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The Neolithic (c. 6200–4900 BC) in the Struma River Valley: Characterizing Change to the Human Ecological Niche from Species Distribution Models

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ABSTRACT

During the Neolithic Period (c. 6200–4900 BC) of the Struma River Valley, early agricultural populations progressively settled in the region until reaching a maximum occupation in the Late Neolithic. The ecological characteristics of the Struma River Valley are particularly heterogeneous along its north-south gradient and also vertically along the valley slopes, suggesting that early agricultural populations may have needed to adapt to this distinctive and localized ecological setting. In this paper, I apply an approach based on maximum entropy species distribution modeling (Maxent) in order to characterize diachronic change in the ecological distribution of Neolithic archaeological settlements in the Struma Valley. The Maxent procedure essentially determines the characteristics and extent of what may be interpreted as the human ecological niche. A diachronic interpretation of the results demonstrates that there is a significant degree of niche conservatism in the Struma Valley all throughout the Neolithic Period—with the majority of settlements generally located on favourable agricultural terrains. However, notable instances of settlement proliferation led to an expansion of the human ecological niche to also include less favourable agricultural terrain over time. The potential implications of such an expansion—among which demographic increase and improvements in agricultural practices likely played a critical role—are subsequently discussed.

KEYWORDS

Neolithic; agriculture; Maxent; ecological niche modeling; Bulgaria; Greece.

Introduction

Understanding the dynamic relationship that exists between humans and their environments has long played an important role in addressing archaeological problems (Butzer 1982; Steward 1955; Winterhalder, Smith 2000). Recently, species distribution modeling techniques have also been adapted towards addressing such problems. More specifically, species distribution models have proven useful for the evaluation of human settlement patterns and in characterizing the ecological niche (for relevant examples see Banks et al. 2008; Conolly et al. 2012; Galletti et al. 2013). Maximum entropy species distribution modeling (Maxent), in particular, lends itself quite well to such tasks. Developed by Phillips, Anderson, Dudik, and Schapire (2006; 2008), Maxent's intuitive interface and readily understandable outputs have proven an invaluable tool in a number of varied applications (Anderson, Raza 2010; Elith et al. 2010; Warren et al. 2008). In this paper, I apply the Maxent species distribution modeling method towards characterizing diachronic change in the ecological niche of

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Fig. 1. Map of the Struma River Valley
Обр. 1. Карта на долината на река Струма

Neolithic settlements in the Struma River Valley (Bulgaria and mainland Greece)[1].

Archaeological context: The Neolithic in the Struma River Valley

The Struma River runs 415 km long from its source on the slopes of Vitosha Mountain – near the Bulgarian capital of Sofia – to its outflow in the Aegean Sea at Orphanos Bay (Zagorchev 2007). It extends from North to South, encompassing a total catchment area of approximately 10 800 km^2

1 This paper stems from a presentation delivered at the Doctoral Student Conference on Balkan Archaeology, Sofia, Bulgaria November 19-21 2017. It communicates the preliminary results of research undertaken by the author under the purview of a Master's program in anthropology at Trent University (2017), Peterborough ON, Canada, which has since been published more fully (see Whitford 2019).

Site Name	Early Neolithic	Middle Neolithic	Late Neolithic	Longitude (DD)	Latitude (DD)
Divotino	√		√	23.05608	42.66116
Gabrov Dol	√			22.78234	42.63514
Pernik	√		√	23.09958	42.60527
Divlya	√			22.67778	42.59958
Krakra			√	23.01791	42.59432
Batanovtsi			√	22.93516	42.58157
Radomir			√	22.95085	42.53305
Priboi	√		√	22.92093	42.49519
Negovantsi	√			22.96482	42.46111
Galabnik	√	√	√	23.06337	42.42037
Shipochano			√	22.72060	42.36661
Shishkovtsi Mogila	√			22.72435	42.34399
Dozdevitsa			√	22.56697	42.32699
Krainitsi	√			23.21023	42.32658
Saparevo	√	√	√	23.29145	42.32383
Kutugertsi	√			22.49945	42.32227
Tavalichevo-Gigan		√	√	22.86232	42.31121
Shatrovo-Golemi Vrum			√	22.96745	42.30672
Dolistovo-Ochilishteto	√			23.00970	42.30316
Dolno Selo			√	22.48693	42.29367
Sapareva Bania-Krevnik	√	√	√	23.22564	42.28844
Kjustendil-Kameni Bradvi	√			22.69321	42.28708
Piperkov Chiflik	√			22.73413	42.28084
Dupnitsa	√	√		23.09366	42.26104
Nevestino-Moshteni	√	√		22.85653	42.25741
Chetirtsi - Peshterata	√			22.88490	42.24718
Bersin	√	√		22.77752	42.24579
Dzherman-Bela Voda	√			23.08402	42.23466
Vaxevo-Studena Voda	√	√		22.85873	42.17065
Slatino-Karo			√	23.04976	42.16548
Slatino-Tchardako			√	23.04812	42.16510
Slatino-Guerena			√	23.03676	42.11369
Mursalevo	√	√	√	23.03620	42.11212
Dragodan			√	23.03126	42.11171
Kocherinovo-Quartal Levski	√	√	√	23.03898	42.06500
Kocherinovo-Lilacheto	√	√	√	23.02948	42.06440
Golio Rid			√	23.02555	42.06261
Lisieska Chuka			√	22.97661	42.05978
Nivite			√	22.99722	42.05130
Suhate Cheshma			√	23.00014	42.04691
Balgarchevo	√	√	√	23.03908	42.02609
Drenkovo-Ploshteko	√		√	22.97206	42.00055
Drenkovo-Gurleshki Nivi		√		22.96738	42.00001
Berovakitka			√	22.96897	41.99489
Strumsko			√	23.09297	41.97702
Pepelnikov Chukar	√			23.05715	41.97668
Grobishtartsie			√	23.03085	41.97254
Popovska Mahala			√	23.06372	41.95824
Brezhani	√			23.19515	41.86106
Ilindentsi	√	√		23.21940	41.64456

