Red List Criteria and Predictive Ecological Modeling Paradigms

Across more than 160,000 assessed species, the IUCN Red List evaluates climate-driven threats primarily through Criterion A3 (projected future population reductions over three generations or ten years, up to 100 years) and Criterion E (quantitative Population Viability Analysis estimating extinction probability)[1][7][8]. Temporal scaling alone introduces substantial bias: replacing naive 10-year default windows with trait-predicted generation lengths in forest-dependent amphibians increases projected climate-driven declines from 1% to 20%[7]. Even more consequential is Criterion A3's permission to substitute forecasted habitat loss from correlative Species Distribution Models (SDMs) as a 1:1 linear proxy for population decline[1].

| Red List Criterion | | Primary Focus of Measurement | | Application to Climate Change Forecasts | | Key Methodological Limitations |

| Criterion A3 | | Projected future population reduction | | Uses modeled future habitat loss as a direct 1:1 proxy for population decline. | | Assumes a linear relationship between habitat area and population; strongly sensitive to temporal horizons. |

| Criterion B | | Geographic range size and fragmentation | | Identifies restricted spatial distributions combined with ongoing environmental threats. | | Can

overestimate risk for naturally rare but stable localized endemics if future threats are only suspected. |

| Criterion C & D | | Small population sizes and declines | | Focuses on numeric abundance thresholds and acute rarity. | | Difficult to project future population abundances without complex demographic data. |

| Criterion E | | Quantitative probability of extinction | | Uses population viability analysis to forecast extinction probability (e.g., 10% in 100 years). | | Requires extensive species-specific empirical data; often produces overly conservative estimates. |

Correlative SDMs -- built with Generalized Additive Models, Random Forests, MaxEnt, and ensemble frameworks like biomod2 -- statistically map abiotic niches onto future climate layers but assume environmental equilibrium and omit dispersal limits, carrying capacity, and demographic vital rates[1][9][10]. Conversely, mechanistic Spatially Explicit Population Models (SEPMs) used under Criterion E -- such as the individual-based C++/R platform RangeShiftR -- explicitly simulate stage-structured demography, dispersal kernels, population genetics, and density-dependent mortality across changing landscapes, but require intensive empirical parameterization unavailable for most taxa[8][11][12].

Virtual Ecology Simulations: Convex vs. Concave Collapse

To test IUCN assessment criteria against known ground-truth demography, researchers at the University of Potsdam simulated 16 virtual species across three stochastically replicated landscapes over a 90-year warming scenario resulting in deterministic extinction[1]. Species varied across four life-history axes: niche breadth, intrinsic growth rate, dispersal capability, and initial niche position[1]. Cold-adapted species at the northern landscape boundary experienced pure range-contracting dynamics, whereas interior species experienced range-shifting dynamics requiring northward migration[1].

Although ensemble SDMs trained on pre-warming occurrences achieved high spatial accuracy (AUC = 0.95, TSS = 0.78), Bayesian ordered beta regression comparing true simulated abundances against SDM-predicted habitat loss refuted the linear 1:1 proxy[1]:

* Range-Contracting Species (Convex Relationship): Populations persisted in situ at high densities within shrinking habitat remnants, maintaining stable abundance until more than 50% of suitable area was lost, after which rapid collapse occurred[1]. Because geographic habitat loss preceded demographic crash, SDMs under Criterion A3 provided timely early warnings[1].

* Range-Shifting Species (Concave Relationship): Migrating populations suffered immediate, disproportionate demographic collapses at the onset of warming[1]. Trailing-edge populations succumbed rapidly to thermal stress and drought while leading-edge colonization lagged behind climate velocity due to dispersal constraints, landscape fragmentation, genetic drift, and transit mortality[1][4]. Consequently, abundance plummeted long before SDMs registered sufficient net habitat loss to trigger a Criterion A3 listing[1].

| Range Dynamic Type | | Biological Niche Position | | Habitat-Population

Relationship | | Primary Ecological Mechanism | | Efficacy of Model Warning Time |

| Range-Contracting | | Marginal / Boundary | | Convex | | In-situ persistence at high densities until a tipping-point spatial threshold is breached. | | Adequate (Geographic habitat loss clearly precedes the demographic population crash) |

| Range-Shifting | | Central / Interior | | Concave | | Dispersal lags, landscape friction, and high mortality during migration. | | Substantially Delayed (Demographic population crashes occur long before habitat loss registers) |

Warning Time Truncation and Modernizing Assessment Guidelines

The Potsdam simulations further revealed that probabilistic Criterion E assessments derived from mechanistic SEPMs were overly conservative due to strict statistical certainty thresholds, delaying warnings across all species types[1]. When combined with empirical projections showing climate change elevating extinction risk in endemic ectotherms from <1% to nearly 28% by 2100[15], truncated warning times for range-shifters threaten to misdirect funding under the Kunming-Montreal Global Biodiversity Framework and allow functional ecosystem collapse before species are formally flagged as threatened[1][5][16][17].

To modernize global risk assessments, conservation science must implement four structural reforms: (1) replace the linear habitat-population assumption under Criterion A3 with concave risk weightings for range-shifting species[1]; (2) constrain correlative SDMs with species-specific dispersal buffers and macroecological life-history covariates (body mass, generation length, reproductive rate)[6][13][15]; (3) track trailing-edge density declines and community trait homogenization as leading early-warning metrics[1][4]; and (4) construct permeable wildlife corridors linking current habitats to future climate refugia to reduce migratory friction and preserve natural selection potential[1][14].

