Breaking Disciplinary Boundaries: Bringing the Biological Role out of the Blind Spot in DRF-Based Assessments of Limestone Weathering under a Changing Climate

Snežana Radulović[1,2], Goran Anačkov[2], Boris Radak[2], Miloš Ilić[2], Božidar Radulović[2], Maja Novković[2], Samir Đug[1], Lejla Smailagić Vesnić[1], Saida Ibragić[1], and Nusret Drešković[1]

[1]University of Sarajevo, Faculty of Science, Bosnia and Herzegovina
[2]University of Novi Sad, Faculty of Science, Serbia

Lipfert & Kucera DRF for stećci monuments (BiH, RS, CRO, ME) Dreskovic et al. 2025

DOI: 10.13140/RG.2.2.23079.61602

CONDITIONS	STECCI LOCATIONS	Kucera (µm/year)	Lipfert (µm/year)	Kucera (µm/year)	Lipfert (µm/year)	MAIN FACTORS
Urban, High Pollution (SO_2 > 10 µg/m^3, PM_{10} > 50 µg/m^3)	Sarajevo (BIH)	44.58	23.26	40-60+	N/A	SO_2 gas dissolution, particulate deposition
Moderate Pollution (SO_2 <10 µg/m^3, PM_{10} >20 µg/m^3)	Mramorje (RS)	23.89	17.72	20-40	N/A	Particulate deposition
Moderate Pollution, Low Pollution (SO_2 < 5 µg/m^3, PM_{10} < 20 µg/m^3)	Split (CRO)	17.72	27.76	5-20 (SO_2 still contributes, but reduced impact)	considering	Low SO_2 contribution, some acid rain, traffic pollutants
Rural, Moderate Rain (500-1000 mm/year)	Kopošići (BIH) Križevići (BIH) Velika Cista (CRO)	5.33 4.81 5.05	21.02 18.65 25.77	2-7	5-10	Low air pollution, but precipitation increases limestone dissolution
Remote, Very High Rainfall (2000 m/year, tropical/marine)	Žugića Bare (ME)	5.72	29.94	5-15	15-30+	Pure rainfall-driven dissolution

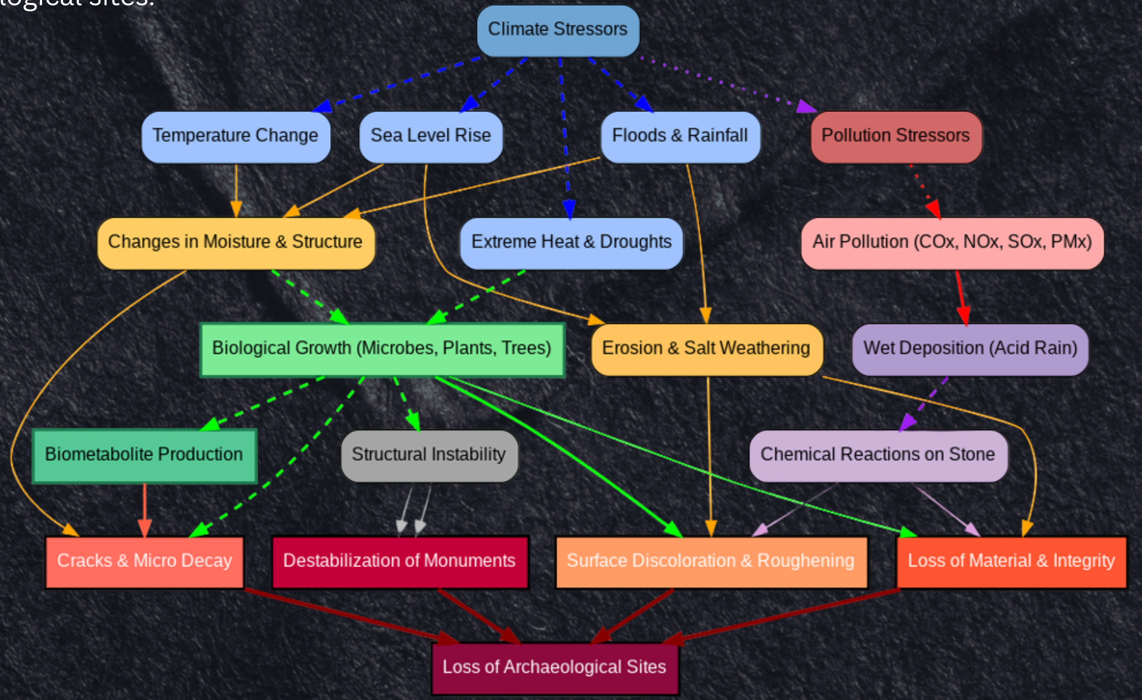
Conservation value of the Dominant lichen species and their impact on stećci

