



O‘ZBEKISTONDA *RHEUM MAXIMOWICZII* NING EKOLOGIK NISHASI VA KELAJAKDAGI TARQALISHINI MAXENT MODELİ ASOSIDA BAHOLASH.

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Annotatsiya. *Rheum maximowiczii* Losinsk. Markaziy Osiyoda tarqalgan, dorivor va oziq-ovqat ahamiyatiga ega tog‘ o‘simligidir. Ushbu tadqiqotning maqsadi turning O‘zbekiston hududidagi hozirgi va kelajakdagi potensial tarqalishini MaxEnt modeli yordamida baholash hamda uning geografik tarqalishini belgilovchi asosiy ekologik omillarni aniqlashdan iborat. 1970-2000-yillar, kelajak prognozlar 2041–2060 va 2061–2080-yillar uchun RCP2.6 hamda RCP8.5 ssenariylarida bajarildi. Natijalarga ko‘ra, yillik yog‘in va eng sovuq chorakdagi yog‘in eng muhim omillar bo‘lib, harorat mavsumiyligi, balandlik, qiyalik va tuproq pH ham sezilarli ta‘sir ko‘rsatdi. 1970–2000-yillarda *Rheum maximowiczii* uchun eng qulay yashash muhiti 7 575,15 km² ni tashkil etdi. 2041–2060-yillarda bu ko‘rsatkich RCP2.6 da 7 544,28 km², RCP8.5 da 8 242,36 km², 2061–2080-yillarda esa mos ravishda 8 275,94 va 8 447,81 km² ni tashkil etdi. Ushbu natijalar *R. maximowiczii* ning tabiiy populyatsiyalarini saqlash, ularning holatini muntazam kuzatib borish hamda turning rivojlanishi uchun eng maqbul ekologik hududlarni belgilashda ilmiy asos sifatida qo‘llanilishi mumkin.

Kalit so‘zlar: Rovoch, *Rheum maximowiczii*, MaxEnt, potensial tarqalish, ekologik omillar.

Kirish. Rovoch dunyoning turli hududlarida qadimdan dorivor ahamiyatga ega bo‘lgan mashhur ko‘p yillik o‘simliklardan biri hisoblanadi. Rovoch O‘rta Osiyo mamlakatlarida, Eron, Xitoy, Turkiya va boshqa davlatlarda xalq tabobatida qimmatli dori mahsuloti hisoblanadi (Tabin et al. 2016; Xiang et al., 2020; Yang et al., 2024; He et al., 2024; Aitzhan et al. 2024). Uning ildizpoyalaridan xalq tabobatida qadimdan qabziyat, ovqat hazm qilish tizimi buzilishlari, ichak faoliyatining sustlashuvi va ayrim yallig‘lanish

kasalliklarini davolashda turli dorivor preparatlar tayyorlashda foydalanib kelingan (Mohtashami et al., 2021; Rakhmataliev et al., 2025). O‘rta Osiyo mamlakatlarida sersuv barg bandlari bahorda iste‘mol qilinadi. *Rheum* turlarining dorivor xususiyatlari, asosan, ularning ildizpoyasi va ildizlarida to‘planadigan biologik faol birikmalar, xususan, antraxinon hosilalari bilan bog‘liq (Wang et al., 2026). Shu sababli rovoch turlarining dorivor va oziq-ovqat mahsuloti sifatida iste‘mol qilinishiga talab yildan-yilga oshib bormoqda (Rakhmataliev et al., 2026a). Dunyo bo‘ylab global isish (Freeman et al., 2026; Murali et al., 2026), aholi soni ortib borishi bilan oziq-ovqat va dori mahsulotlariga ehtiyojning ortib borishi turli dorivor va ozuqabob turlarning tarqalishiga abiotik va antropogen ta‘sirni kuchaytirmoqda (Mykhailenko et al., 2025; Scholz & Scholz, 2026; Latif & Nawaz, 2026).

O‘rta Osiyoda kovrak (*Ferula* L.) turkumiga oid ayrim turlar yuqoridagi holatlarni yaqin o‘tmishda boshdan kechirdi (Sharipov et al., 2025; Makhmudov et al., 2025). O‘rta Osiyoda keng tarqalgan *Rheum maximowiczii* Losinsk. turi ham kovrak kabi nafaqat dorivor balki oziq-ovqat sifatida qadrlanadi. *Rheum maximowiczii* rovoch turkumiga mansub, O‘zbekiston florasida asosan tog‘larda keng tarqalgan tur hisoblanadi (He et al., 2024; Rakhmataliev et al., 2026b). Ushbu turning tabiiy tarqalishi va ekologik talablarini o‘rganish turning dorivor resurslarini muhofaza qilish va barqaror foydalanishda muhim ahamiyatga ega. O‘simlik turlarining tarqalishini belgilovchi ekologik omillarni aniqlash ularning ekologik talablarini tushunish, potensial yashash muhitlarini baholash va samarali muhofaza strategiyalarini ishlab chiqishda muhim ahamiyatga ega (Özkan Tümer et al., 2026).

So‘nggi yillarda kompyuter texnologiyalarining jadal rivojlanishi ekologik, biologik va boshqa ilmiy tadqiqot yo‘nalishlarida zamonaviy yondashuv hamda usullardan foydalanish imkoniyatlarini sezilarli darajada kengaytirdi (Klaassen et al., 2026). Turning tarqalish nuqtalariga tegishli geografik koordinatalar hamda ekologik omillar asosida MaxEnt dasturi yordamida turning hozirgi va kelajakdagi potensial tarqalish areallarini modellashtirish va prognoz qilish mumkin (Xu et al., 2022). Bunda tadqiqot uchun turli iqlim ssenariylari (1970–2080-yillar), tuproq va topografik omillar hamda boshqa muhim bioiqlim o‘zgaruvchi omillardan foydalaniladi. Natijada, turning ekologik jihatdan qulay potensial tarqalish hududlarining maydonini (km²) aniqlash, shuningdek, turning geografik tarqalishini belgilovchi asosiy iqlimiy va topografik omillarning nisbiy ahamiyatini baholash hamda ularning kelajakdagi ta‘sirini prognoz qilish imkoniyati yaratiladi (Wang et al., 2024). Aniqlangan ekologik jihatdan qulay hududlar kelgusida kamyob va dorivor o‘simlik turlarini saqlash, tabiiy populyatsiyalarini muhofaza qilish, shuningdek, zarur hollarda ularni introduksiya qilish va qayta tiklash tadbirlarini rejalashtirish uchun ilmiy asos bo‘lib xizmat qilishi mumkin (Tojibaev et al., 2019; Volis & Beshko, 2023).

Ushbu tadqiqotning maqsadi *Rheum maximowiczii* turining geografik tarqalish koordinatalari hamda ekologik omillar asosida MaxEnt dasturi yordamida turning hozirgi va kelajakdagi potensial tarqalish hududlarini modellashtirish va prognoz qilish, shuningdek, uning geografik tarqalishini belgilovchi iqlimiy, tuproq va topografik omillarning nisbiy ahamiyatini aniqlashdan iborat.