Conclusion: Aligning Conservation Math with Migratory Reality

By demonstrating that range-shifting species follow a concave trajectory of rapid demographic collapse rather than a linear decline proportional to habitat area, virtual ecology has exposed a consequential blind spot in global biodiversity monitoring[1]. Integrating dispersal lags, concave correction factors, and landscape connectivity into IUCN Red List protocols is essential to detect and mitigate climate-driven extinctions before migratory species cross irreversible demographic thresholds[1].

Updates... (Nov 19, 2026): Separated multi-source citations into individual superscripts and standardized reference list identifiers across all 17 primary peer-reviewed DOIs (previously updated Nov 14, 2026 to link the July 2026 Nature Ecology & Evolution publication of Keuth, Fritz, and Zurell).

References & Primary Sources

* [1] Keuth, R., Fritz, S. A., & Zurell, D. (2026). Models used for Red List assessments underestimate climate-related extinction risk of range-shifting species. Nature Ecology & Evolution. -- https://doi.org/10.1038/s41559-026-03125-y

* [2] Lewis, O. T. (2006). Climate change, species-area curves and the extinction

crisis. Philosophical Transactions of the Royal Society B: Biological Sciences. -- https://doi.org/10.1098/rstb.2005.1712

* [3] Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C., et al. (2004). Extinction risk from climate change. Nature. -- https://doi.org/10.1038/nature02121

* [4] Rom n-Palacios, C., & Wiens, J. J. (2020). Recent responses to climate change reveal the drivers of species extinction and survival. Proceedings of the National Academy of Sciences. -- https://doi.org/10.1073/pnas.1913007117

* [5] Rodrigues, A. S. L., Pilgrim, J. D., Lamoreux, J. F., Hoffmann, M., & Brooks, T. M. (2006). The value of the IUCN Red List for conservation. Trends in Ecology & Evolution, 21(2), 71-76. -- https://doi.org/10.1016/j.tree.2005.10.010

* [6] Henry, E., Santini, L., Butchart, S. H. M., Gonz lez-Su rez, M., Lucas, P. M., et al. (2024). Modelling the probability of meeting IUCN Red List criteria to support reassessments. Global Change Biology. -- https://doi.org/10.1111/gcb.17119

* [7] Mancini, G., Mezzanotte, V., Santini, L., & Di Marco, M. (2026). The risk of underestimating generation length for extinction risk assessments. Cambridge Prisms: Extinction. -- https://doi.org/10.1017/ext.2026.10012

* [8] Keith, D. A., Mahony, M., Hines, H., Elith, J., Regan, T. J., et al. (2014). Detecting Extinction Risk from Climate Change by IUCN Red List Criteria. Conservation Biology. -- https://doi.org/10.1111/cobi.12234

* [9] Beaumont, L. J., Graham, E., Duursma, D. E., Wilson, P. D., Cabrelli, A., et al. (2016). Which species distribution models are more (or less) likely to project broad-scale, climate-induced shifts in species ranges? Ecological Modelling. -- https://doi.org/10.1016/j.ecolmodel.2016.10.004

* [10] Valavi, R., Guillera-Arroita, G., Lahoz-Monfort, J. J., & Elith, J. (2022). Predictive performance of presence-only species distribution models: a benchmark study with reproducible code. Ecological Monographs. -- https://doi.org/10.1002/ecm.1486

* [11] Ak akaya, H. R. (2000). Viability analyses with habitat-based metapopulation models. Population Ecology. -- https://doi.org/10.1007/s101440050043

* [12] Bocedi, G., Palmer, S. C. F., Malchow, A.-K., Zurell, D., Watts, K., & Travis, J. M. J. (2021). RangeShifter 2.0: an extended and enhanced platform for modelling spatial eco-evolutionary dynamics and species' responses to environmental changes. Ecography. -- https://doi.org/10.1111/ecog.05687

* [13] Zurell, D., Schifferle, K., Herrando, S., Keller, V., K ry, M., et al. (2024). Range and climate niche shifts in European and North American breeding birds. Philosophical Transactions of the Royal Society B: Biological Sciences. -- https://doi.org/10.1098/rstb.2023.0013

* [14] Javeline, D., Hellmann, J. J., McLachlan, J. S., Sax, D. F., Schwartz, M. W., & Cornejo, R. C. (2015). Expert opinion on extinction risk and climate change adaptation for biodiversity. Elementa: Science of the Anthropocene. -- https://doi.org/10.12952/journal.elementa.000057

* [15] Pearson, R. G., Stanton, J. C., Shoemaker, K. T., Aiello-Lammens, M. E., Ersts, P. J., Horning, N., Fordham, D. A., Raxworthy, C. J., Ryu, H. Y., McNees, J., & Ak akaya, H. R. (2014). Life history and spatial traits predict extinction risk due to climate change. Nature Climate Change. -- https://doi.org/10.1038/nclimate2113

* [16] Ak akaya, H. R., Butchart, S. H. M., Mace, G. M., Stuart, S. N., & Hilton-Taylor, C. (2006). Use and misuse of the IUCN Red List Criteria in projecting climate change impacts on biodiversity. Global Change Biology. -- https://doi.org/10.1111/j.1365-2486.2006.01253.x

* [17] Cazalis, V., Di Marco, M., Butchart, S. H. M., Ak akaya, H. R., Gonz lez-Su rez, M., et al. (2022). Bridging the research-implementation gap in IUCN Red List assessments. Trends in Ecology & Evolution. -- https://doi.org/10.1016/j.tree.2021.12.002