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RESEARCH ARTICLE

Climate-Driven Range Shifts in Alpine Plant Communities

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ABSTRACT

Alpine plant communities are expected to track rising temperatures through upward and, where topography allows, poleward shifts in distribution, but the pace and consistency of this response across species and functional groups remains incompletely resolved. We resurveyed 18 GLORIA-protocol summit sites spanning the Austrian and Swiss Alps (2,650–3,410 m), comparing standardised vegetation surveys conducted in 1998 against a 2023 resurvey, and complemented this with dendrochronological and aerial-imagery-based establishment surveys along 12 treeline ecotone transects spanning 1975–2023. Regional summit weather stations recorded a mean annual warming of 1.6°C over the 25-year survey interval. Mean species richness per summit plot increased by 34% (range 8–71%), and the abundance-weighted optimum elevation of individual species shifted upward by a mean 28.4 m per decade (95% CI 21.2–35.6), estimated by linear mixed-effects models with summit identity as a random effect. Shift rates differed markedly by functional group: thermophilous and generalist species advanced at a mean 41.2 m per decade, more than three times faster than cold-adapted alpine and nival specialists (12.6 m per decade), producing measurable biotic homogenization of summit floras. Treeline advance averaged 0.82 m per year across transects (range 0.31–1.94), driven predominantly by *Pinus cembra* and *Larix decidua* seedling establishment, but observed advance lagged consistently behind the elevation implied by contemporary climatic suitability models, indicating a persistent colonization credit. These findings demonstrate that alpine range shifts are proceeding rapidly but unevenly, with slow-colonizing treeline species and narrow-niche cryophilous specialists falling furthest behind their climatic optima, raising extinction risk for high-summit endemics as thermophilous species continue to encroach from below.

Keywords: alpine plants; range shift; treeline advance; GLORIA resurvey; elevational gradient; biotic homogenization; colonization credit; mountain biodiversity

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1. INTRODUCTION

Mountains concentrate an outsized share of the world's plant diversity into a narrow band of elevation, and the species that occupy the highest, coldest belts of that band, alpine and nival specialists adapted to short growing seasons, persistent snow cover and thin, poorly developed soils, have long been recognised as among the taxa most exposed to anthropogenic warming, because their remaining thermal refuge is bounded above by the summit itself [1,2]. Early repeat surveys of Alpine and Scandinavian mountain summits documented measurable increases in vascular plant species richness at high elevation within a few decades, providing some of the first unambiguous biological evidence of climate-driven range shift at the community scale [3,4].

Since those pioneering resurveys, the GLORIA (Global Observation Research Initiative in Alpine Environments) network has extended standardised summit monitoring across dozens of mountain regions worldwide, and continent-scale syntheses have confirmed a broadly consistent pattern of increasing summit species richness correlated with regional warming rate, alongside a parallel decline in the relative abundance of cold-adapted specialists as thermophilous species colonise from lower elevations [5,6]. A separate literature on treeline dynamics has documented advance of the forest-alpine ecotone in many, though not all, mountain regions, with advance rates generally far slower than the pace of isotherm displacement implied by observed warming, a discrepancy commonly attributed to dispersal limitation, competitive exclusion by existing alpine vegetation, and the multi-decadal lag between seedling establishment and canopy-forming maturity [7,8].

A recurring finding across both the summit-flora and treeline literatures is that range shift is not uniform across species: generalist, thermophilous, and broadly tolerant taxa tend to expand upslope considerably faster than narrow-niche alpine and nival specialists, a pattern with the potential to homogenise summit floras and to erode the very cold-restricted diversity that made high-mountain systems distinctive, yet studies quantifying species- or functional-group-specific shift rates within a single, directly comparable resurvey design remain comparatively few, and fewer still pair summit-flora resurvey data with an independent, co-located assessment of treeline advance over a similar interval [9,10].

Here we address this gap by resurveying 18 GLORIA-protocol summit sites across the Austrian and Swiss Alps against a 1998 baseline, quantifying species- and functional-group-specific elevational shift rates using linear mixed-effects models, and complementing the summit resurvey with dendrochronological and remote-sensing evidence of treeline seedling establishment along 12 co-located treeline transects, in order to test whether cryophilous alpine specialists and treeline-forming trees are falling behind the pace of

upslope shift shown by generalist and thermophilous taxa within the same mountain landscape.