Material va Metodlar. Tadqiqot hududi asosan O‘zbekiston tog‘li hududlarini qamrab oladi. Biroq, *Rheum maximowiczii* O‘rta Osiyoning tog‘li hududlarida keng

tarqalganligi sababli (He et al., 2024), MaxEnt modelini yaratishda turning O‘rta Osiyo bo‘ylab mavjud tarqalish qaydlari hisobga olindi (1-rasm). Bu yondashuv turning ekologik talablarini uning tabiiy geografik tarqalish areali doirasida baholash imkonini beradi (Phillips et al., 2006; Amaro et al., 2023). Turning geografik GPS koordinatalarini yig‘ishda Toshkent gerbariy fondida saqlanayotgan gerbariy namunalari, shuningdek, Global biologik xilmaxillik axborot tizimi (Global Biodiversity Information Facility - GBIF), Plantarium.ru va iNaturalist onlayn platformalaridagi ma’lumotlardan foydalanildi. Bundan tashqari 2024-2026 yillar davomida dala tadqiqotlari olib borildi va umumiy hisobda 139 ta tarqalish geografik GPS koordinatalari to‘plandi.

Rheum maximowiczii turining tarqalishiga ta’sir qiluvchi omillarni baholash uchun jami 43 ta ekologik o‘zgaruvchi omillar tanlandi. Ular 19 ta bioiqlimiy o‘zgaruvchi omillar, 13 ta topografik omillar (balandlik, qiyaliklar 8 ta, yonbag‘irlar 4 ta) va 11 ta tuproq omilidan iborat edi (2-rasm). Bioiqlimiy ma’lumotlar WorldClim ma’lumotlar bazasidan olindi (<https://worldclim.org>). Tarixiy iqlim sharoitini ifodalash uchun 1970–2000-yillar oralig‘idagi ma’lumotlardan foydalanildi. Kelajakdagi iqlim sharoitlarini baholash uchun esa CMIP5 (Coupled Model Intercomparison Project Phase 5) asosidagi ma’lumotlardan olindi. Tahlil va modellashtirish uchun 2041–2060 (2050-yillar) va 2061–2080 (2070-yillar) davrlaridagi mavjud to‘rtta Representative Concentration Pathways (RCP2.6, RCP4.5, RCP6.0 va RCP8.5) orasidan RCP2.6 va RCP8.5 ssenariylari tanlandi (Volis & Beshko, 2023). Buning sababi shundaki, ushbu ikki ssenariy 2100-yilga kelib, 1986–2005-yillardagi bazaviy CO₂ konsentratsiyasiga nisbatan eng past (RCP2.6) va eng yuqori CO₂ konsentratsiyasini (RCP8.5) nazarda tutadi. Shu sababli, ular kelajakdagi iqlim o‘zgarishining mos ravishda eng kam va eng keskin (ekstremal) variantlarini ifodalaydi (Tojibaev et al., 2019). Tuproq omillari Harmonized World Soil Database (HWSD) ma’lumotlar bazasidan yuklab olindi. Barcha ekologik raster qatlamlari MaxEnt modelida bir-biriga mos bo‘lishini ta’minlash maqsadida bir xil fazoviy rezolyutsiya (30 arc-second), geografik koordinata tizimi, geografik qamrov va raster kataklari o‘lchamiga R version 4.5.1 programmasida keltirildi.

Ekologik o‘zgaruvchilar o‘rtasidagi yuqori korrelyatsiyani kamaytirish, bu esa overfittingga olib kelishi mumkinligi sababli (Sillero, 2011), R version 4.5.1 programmasida ekologik o‘zgaruvchi omillar uchun ularning o‘zaro korrelyatsiyasi R version 4.5.1 dasturi yordamida tahlil qilindi (2-rasm). Pearson korrelyatsiya koeffitsienti uchun 0,8 chegaraviy qiymat qabul qilindi (Santana et al., 2019; Cai et al., 2026) va korrelyatsiyasi 0,8 dan yuqori bo‘lgan ekologik omillar yuqori korrelyatsiyalangan deb hisoblandi va model ishga tushirishda yuqori korrelyatsiyalangan ekologik omillar ishlatilmadi. Ushbu saralash jarayonidan so‘ng, turning tarqalish modelini (Species Distribution Model — SDM) yaratish uchun jami 29 ta ekologik omillar saqlab qolindi (1-jadval).

Rheum maximowiczii turining tarqalishi bo‘yicha qayd etilgan ma’lumotlari va saralangan ekologik o‘zgaruvchi omillari MaxEnt modeliga kiritilib, turning yashash uchun qulay hududlari modellashtirildi. Ushbu tadqiqotda joylashuv ma’lumotlarining 75% qismi modelni o‘qitish (training) uchun, qolgan 25% qismi esa test qilish (testing) uchun ishlatildi.

Bootstrap jarayoni 10 marta takrorlandi (Phillips va boshq., 2017). Model aniqligini oshirish maqsadida iteratsiyalar soni 10 000 etib belgilandi (Lu va boshq., 2024).



1-rasm. MaxEnt modellashtirishda foydalanilgan *Rheum maximowiczii* turining geografik qayd nuqtalari.

ROC egri chizig‘i turlarning potensial tarqalishini bashorat qilish modellarini baholash uchun keng qo‘llaniladi, bunda egri chiziq ostidagi maydon (AUC) 0 dan 1 gacha bo‘ladi. AUC qiymatining yuqoriroq bo‘lishi model tomonidan bashorat qilingan turning tarqalishi va ekologik omillari o‘rtasidagi kuchliroq bog‘liqlikni ko‘rsatadi va bashorat qilish samaradorligining yaxshiroq ekanligini bildiradi. AUC bilan tavsiflanadigan aniqlik quyidagicha tasniflanadi: 0,50–0,60 (yaroqsiz), 0,60–0,70 (past), 0,70–0,80 (qoniqarli), 0,80–0,90 (yaxshi) va 0,90–1,00 (a‘lo) (Hanley va McNeil, 1982). MaxEnt modeli natijalari formatni o‘zgartirish va qayta tasniflash uchun ArcGIS 10.8 dasturiga import qilindi. Nisbiy moslik darajalaridagi farqlarni vizual tarzda ko‘rsatish va ekologik talqinni osonlashtirish maqsadida tur o‘sishi uchun hududning qulaylik qiymatlari ArcGIS 10.8 dasturidagi Jenks tabiiy uzilishlar (Jenks natural breaks) algoritmi yordamida to‘rtta sinfga ajratildi: noqulay, past qulaylik, o‘rtacha qulaylik, eng qulay hududlar (Chen et al., 2013; Cai et al., 2026).