Site Name	Early Neolithic	Middle Neolithic	Late Neolithic	Longitude (DD)	Latitude (DD)
Ploski	√	√		23.26430	41.63497
Sandanski			√	23.24867	41.53402
Damyanitsa			√	23.27179	41.51560
Vinogradi	√	√		23.38079	41.50452
Chereshnitsa II		√	√	23.45475	41.50078
Kovachevo	√	√		23.47573	41.48519
Baskaltsi		√	√	23.01011	41.48448
Churichene		√	√	23.13621	41.46340
Petrovo I		√	√	23.51077	41.46097
Katuntsi III		√		23.44003	41.45810
Kalimantsi	√	√		23.47099	41.45755
Dolna Ribnitsa		√		23.11244	41.45160
Goleshovo		√	√	23.56803	41.44912
Vishlene		√		23.06417	41.44010
Mitino			√	23.26564	41.44009
Katuntsi I		√		23.41955	41.43961
Katuntsi II		√		23.42366	41.43741
Gega		√		23.00411	41.43588
Petrovo II			√	23.52048	41.43474
Harsovo		√	√	23.36921	41.43367
Yanovo		√	√	23.48561	41.43324
Parvomai		√	√	23.14068	41.41743
Drenovitsa I			√	23.07764	41.41397
Drenovitsa II			√	23.06864	41.41244
Piperitsa			√	23.44960	41.40952
Topolnitsa			√	23.32761	41.39080
Kamena			√	23.06401	41.38128
Xeropotamos			√	24.10834	41.19334
Kallyphitos			√	24.20683	41.17432
Bunar Bashi			√	24.05699	41.16088
Mikri Toumba			√	24.01965	41.15805
Kali Vryssi			√	23.93728	41.15592
Petroussa			√	24.03907	41.15083
Mylopotamos			√	24.06645	41.14728
Arkadikos		√	√	24.13492	41.14210
Chorla		√	√	24.08359	41.13634
Adriani-Agora			√	24.28418	41.13502
Megalokampos			√	23.97241	41.13116
Agio Pnevma			√	23.67579	41.10497
Agrianitsa			√	23.61777	41.10071
Sitagroi		√	√	24.02998	41.08105
Kephalari			√	24.26318	41.07916
Doxaton		√	√	24.20110	41.07185
Monovrisis			√	23.57599	41.05733
Fakistra			√	23.61752	41.05281
Toumba Seron			√	23.66462	41.03910
Kourovo			√	24.07835	41.03783
Sidirodromikos Strathmos			√	23.62327	41.03505
Symvoli			√	24.02535	41.03494
Dikili Tash		√	√	24.32005	41.02034

Site Name	Early Neolithic	Middle Neolithic	Late Neolithic	Longitude (DD)	Latitude (DD)
Tholos			√	23.72160	41.01263
Paliokostra			√	23.95706	41.01124
Nea Baphra		√	√	24.02352	40.99496
Polystylon		√	√	24.33439	40.99276
Aïri Baïri			√	23.81914	40.98155
Kéramidès			√	23.97508	40.98097
Dimitra		√	√	23.88567	40.96418
Myrkinos			√	23.82132	40.92955
Paliambela-Eleftheroupolis			√	24.27564	40.92510
Fidokorifi			√	23.78216	40.91920
Mikro Souli		√	√	23.93730	40.90902
Kryoneri		√	√	23.76203	40.84450
Moustheni			√	24.13767	40.84358
Hill 133			√	23.84070	40.83996
Gialimia-Podochori			√	24.05983	40.82709
Galepsos			√	23.97696	40.81365
Akropotamos			√	24.04002	40.79341