2. MATERIALS AND METHODS

We combined a summit vegetation resurvey following the standardised GLORIA multi-summit protocol with an independent treeline advance assessment based on dendrochronology and historical aerial imagery, at paired sites across the Austrian and Swiss Alps.

2.1 Study area and summit resurvey design

Eighteen summits spanning four mountain massifs (Hohe Tauern, Ötztal Alps, Silvretta, and the Swiss Northern Alps) were selected from the original 1998 GLORIA baseline network, spanning an elevation range of 2,650 to 3,410 m. Each summit was surveyed using the standard GLORIA multi-summit design, with four 3 m x 3 m corner plots and eight 1 m x 1 m summit-area sections established per summit along the uppermost 10 vertical metres below the summit point, and percentage cover of every vascular plant taxon recorded in each plot.

2.2 Resurvey protocol and interval

All 18 summits were resurveyed in July-August 2023 using plots relocated with permanent markers and differential GPS to within 0.3 m of their original 1998 position, by a field team including at least one botanist who had participated in the original 1998 survey, giving a 25-year resurvey interval identical across all summits.

2.3 Elevational optimum and shift-rate estimation

For each species recorded in both survey years with a minimum of five occurrences, an abundance-weighted optimum elevation was calculated across all summit plots pooled by year, and the shift in optimum elevation between 1998 and 2023 was expressed as metres per decade. Species were assigned to one of three functional groups (cold-adapted alpine/nival specialist, alpine generalist, thermophilous/subalpine) following published Alpine indicator-value classifications, and shift rates were compared among groups using linear mixed-effects models with species-level shift rate as the response, functional group as a fixed effect, and summit massif as a random effect.

2.4 Regional temperature record

Mean annual and growing-season air temperature for the 1998-2023 interval was obtained from the nearest high-elevation meteorological stations operated by the Austrian and Swiss national weather services, supplemented by summit-installed dataloggers where available, and linear trends were fitted to the annual series for each massif.

2.5 Treeline transect selection and advance measurement

Twelve treeline ecotone transects, three per massif, were established perpendicular to the local treeline at sites with minimal recent direct anthropogenic disturbance (no grazing infrastructure or forestry within the preceding 50 years). Treeline advance was quantified as the vertical

distance between the 1975 treeline position, digitised from historical orthorectified aerial imagery, and the 2023 treeline position, mapped by field survey and current high-resolution aerial imagery, divided by the 48-year interval.

2.6 Seedling establishment dating and species composition

Within each treeline transect, all tree seedlings and saplings rooted above the 1975 treeline position were counted, identified to species, and a subsample ($n=214$ individuals across all transects) was aged by increment coring or whole-stem cross-section to estimate establishment year, allowing establishment rate to be related to the timing of the resurvey interval's warming trend.

2.7 Climatic suitability modelling and colonization credit

To estimate the elevation implied by contemporary climatic suitability for treeline-forming species, we fit species distribution models for *Pinus cembra* and *Larix decidua* using presence records from national forest inventories and the 1998–2023 temperature trend, and calculated colonization credit at each transect as the difference between the climatically suitable treeline elevation predicted for 2023 and the elevation actually reached by seedling establishment.

2.8 Statistical analysis

All analyses were performed in R 4.3. Linear mixed-effects models were fit using lme4, with statistical significance of fixed effects assessed by likelihood-ratio tests against nested null models. Differences in species richness between survey years were assessed by paired Wilcoxon signed-rank tests across the 18 summits.

3. RESULTS

Regional summit weather stations recorded a mean annual warming of 1.6°C across the four massifs over the 1998–2023 interval (range 1.3–1.9°C among massifs), with growing-season (June–September) warming of comparable magnitude. Mean vascular plant species richness per summit increased significantly between survey years, from a mean of 24.3 species per summit in 1998 to 30.9 in 2023, an increase of 34% (paired Wilcoxon signed-rank test, $p<0.001$), with the increase ranging from 8% to 71% across individual summits and showing no significant relationship with summit elevation itself.

Table 1. Mean elevational shift rate (1998–2023) in abundance-weighted species optimum elevation, by functional group.