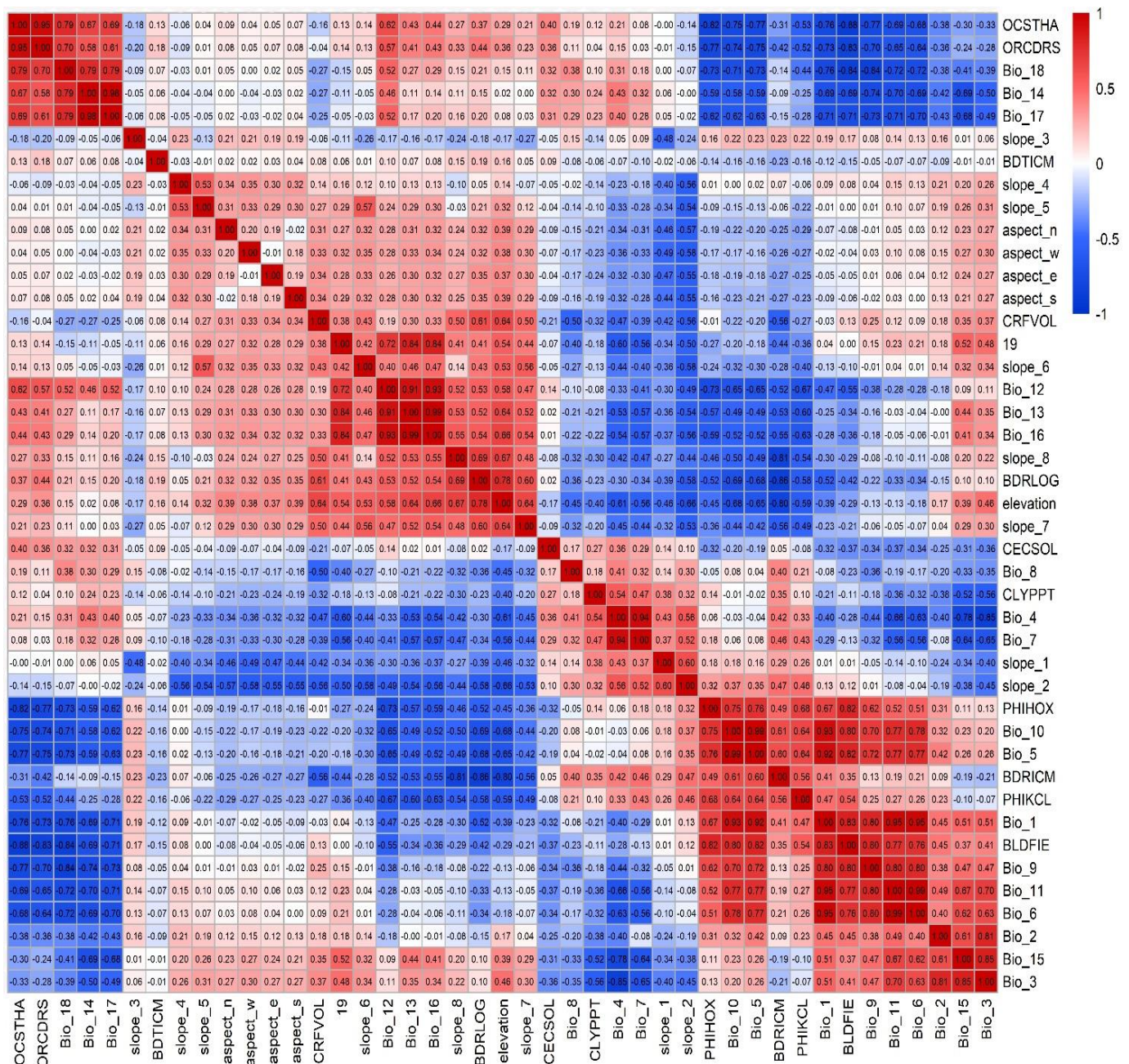
1-jadval. MaxEnt modellarida ekologik o‘zgaruvchi omillarning hisssasi va har bir model bashoratiga ta’sir darajasi

Ekologik o‘zgaruvchi omillar kodi	Ekologik o‘zgaruvchi omillar tavsifi	Percent contribution (%)*	Permutation importance (%)**
slope_7	$30 \% \leq \text{qiyalik} \leq 45 \%$	39.3	3.5
slope_8	$\text{qiyalik} > 45 \%$	10.2	7.6
Bio_14	Eng qurg‘oqchillik oyidagi yog‘ingarchilik miqdori	8.1	2
Bio_19	Eng sovuq chorakdagi yog‘ingarchilik	6.8	46.3

	miqdori		
Bio_9	Eng quruq chorakning o‘rtacha harorati	6.4	2.8
Elevation	Balandlik	5.2	6.9
Bio_15	Yog‘ingarchilikning mavsumiyligi	4.3	6.5
slope_2	$0.5 \% \leq \text{qiyalik} \leq 2 \%$	3.8	0.1
Bio_2	O‘rtacha kunlik harorat amplitudasi	2.2	0.8
PHIHOX	Suvdagi tuproq pH qiymati	2.2	1.4
Bio_12	Yillik yog‘ingarchilik miqdori	2.1	5.4
CLYPPT	Loy (gil) miqdori	2	0.4
PHIKCL	KCl dagi tuproq pH qiymati	1.2	0.1
Bio_4	Haroratning mavsumiyligi	0.9	0.8
CECSOL	Tuproqning kation almashinish sig‘imi	0.8	0.3
Bio_8	Eng nam chorakning o‘rtacha harorati	0.8	0.8
slope_6	$15 \% \leq \text{qiyalik} \leq 30 \%$	0.7	3.5
slope_1	$0 \% \leq \text{qiyalik} \leq 0.5 \%$	0.5	0
CRFVOL	Tuproqdagi qattiq, yirik bo‘laklar hajmi	0.5	0.4
slope_3	$2 \% \leq \text{qiyalik} \leq 5 \%$	0.4	4.8
aspect_w	G‘arb: $225^\circ < \text{aspect} \leq 315^\circ$	0.3	0.6
aspect_n	Shimol: $0^\circ < \text{aspect} \leq 45^\circ$ or $315^\circ < \text{aspect} \leq 360^\circ$	0.3	0.8
Bio_6	Eng sovuq oyning minimal harorati	0.2	0.9
aspect_s	Janub: $135^\circ < \text{aspect} \leq 225^\circ$	0.2	0.6
slope_4	$5\% \leq \text{qiyalik} \leq 10 \%$	0.2	0.9
aspect_e	Sharq: $45^\circ < \text{aspect} \leq 135^\circ$	0.2	0.4
slope_5	$10 \% \leq \text{qiyalik} \leq 15 \%$	0.1	0.4
ORCDRS	Tuproqdagi organik uglerod miqdori	0.1	0.9
BDTICM		0.1	0.3

* Percent contribution - PC (%) - Model ishlashidagi ekologik o‘zgaruvchi omillarning hissa qo‘shishi.

** Permutation importance - PI (%) - Model ishlashidagi ekologik o‘zgaruvchini tasodifiy o‘zgartirganda model AUC bashorat ko‘rsatkichiga ta'sir ahamiyati.