LICHEN SPECIES	GROWTH FORMS	IMPACT ON STONE	RECOMMENDATION
Bagliettoa marmorea *Bryoplaca jungermanniae*, *Lepraria incana*, *Lobothallia cheresina*, *Protoparmeliopsis muralis*, *Squamarina gypsacea*, *Xanthoria calcicola*, *Xanthoria elegans*	Crustose lichen	Causes chemical and physical weathering but may stabilize surfaces.	Retain
Collema furfuraceum *Dermatocarpon miniatum* *Parmelia saxatilis* *Peltigera canina* *Physcia adscendens* *Physcia caesia*	Foliose lichen	Causes discoloration, mineral leaching, and erosion via acid production.	Remove
Not recorded	Fruticose lichen	Trap moisture within its branched structure, prolonging stone dampness and enhancing chemical weathering through acid production.	Remove

Funded by the European Union

EGU26

The deterioration of limestone monuments is not driven by isolated climatic or pollution stressors, but by their cascading interaction with biological growth, which amplifies moisture retention, chemical alteration, micro-decay, surface loss, and ultimately the vulnerability of archaeological sites.



Limestone cultural heritage is increasingly threatened by the combined effects of climate stressors, air pollution, and biological colonisation. Within the STECCI study, a bio-geochemical dose-response framework was developed to assess the decay of medieval limestone tombstones stećci , across UNESCO culturally significant sites across the Balkans. Although dose-response functions are widely used to evaluate climatic, chemical, and physical weathering, biological colonisation has often remained insufficiently addressed. However, lichens, mosses, and microbial communities can actively contribute to limestone deterioration through moisture retention, organic acid production, mineral leaching, increased porosity, and micro-fracturing.

Dominant biodeteriogens contribute to limestone deterioration in different ways depending on their growth form: crustose lichens may both weather and stabilise stone surfaces and should generally be retained when they do not threaten inscriptions or structural integrity, while foliose and potential fruticose lichens are more likely to promote discoloration, mineral leaching, erosion, and moisture retention, and should therefore be considered for controlled removal.

DISCLAIMER
Funded by the European Union under Grant Agreement No. 101094822. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

By linking the recorded lichen taxa and their growth forms with biological growth coverage, the modified DRF models operationalise biocolonisation as a measurable weathering driver through the β(BGC) coefficient, thereby bridging field-based biodeterioration evidence with quantitative predictions of limestone surface recession.

The modified Kucera Model could look like this:
R=3.95+0.0059[SO2]RH60+0.054Rain[H+]+0.078[HNO3]RH60+0.0258PM10+β(BGC)R=3.95+0.0059[SO2]RH60+0.054Rain[H+]+0.078[HNO3]RH60+0.0258PM10+β(BGC)
Where: β (BGC) is the additional term accounting for biological growth coverage.
If biological growth increases surface recession linearly with coverage:
β(BGC)= k×BGC where, k is a constant that need to be determined based on experimental data or literature.

Modified Lipfert Model with Biological Growth
The original Lipfert model is:
L=18.8·R+0.016·[H+]·R+0.18·(VdS·[SO2]+VdN·[HNO3])
To incorporate biological growth, we add a term β(BGC):
L=18.8·R+0.016·[H+]·R+0.18·(VdS·[SO2]+VdN·[HNO3])+β(BGC)


Physcia adscendens, SA_S1_L3, 09.08.2024., photo S. Radulović


Bagliettoa marmorea, BL_X, 11.08.2024., photo S. Radulović


Protoparmeliopsis muralis, KR_S5_L1, 10.08.2024., photo S. Radulović


Xanthoria elegans, RV_X, 11.08.2024., photo N. Drešković


Squamarina gypsacea, SA_S2_L1, 09.08.2024., photo N. Drešković


Bryoplaca jungermanniae, BL_X1, 11.08.2024., photo N. Drešković


Xanthoria calcicola, RV_S10_L4, 11.08.2024., photo N. Drešković


Collema furfuraceum, KR_S6_L5, 10.08.2024., photo S. Radulović


Physcia caesia, RV_S10_L7, 11.08.2024., photo S. Radulović


Dermatocarpon miniatum, KO_S3_L1, 10.08.2024., photo S. Radulović


Lobothallia cheresina, RV_S10_L3, 11.08.2024., photo N. Drešković


Lepraria incana, KR_S6_L3, 10.08.2024., photo N. Drešković


Parmelia saxatilis (grey lichen), RV_S10_L1B, 11.08.2024., photo N. Drešković


Peltigera canina, KR_SX, 10.08.2024., photo S. Radulović