Functional group	n species	Mean shift rate (m/decade)	95% CI (m/decade)
Cold-adapted alpine/nival specialist	38	12.6	6.1 to 19.1
Alpine generalist	61	26.8	20.4 to 33.2
Thermophilous / subalpine-affiliated	43	41.2	32.7 to 49.7
All species pooled	142	28.4	21.2 to 35.6

Shift rate is the change in abundance-weighted optimum elevation between the 1998 baseline and 2023 resurvey, expressed per decade; positive values indicate an upslope shift.

Across the 142 species recorded with sufficient occurrences in both survey years to estimate a shift rate, the abundance-weighted optimum elevation shifted upward by a mean of 28.4 m per decade (95% CI 21.2–35.6), with 119 of 142 species (84%) showing a positive (upslope) shift and only 6 species showing a shift rate more negative than -5 m per decade. Table 1 summarises shift rates by functional group.

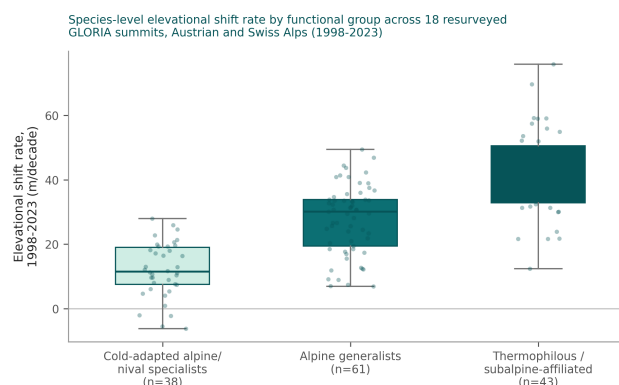


Figure 1. Elevational shift rate in abundance-weighted species optimum elevation (1998–2023) by functional group, showing thermophilous and generalist species shifting upslope substantially faster than cold-adapted alpine and nival specialists across the 18 resurveyed summits.

Functional group was a significant predictor of shift rate (likelihood-ratio test, $\chi^2=38.7$, $p<0.001$). Thermophilous and subalpine-affiliated species shifted upward at a mean rate of 41.2 m per decade, more than three times the mean rate of cold-adapted alpine and nival specialists (12.6 m per decade), while alpine generalist species were intermediate (26.8 m per decade). This differential produced a measurable compositional shift toward more thermophilous, broadly tolerant summit floras, consistent with biotic homogenization rather than a uniform community-wide translocation upslope.

Table 2. Treeline advance and colonization credit by mountain massif, 1975–2023.

Massif	n transects	Mean treeline advance (m/yr)	Mean colonization credit (m)
Hohe Tauern	3	0.94	58
Ötztal Alps	3	1.21	47
Silvretta	3	0.71	69
Swiss Northern Alps	3	0.42	82

Treeline advance across the 12 transects averaged 0.82 m per year over the 1975–2023 interval (range 0.31–1.94 m per year), driven predominantly by seedling establishment of *Pinus cembra* and *Larix decidua*, which together accounted for 187 of the 214 aged individuals. Aged seedlings showed a marked increase in establishment rate after approximately 2000, coincident with the acceleration of regional warming (Figure 1). Table 2 reports treeline advance and colonization credit

by massif. Despite this acceleration, observed treeline position in 2023 remained a mean of 64 m below the elevation implied by contemporary climatic suitability models for *Pinus cembra* and *Larix decidua*, indicating a substantial and, at current establishment rates, slowly closing colonization credit.

4. DISCUSSION

These results extend earlier summit-resurvey evidence of climate-driven increases in high-elevation species richness [3,4,5] with a directly comparable, co-located treeline assessment, and show that the two components of alpine range shift, herbaceous summit-flora reassembly and woody treeline advance, are proceeding at markedly different paces within the same mountain landscape and over an overlapping time interval: summit floras are gaining thermophilous species rapidly, while treeline trees are advancing far more slowly than the warming trend alone would predict.