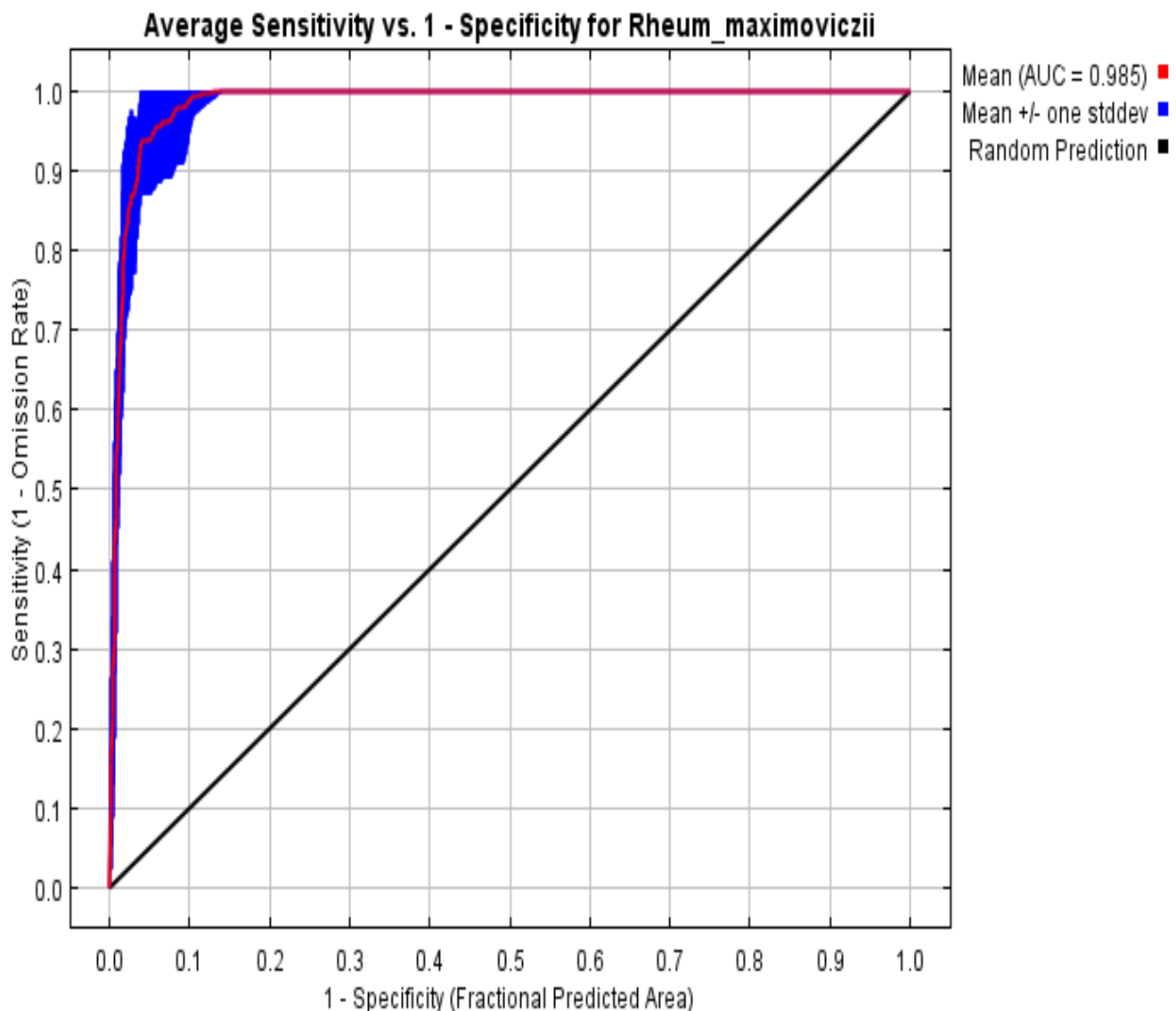


2-rasm. Ekologik o‘zgaruvchi omillari o‘rtasidagi Pearson korrelyatsiya matritsasi ($|r| \geq 0,8$). Bio_1 - 19 bioiklimiy o‘zgaruvchi omillar. Aspect - ekspozitsiya (yonbag‘ir yo‘nalishlari); Elevation - balandlik; Slope - qiyalik; Qolgan barcha qisqartmalar tuproq omillari. Rangning to‘yinganligi korrelyatsiya koeffitsiyentlariga mutanosib ravishda ifodalangan.

Natija va Muhokamalar

MaxEnt modelining bashorat qilish samaradorligi ROC egri chizig‘i va AUC qiymati asosida baholandi (3-rasm). ROC egri chizig‘ining tasodifiy bashoratni ifodalovchi diagonal chiziqdan yuqorida joylashishi model turning mavjudligi qayd etilgan nuqtalarni (presence) va mavjudlik qayd etilmagan (background) nuqtalaridan yaxshi ajrata olishini ko‘rsatadi. AUC qiymatining yuqori bo‘lishi esa modelning *Rheum maximowiczii* uchun qulay va nisbatan noqulay ekologik sharoitlarni farqlash qobiliyati yuqori ekanligini bildiradi. Shunga ko‘ra, olingan ROC–AUC natijalari model tomonidan *R. maximowiczii* ning potensial tarqalish hududlarini bashorat qilishda yaxshi farqlash qobiliyati mavjudligini ko‘rsatadi (3-rasm).

Ushbu natija 2026-yilda e‘lon qilingan tadqiqotlar bilan ham mos keladi. Masalan, *Xylobolus subpileatus* uchun MaxEnt modelida training AUC 0.957–0.963, test AUC esa 0.948–0.956 oralig‘ida bo‘lib, mualliflar yuqori AUC qiymatlarini modelning kuchli bashorat qobiliyati va barqarorligi bilan bog‘laganlar. Shuningdek, 2026-yilda kauchuk yetishtirish uchun turning o‘ishi uchun muhitning mosligini baholashda MaxEnt modeli $AUC = 0.973$ ko‘rsatib, boshqa SDM usullariga nisbatan yuqori aniqlik va boshqa hududga yoki boshqa ekologik sharoitga qo‘llanganda ham yaxshi bashorat qila olishi qobiliyatini namoyon qilgan. Bu natijalar yuqori AUC qiymati turning potensial yashash muhitlarini modellashtirishda modelning yaxshi ajratish va bashorat qilish qobiliyatini ko‘rsatishi mumkinligini tasdiqlaydi.



3-rasm. Receiver operating characteristic (ROC) egri chizig‘i va AUC. AUC. ROC egri chizig‘i ostidagi maydon bo‘lib, MaxEnt modeli mavjudlik (presence) va mavjudlik qayd etilmagan (background) nuqtalarini qanchalik yaxshi ajrata olish ko‘rsatkichini ifodalaydi.

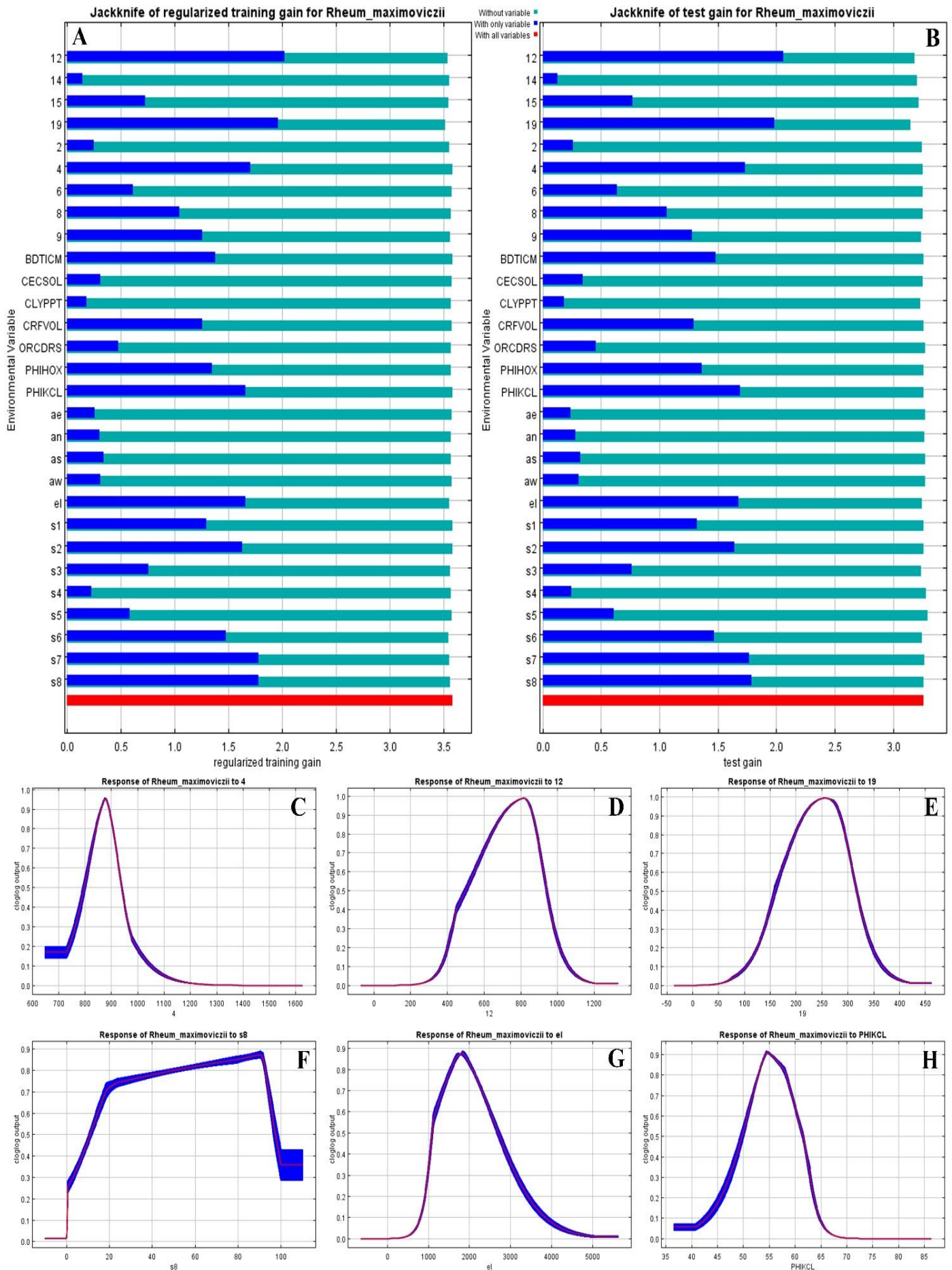
Jackknife natijalariga ko‘ra, Bio_12 (yillik yog‘in miqdori) va Bio_19 (eng sovuq chorakdagi yog‘in miqdori) eng muhim bioklimatik omillar bo‘lib, ular yakka holda ham yuqori qiymatlarini hosil qilgan. Shuningdek, Bio_4 (Haroratning mavsumiyliigi), Slope_8 (qiyalik darajasi), elevation (balandlik) va PHIKCL (KCl dagi tuproq pH qiymati) ham

turning tarqalishini tushuntirishda muhim rol o‘ynagan (4-rasm). Bu natijalar *R. maximowiczii* ekologik nishasining shakllanishida, avvalo, namlik rejimi, shuningdek harorat mavsumiyligi, relyef va tuproq xususiyatlari muhim ekanligini ko‘rsatadi.

Bio_4 (harorat mavsumiyligi) bo‘yicha turning eng yuqori ekologik mosligi 850–900 indeks qiymatlarida, ya’ni haroratning standart og‘ishi taxminan 8.5–9.0 °C bo‘lgan sharoitlarda kuzatildi (4-rasm C). Bu *R. maximowiczii* ning harorat mavsumiyligi nisbatan yuqori bo‘lgan kontinental tog‘ sharoitlariga moslashganligini ko‘rsatadi. Bio_12 (yillik yog‘ingarchilik miqdori) bo‘yicha eng yuqori ekologik muhit mosligi yillik yog‘ingarchilik miqdori taxminan 800–900 mm bo‘lgan sharoitlarda kuzatildi (4-rasm D). Bu turning yillik yog‘in miqdori nisbatan yuqori bo‘lgan namroq tog‘ sharoitlariga moyilligini ko‘rsatadi. Bio_19 (eng sovuq chorakdagi yog‘ingarchilik miqdori) bo‘yicha eng yuqori ekologik moslik taxminan 220–280 mm oralig‘ida kuzatildi (4-rasm E). Bu natija *R. maximowiczii* tarqalishida nafaqat yillik yog‘ingarchilik miqdori, balki sovuq mavsumdagi yog‘in rejimi ham muhim ekologik omil ekanligini ko‘rsatadi. Boshqa *Rheum* turlarida ham yog‘in va harorat ko‘rsatkichlari muhim ekologik prediktorlar sifatida qayd etilga (Wani et al., 2021; Xu et al., 2022; Paudel et al., 2025).

Topografik omillar orasida elevation muhim ahamiyatga ega bo‘ldi. Umuman olganda, tur uchun o‘rish muhiti 1000-3000 m balandlik oralig‘ida bo‘lib, tur uchun eng yuqori hudud mosligi taxminan 1700–2000 m balandliklarni ko‘rsatgan (4-rasm G). Avvalgi tadqiqotimizda *Rheum* turlarining balandlik bo‘yicha tarqalishi tahlil qilinib, turkum vakillarining eng yuqori tur boyligi dengiz sathidan taxminan 1500–2000 m balandlik oralig‘ida kuzatilishi aniqlangan edi (Rakhmataliev et al., 2026b). Bu holat *R. maximowiczii* ning asosan o‘rta tog‘ mintaqalari, o‘tloqli va shag‘alli yonbag‘irlar bilan bog‘liqligi haqidagi floristik ma’lumotlarga mos keladi (Aitzhan et al., 2024).

Qiyalik - Slope_8 bo‘yicha ham turning nishabli va yaxshi drenajlangan tog‘ hududlariga moyilligi kuzatildi. Qiyalik qiymati oshishi bilan yashash muhiti qulayligi dastlab keskin ortib, taxminan 20 dan yuqori qiymatlarda yuqori darajaga yetdi. Qulaylik 20–90 oralig‘ida nisbatan yuqori bo‘lib, taxminan 80–90 atrofida maksimal darajaga yetdi. Biroq qiyalik qiymati 90 dan oshgach, turning potensial yashash muhiti qulayligi keskin pasaydi. Bu holat *R. maximowiczii* ning o‘rtacha va nisbatan yuqori qiyalikdagi hududlarga ko‘proq moslashganligini, ekstremal qiyalik sharoitlari esa uning tarqalishini cheklashi mumkinligini ko‘rsatadi (4-rasm F).