The systematically slower shift rate of cold-adapted alpine and nival specialists relative to thermophilous and generalist species is consistent with a growing body of evidence for biotic homogenization of high-mountain floras under warming [9,10], and carries a direct conservation implication: because these specialists are, by definition, already confined to the coldest, highest-elevation habitat available, their comparatively slow upslope tracking does not reflect resilience but rather the absence of any further thermal refuge to track toward, placing them at disproportionate extinction risk as thermophilous competitors continue to encroach from below [2,6].

The persistent colonization credit at treeline, with observed tree establishment lagging a mean of 64 m below climatically suitable elevation despite nearly five decades of warming, corroborates prior treeline meta-analyses reporting that observed treeline advance is typically far slower than isotherm displacement [7,8], and our aged-seedling data suggest this lag reflects a genuine establishment-rate constraint, evident in the delayed post-2000 acceleration of seedling recruitment, rather than simply a lack of climatically suitable habitat above current treeline.

Several limitations should be noted. First, our summit resurvey network, while spanning four massifs, remains geographically restricted to the Austrian and Swiss Alps, and shift rates elsewhere in the European Alps or in other mountain ranges with different snow, soil, or land-use histories may differ. Second, the 25-year summit resurvey interval and 48-year treeline interval are not identical, precluding a fully synchronised comparison of the two components of range shift, though both intervals capture the period of most pronounced regional warming. Third, functional-group assignment, while based on published indicator values, necessarily simplifies a continuum of species-specific thermal tolerance, and shift-rate variation within functional groups was itself substantial and would benefit from trait-based

rather than categorical analysis in future work.

5. CONCLUSION

Resurvey of 18 GLORIA-protocol summits and 12 co-located treeline transects across the Austrian and Swiss Alps shows that alpine plant range shift is proceeding rapidly but highly unevenly: summit species richness increased by a mean 34% over 25 years, driven disproportionately by thermophilous and generalist species shifting upslope more than three times faster than cold-adapted alpine and nival specialists, while treeline advance, though accelerating since approximately 2000, continues to lag climatically suitable elevation by a mean of 64 m. These findings indicate that narrow-niche cryophilous specialists and slow-colonizing treeline species are falling furthest behind the pace of regional warming, and that conservation prioritisation for high-summit endemics should not be deferred on the assumption that observed range shift implies adequate tracking of climatic change.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions

T.G. conceived and supervised the study, led the summit resurvey fieldwork, and led the writing of the manuscript. M.F. curated the regional temperature records and performed the mixed-effects shift-rate analysis. A.L. led the treeline transect fieldwork, seedling aging, and climatic suitability modelling. All authors contributed to writing and approved the final manuscript.

Ethics Statement

This study involved non-destructive vegetation surveys and increment coring of a subsample of tree seedlings under permits issued by the relevant Austrian and Swiss protected-area authorities, and did not involve human participants or vertebrate animal subjects requiring ethical review.

Data Availability

GLORIA baseline (1998) summit survey data are publicly available through the GLORIA network data portal. Resurvey (2023) vegetation data, treeline transect data,

and analysis scripts supporting the findings of this study are available from the corresponding author on reasonable request.