4-rasm. *Rheum maximowiczii* turining ekologik o‘zgaruvchilari bo‘yicha training (A) va test (B) gain qiymatlarining Jackknife tahlili: Bio_4 (C), Bio_12 (D), Bio_19 (E), Slope_8 (F), Elevation (G) va PHIKCL (H).

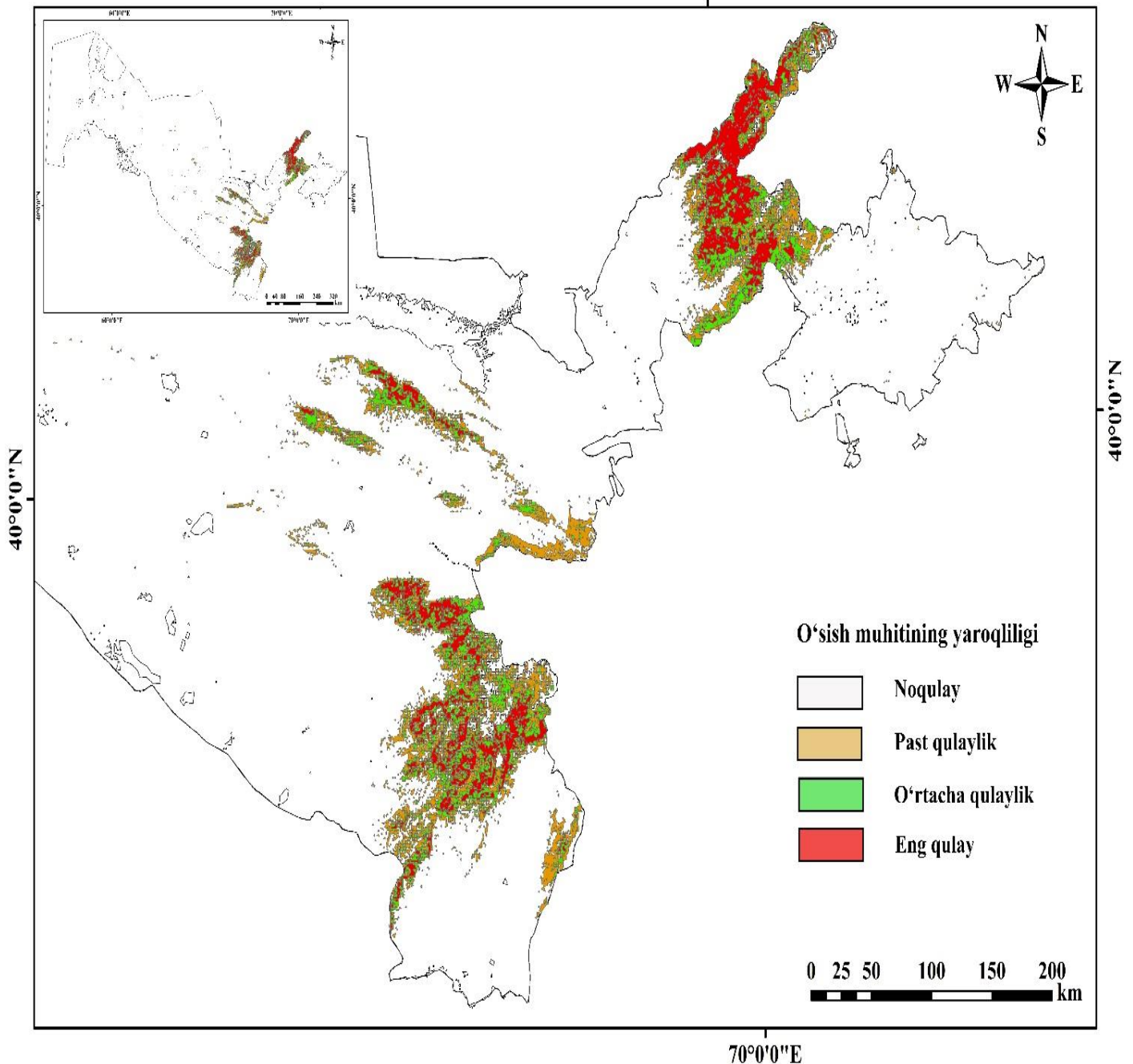
PHIKCL ning muhimligi esa tuproq reaksiyasi ham turning potensial tarqalishini cheklovchi omillardan biri ekanligini ko‘rsatadi. *Rheum maximowiczii* ning KCl eritmasida o‘lchangan tuproq pH ko‘rsatkichiga (PHIKCL) javob egri chizig‘i bitta aniq optimal diapazonni namoyon etdi (4-rasm H). PHIKCL qatlamidagi qiymatlar $\text{pH} \times 10$ ko‘rinishida ifodalanganligi sababli, grafikdagi 40, 50 va 60 qiymatlari mos ravishda pH 4,0; 5,0 va 6,0 ga to‘g‘ri keladi (Buzatti et al., 2019). Umuman olganda, turning yashash muhiti uchun nisbatan yuqori qulaylik PHIKCL qiymatining taxminan 45–63 ($\text{pH} \approx 4,5\text{--}6,3$) oralig‘ida kuzatildi. Yashash muhiti qulayligi PHIKCL qiymati 45–50 dan boshlab keskin ortib, 55 atrofida ($\text{pH} \approx 5,5$) maksimal darajaga yetdi. Shundan so‘ng qulaylik asta-sekin pasayib, 65 dan yuqori ($\text{pH} > 6,5$) qiymatlarda juda past darajaga tushdi. Ushbu natija *R. maximowiczii* ning nisbatan kislotali tuproq sharoitlarini afzal ko‘rishini ko‘rsatadi.

Umuman, MaxEnt Jackknife va response curve natijalari *R. maximowiczii* tarqalishini belgilashda yillik yog‘in, sovuq mavsumdagi yog‘in, harorat mavsumiyligi, balandlik, qiyalik va tuproq pH ko‘rsatkichlari asosiy ekologik omillar ekanligini ko‘rsatdi. Ayniqsa, Bio_12 va Bio_19 ning yuqori qiymatlari turning tarqalishida suv bilan ta‘minlanish rejimi yetakchi ekologik cheklovchi ekanligini ko‘rsatadi. Biroq ekologik omillar javob egri chizig‘idagi optimum qiymatlar turning mutlaq ekologik chegaralari emas, balki model doirasidagi eng mos sharoitlarni ifodalaydi (Merow et al., 2013).