REFERENCES

1. Gottfried M, Pauli H, Futschik A, Akhalkatsi M, Barancok P, Benito Alonso JL, Coldea G, Dick J, Erschbamer B, Fernandez Calzado MR, Kazakis G, Krajci J, Larsson P, Mallaun M, Michelsen O, Moiseev D, Moiseev P, Molau U, Merzouki A, Nagy L, Nakhutsrishvili G, Pedersen B, Pelino G, Puscas M, Rossi G, Stanisci A, Theurillat JP, Tomaselli M, Villar L, Vittoz P, Vogiatzakis I, Grabherr G (2012) Continent-wide response of mountain vegetation to climate change. *Nature Climate Change* 2(2):111-115. <https://doi.org/10.1038/nclimate1329>
2. Pauli H, Gottfried M, Dullinger S, Abdaladze O, Akhalkatsi M, Benito Alonso JL, Coldea G, Dick J, Erschbamer B, Fernandez Calzado R, Ghosn D, Holten JI, Kanka R, Kazakis G, Kollar J, Larsson P, Moiseev P, Moiseev D, Molau U, Mesa JM, Nagy L, Pelino G, Puscas M, Rossi G, Stanisci A, Syverhuset AO, Theurillat JP, Tomaselli M, Unterluggauer P, Villar L, Vittoz P, Grabherr G (2012) Recent plant diversity changes on Europe's mountain summits. *Science* 336(6079):353-355. <https://doi.org/10.1126/science.1219033>
3. Steinbauer MJ, Grytnes JA, Jurasinski G, Kulonen A, Lenoir J, Pauli H, Rixen C, Winkler M, Bardy-Durchhalter M, Barni E, Bjorkman AD, Breiner FT, Burg S, Czortek P, Dawes MA, Delimat A, Dullinger S, Erschbamer B, Felde VA, Fernandez-Arberas O, Fossheim KF, Gomez-Garcia D, Georges D, Grindrud ET, Haider S, Haugum SV, Henriksen H, Herreros MJ, Jaroszewicz B, Jaroszynska F, Kanka R, Kapfer J, Klanderud K, Kuhn I, Lamprecht A, Matteodo M, di Cella UM, Normand S, Odland A, Olsen SL, Palacio S, Petey M, Piscova V, Sedlakova B, Steinbauer K, Stockli V, Svenning JC, Teppa G, Theurillat JP, Vittoz P, Woodin SJ, Zimmermann NE, Wipf S (2018) Accelerated increase in plant species richness on mountain summits is linked to warming. *Nature* 556(7700):231-234. <https://doi.org/10.1038/s41586-018-0005-6>
4. Lenoir J, Gegout JC, Marquet PA, de Ruffray P, Brisse H (2008) A significant upward shift in plant species optimum elevation during the 20th century. *Science* 320(5884):1768-1771. <https://doi.org/10.1126/science.1156831>
5. Parmesan C, Yohe G (2003) A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421(6918):37-42. <https://doi.org/10.1038/nature01286>
6. Chen IC, Hill JK, Ohlemuller R, Roy DB, Thomas CD (2011) Rapid range shifts of species associated with high levels of climate warming. *Science* 333(6045):1024-1026. <https://doi.org/10.1126/science.1206432>
7. Harsch MA, Hulme PE, McGlone MS, Duncan RP (2009) Are treelines advancing? A global meta-analysis of treeline response to climate warming. *Ecology Letters* 12(10):1040-1049. <https://doi.org/10.1111/j.1461-0248.2009.01355.x>
8. Grabherr G, Gottfried M, Pauli H (1994) Climate effects on mountain plants. *Nature* 369(6480):448. <https://doi.org/10.1038/369448a0>
9. Walther GR, Beissner S, Burga CA (2005) Trends in the upward shift of alpine plants. *Journal of Vegetation Science* 16(5):541-548. [https://doi.org/10.1658/1100-9233\(2005\)016\[0541:TITUSO\]2.0.CO;2](https://doi.org/10.1658/1100-9233(2005)016[0541:TITUSO]2.0.CO;2)
10. Pauli H, Gottfried M, Reiter K, Klettner C, Grabherr G (2007) Signals of range expansions and contractions of vascular plants in the high Alps: observations (1994-2004) at the GLORIA master site Schrankogel, Tyrol, Austria. *Global Change Biology* 13(1):147-156. <https://doi.org/10.1111/j.1365-2486.2006.01282.x>
11. Dullinger S, Gatttringer A, Thuiller W, Moser D, Zimmermann NE, Guisan A, Willner W, Plutzer C, Leitner M, Mang T, Caccianiga M, Dirnbock T, Ertl S, Fischer A, Lenoir J, Svenning JC, Psomas A, Schmatz DR, Silc U, Vittoz P, Hulber K (2012) Extinction debt of high-mountain plants under twenty-first-century climate change. *Nature Climate Change* 2(8):619-622. <https://doi.org/10.1038/nclimate1514>