1970–2000-yillardagi iqlim sharoitida *Rheum maximowiczii* uchun potensial yashash muhitlarining fazoviy taqsimoti hudud bo‘yicha keskin bir xil emasligi aniqlandi. MaxEnt model natija qismida olingan fayl asosida tur o‘shishi uchun noqulay, past qulaylik, o‘rtacha qulaylik, eng qulay muhitlar rangli ko‘rinishda farqlangan xaritasi shakllantirildi (5,6-rasmlar). Model natijalariga ko‘ra, turning eng qulay va o‘rtacha qulay yashash muhitlari, asosan, O‘zbekistonning Toshkent, Namangan, Jizzax, Samarqand, Qashqadaryo va Surxondaryo viloyatlarining tog‘li hududlarga to‘g‘ri kelgan (5-rasm). Bu holat turning tabiiy ekologik xususiyatlariga mos keladi chunki *R. maximowiczii* Markaziy Osiyoda, jumladan O‘zbekiston, Qirg‘iziston, Tojikiston va Qozog‘istonning tog‘li hududlarida ko‘p yillik dorivor o‘simlik sifatida tarqalganligi tadqiqotlarda yoritilgan (He et al., 2024; Aitzhan et al., 2024; Rakhmataliev et al., 2026b). Plants of the World Online (POWO - <https://powo.science.kew.org>) ma‘lumotlarida ham uning tabiiy areali Markaziy Osiyodan Afg‘onistonning shimoli-sharqiy hududlarigacha cho‘zilganligi ko‘rinadi (ko‘rilgan: 12.09.2026).

1970–2000-yillar davrida *R. maximowiczii* uchun noqulay hududlarning umumiy maydoni 403 613,7 km² ni tashkil etgan bo‘lsa, past qulaylikdagi yashash muhitlari 9 441,14 km², o‘rtacha qulay hududlar 7 597,17 km² va eng qulay yashash muhitlari 7 575,15 km² ni tashkil etdi (2-jadval). Bu qulay muhit ko‘rsatkichlari umumiy o‘rganilgan hududning nisbatan kichik qismini egallashi turning o‘shishi uchun mos ekologik sharoitlari, avvalo, tog‘ landshaftlari bilan cheklanganligini ko‘rsatadi.

70°0'0"E



5-rasm. 1970–2000-yillar davrida *Rheum maximowiczii* ning qulay yashash muhitlari xaritalari.

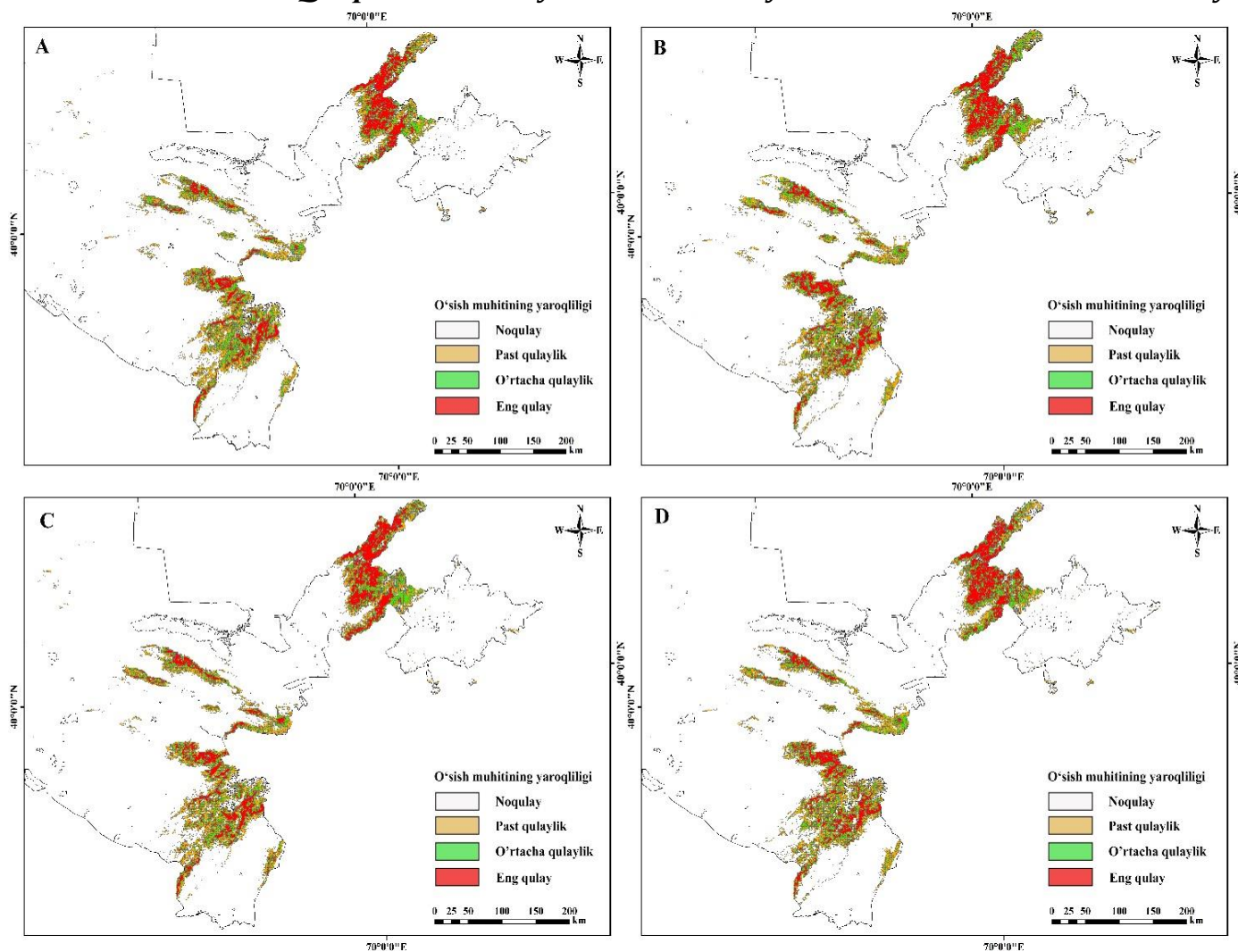
Kelajak iqlim ssenariylari ostida yashash muhiti maydonlarining o'zgarishi bir yo'nalishli qisqarish shaklida emas, balki qulaylik sinflari o'rtasidagi **fazoviy qayta taqsimlanish** sifatida namoyon bo'ldi (6-rasm). 2050-yillar uchun RCP2.6 ssenariysida noqulay hudud maydoni 403 309,7 km², past qulay muhit 9 924,92 km² tashkil etdi va o'rtacha qulay muhit 7427.468 km², eng qulay muhit 7544.278 km² gacha ortadi. 2050-yillardagi RCP8.5 ssenariysi boshqacha yo'nalishlarni ko'rsatdi. Ushbu sharoitda noqulay hudud maydoni 402 659.3 km², past qulay muhit 9236.046 km² tashkil etdi va o'rtacha qulay muhit 8087.115 km², eng qulay muhit 8242.355 km² gacha ortadi (2-jadval).

2070-yillarga kelib RCP2.6 ssenariysida noqulay hudud maydoni 403 041.8 km², past qulay muhit 9 595.366 km² ni tashkil etdi, o'rtacha qulay muhit 7 299.235 km², eng qulay muhit esa 8 275.935 km² ni tashkil etdi. 2070-yillarga kelib RCP8.5 ssenariysida noqulay hudud maydoni 402 700.5 km², past qulay muhit 9 224.981 km² ni tashkil etdi, o'rtacha

qulay muhit 7 853.09 km², eng qulay muhit esa 8 447.813 km² ni tashkil etdi. Bunday natija boshqa tog‘ va dorivor o‘simliklar uchun o‘tkazilgan modellashtirish tadqiqotlariga ham muvofiq keladi. Masalan, Yang va boshqalar (2024) tomonidan 12 ta xavf ostidagi dorivor o‘simlikning 2050- va 2070-yillardagi tarqalishini MaxEnt modeli yordamida baholab, iqlim o‘zgarishiga javob turlar kesimida keskin farq qilishini aniqlagan: ayrim turlarda qulay areal qisqargan bo‘lsa, boshqalarida uning kengayishi prognoz qilingan. Mualliflar o‘rgangan turlarning 33,3 % ida kelajakda qulay yashash maydonining ortishi mumkinligini ko‘rsatgan. Bu holat *R. maximowiczii* uchun aniqlangan nisbatan kichik umumiy kengayish bilan birga, yuqori qulaylik muhitining ayrim ssenariylarda sezilarli ko‘payishini ekologik jihatdan izohlaydi.

Shunga o‘xshash tendensiya janubi-g‘arbiy va Markaziy Osiyoda tarqalgan dorivor tog‘ o‘simligi *Nepeta glomerulosa* uchun ham aniqlangan. Karami va boshqalar (2022) tomonidan MaxEnt modellashtirish natijasida kelajakdagi iqlim sharoitida turning umumiy qulay areali kengayishi mumkinligini ko‘rsatgan, biroq o‘zgarish darajasi va yo‘nalishi hududlar bo‘yicha farqlanishini ta’kidlagan. Demak, iqlim isishi tog‘ o‘simliklari uchun har doim ham qulay arealning to‘liq qisqarishini anglatmaydi, aksincha, mavjud ekologik optimum, topografik, yog‘in rejimi va turning iqlimga moslashuv diapazoniga qarab yangi qulay maydonlar shakllanishi ham mumkin (Graae et al., 2018). Bu holatning yaqqol misoli sifatida, bir nechta turlar tarqalishi modellaridan foydalangan holda *Rheum nobile* Hook.f. & Thomson va *Rheum alexandrae* Batalin turlarining tarixiy, hozirgi hamda kelajakdagi potensial tarqalish dinamikasi baholangan (Rana et al., 2022). Shuningdek, *R. maximowiczii* uchun MaxEnt modeli tomonidan eng yuqori qulaylikka ega deb baholangan hududlar dala tadqiqotlari olib borildi va natijalar bilan ham mos keldi. Xususan, model xaritalarida yuqori suitability qiymatlari bilan, ya’ni qizil rangda ajratilgan hududlarda turning tabiiy populyatsiyalari eng ko‘p va nisbatan zich uchrashi kuzatildi. Bu holat modelning *R. maximowiczii* ning real ekologik afzalliklarini qoniqarli darajada aks ettirayotganini hamda “eng qulay” deb tasniflangan hududlar biologik jihatdan mazmunli ekanini ko‘rsatadi. Biroq bu yuqori emissiyali ssenariy turning umumiy ekologik holati uchun foydali bo‘ladi degan xulosani bermaydi chunki turning ushbu hududlarni amalda egallashi urug‘ tarqalishi, migratsiya tezligi, tuproq xususiyatlari, yaylov bosimi, antropogen va biotik munosabatlarga ham bog‘liq (Guisan & Thuiller, 2005; Soberón & Peterson, 2005; Merow et al., 2013; Anderson, 2013).

Yang va boshqalar (2024) ham tur tarqalishi modellarida uchrash nuqtalari va ekologik o‘zgaruvchilar asosida nisbiy o‘sish muhit qulayligi hisoblanishini ta’kidlaydi. Shu sababli 6-rasmda yangi qizil yoki yashil zonalarning paydo bo‘lishi u yerlarda kelajakda *R. maximowiczii* populyatsiyalari shakllanishini anglatmaydi lekin tur arealini kengaytirish uchun ko‘chirib o‘tqazish, ildizpoyalarini ekish, urug‘larini ekish uchun qulay muhit mavjud bo‘lishini aks ettiradi (Tojibaev et al., 2019; Volis & Beshko, 2023).



6-rasm. Kelajak davrlarida, 2050-yillar va 2070-yillarda, qulay yashash muhitlari xaritalari: (A) 2041–2060-yillar, RCP2.6; (B) 2041–2060-yillar, RCP8.5; (C) 2061–2080-yillar, RCP2.6; (D) 2061–2080-yillar, RCP8.5.

2-jadval. Turli davrlarda *Rheum maximowiczii* uchun qulay yashash muhitlari maydoni (km²).

Muhit qulayligi	1970-2000	2041-2060		2061-2080	
		RCP2.6	RCP8.5	RCP2.6	RCP8.5
Noqulay	403613.7	403309.7	402659.3	403041.8	402700.5
Past qulaylik	9441.137	9924.92	9236.046	9595.366	9224.981
O‘rtacha qulaylik	7597.167	7427.468	8087.115	7299.235	7853.09
Eng qulaylik	7575.147	7544.278	8242.355	8275.935	8447.813

Xulosa. Ushbu tadqiqot *Rheum maximowiczii* ning O‘zbekiston hududidagi potensial tarqalishi va ekologik talablarini baholashda MaxEnt modelining samarali ekanligini ko‘rsatdi. Turning tarqalishini belgilovchi asosiy omillar sifatida yillik yog‘in miqdori va eng sovuq chorakdagi yog‘in miqdori ajralib chiqdi, shuningdek harorat mavsumiyligi, balandlik, qiyalik va tuproq pH ko‘rsatkichi ham muhim ahamiyat kasb etdi. Hozirgi iqlim sharoitida eng qulay yashash hududlari asosan O‘zbekistonning tog‘li mintaqalarida shakllangan bo‘lib, dala kuzatuvlari ham model tomonidan yuqori qulaylikka ega deb baholangan hududlarda turning ko‘p va zich uchrashini tasdiqladi. Olingan natijalar *R. maximowiczii* ning tabiiy

populyatsiyalarini muhofaza qilish, monitoring qilish va tur o‘shishi uchun qulay muhitga ega hududlarni aniqlashda ilmiy asos bo‘lib xizmat qilishi mumkin.

Moliyalashtirish: Ushbu tadqiqot O‘zbekiston Respublikasi Fanlar akademiyasi Botanika instituti tomonidan 2025–2029-yillarda amalga oshirilayotgan “Raqamli tabiat: Markaziy O‘zbekiston florasi uchun raqamli platformani ishlab chiqish” davlat dasturi doirasida hamda "Xitoy-O‘zbekiston hamkorligi doirasida *Rheum* turlarida biologik faol moddalarni sintez qiluvchi asosiy biosintetik genlarni aniqlash va ularning samaradorligi hamda toksikligini baholash" (AL-10525067259) loyihasi doirasida moliyalashtirildi.

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