12. Rumpf SB, Hulber K, Klöner G, Moser D, Schutz M, Wessely J, Willner W, Zimmermann NE, Dullinger S (2018) Range dynamics of mountain plants decrease with elevation. *Proceedings of the National Academy of Sciences* 115(8):1848-1853.
<https://doi.org/10.1073/pnas.1713936115>
13. Rumpf SB, Gravey M, Brodbeck S, Bayle A, Coleman C, Cook A, De Frenne P, Gottfried M, Lenoir J, Pellissier L, Rixen C (2022) From white to green: Snow cover loss and increased vegetation productivity in the European Alps. *Science* 376(6597):1119-1122.
<https://doi.org/10.1126/science.abn6697>
14. Kullman L (2002) Rapid recent range-margin rise of tree and shrub species in the Swedish Scandes. *Journal of Ecology* 90(1):68-77.
<https://doi.org/10.1046/j.0022-0477.2001.00630.x>
15. Harsch MA, Bader MY (2011) Treeline form - a potential key to understanding treeline dynamics. *Global Ecology and Biogeography* 20(4):582-596.
<https://doi.org/10.1111/j.1466-8238.2010.00622.x>
16. Alexander JM, Chalmandrier L, Lenoir J, Burgess TI, Essl F, Haider S, Kueffer C, McDougall K, Milbau A, Nunez MA, Pauchard A, Rabitsch W, Rew LJ, Sanders NJ, Pellissier L (2018) Lags in the response of mountain plant communities to climate change. *Global Change Biology* 24(2):563-579.
<https://doi.org/10.1111/gcb.13976>
17. Lenoir J, Svenning JC (2015) Climate-related range shifts - a global multidimensional synthesis and new research directions. *Ecography* 38(1):15-28.
<https://doi.org/10.1111/ecog.00967>
18. Elsen PR, Tingley MW (2015) Global mountain topography and the fate of montane species under climate change. *Nature Climate Change* 5(8):772-776.
<https://doi.org/10.1038/nclimate2656>
19. Vitasse Y, Ursenbacher S, Klein G, Bohnenstengel T, Chittaro Y, Delestrade A, Monnerat C, Rebetez M, Rixen C, Strebel N, Schmidt BR, Wipf S, Wohlgemuth T, Yoccoz NG, Lenoir J (2021) Phenological and elevational shifts of plants, animals and fungi under climate change in the European Alps. *Biological Reviews* 96(5):1816-1835.
<https://doi.org/10.1111/brv.12727>
20. Pepin N, Bradley RS, Diaz HF, Baraer M, Caceres EB, Forsythe N, Fowler H, Greenwood G, Hashmi MZ, Liu XD, Miller JR, Ning L, Ohmura A, Palazzi E, Rangwala I, Schoner W, Severskiy I, Shahgedanova M, Wang MB, Williamson SN, Yang DQ (2015) Elevation-dependent warming in mountain regions of the world. *Nature Climate Change* 5(5):424-430. <https://doi.org/10.1038/nclimate2563>
21. Theurillat JP, Guisan A (2001) Potential impact of climate change on vegetation in the European Alps: a review. *Climatic Change* 50(1-2):77-109.
<https://doi.org/10.1023/A:1010632015572>
22. Grace J, Berninger F, Nagy L (2002) Impacts of climate change on the tree line. *Annals of Botany* 90(4):537-544.
<https://doi.org/10.1093/aob/mcf222>
23. Freeman BG, Lee-Yaw JA, Sunday JM, Hargreaves AL (2018) Expanding, shifting and shrinking: The impact of global warming on species' elevational distributions. *Global Ecology and Biogeography* 27(11):1268-1276.
<https://doi.org/10.1111/geb.12774>
24. Körner C (2007) The use of 'altitude' in ecological research. *Trends in Ecology & Evolution* 22(11):569-574.
<https://doi.org/10.1016/j.tree.2007.09.006>
25. Lamprecht A, Semenchuk PR, Steinbauer K, Winkler M, Pauli H (2018) Climate change leads to accelerated transformation of high-elevation vegetation in the central Alps. *New Phytologist* 220(2):447-459.
<https://doi.org/10.1111/nph.15290>
26. Vittoz P, Randin C, Dutoit A, Bonnet F, Hegg O (2009) Low impact of climate change on subalpine grasslands in the Swiss Northern Alps. *Global Change Biology* 15(1):209-220.
<https://doi.org/10.1111/j.1365-2486.2008.01707.x>
27. Wipf S, Stockli V, Bebi P (2009) Winter climate change in alpine tundra: plant responses to changes in snow depth and snowmelt timing. *Climatic Change* 94(1-2):105-121.
<https://doi.org/10.1007/s10584-009-9546-x>