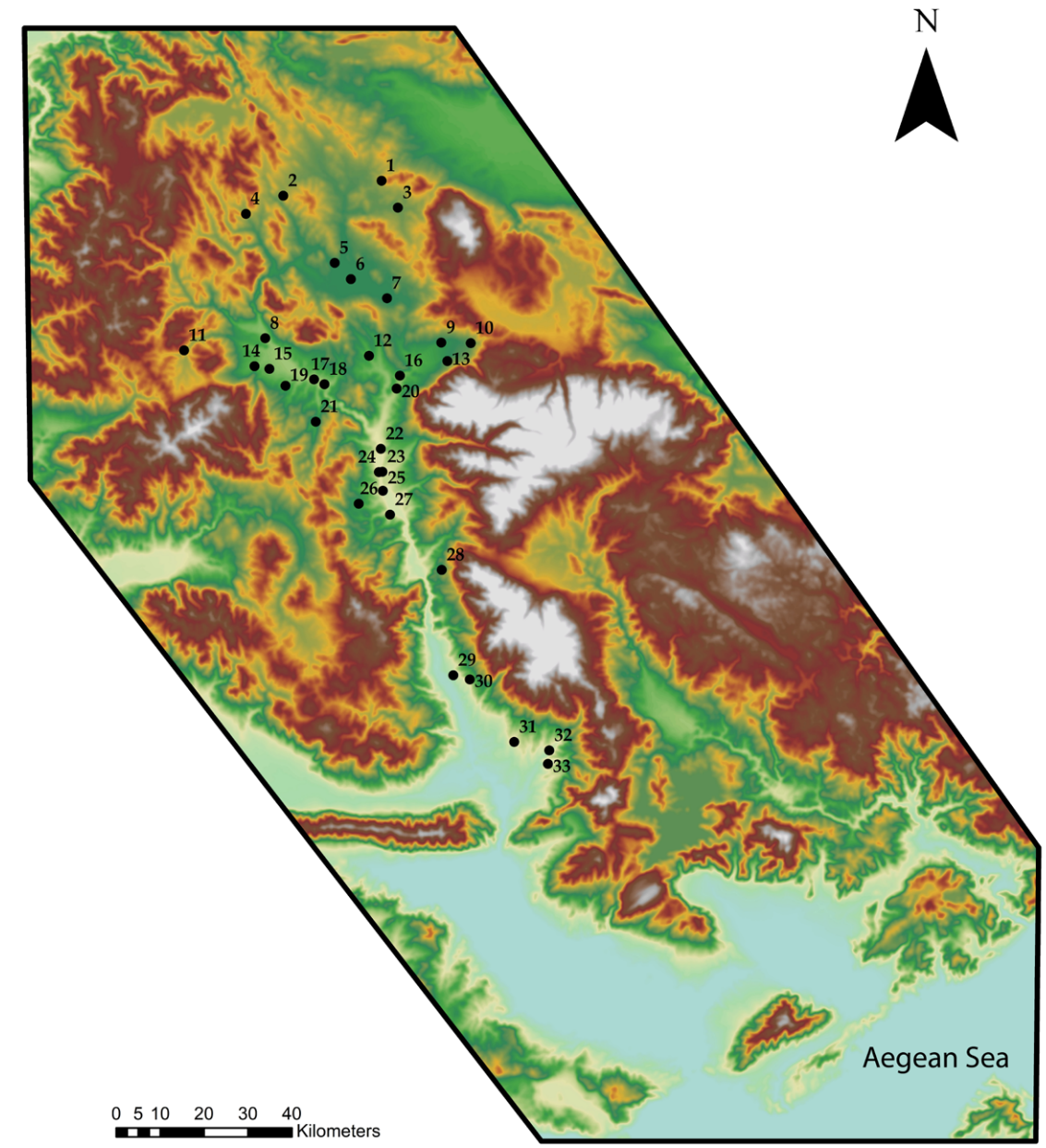
Table 1. Neolithic site coordinates and their relative chronological affiliation (DD = decimal degrees; datum WGS84); Chohadzhiev 2007; Genadieva 2007; Grebska-Kulova 2009; Koukouli-Chryssanthaki et al. 2008; Pernicheva 1995; Pernicheva-Perets et al. 2011; Renfrew et al. 1986

Таблица 1. Координати и относителна хронология на неолитните обекти (DD = децимални градуси; datum WGS84); Chohadzhiev 2007; Genadieva 2007; Grebska-Kulova 2009; Koukouli-Chryssanthaki et al. 2008; Pernicheva 1995; Pernicheva-Perets et al. 2011; Renfrew et al. 1986

(fig. 1). The north-south gradient of the Struma River Valley provides a myriad of different possible ecological niches within which the first agriculturalists of the region could have settled. To the East rise the Rila and Pirin massifs (the former recorded as the highest peak in the Balkan Peninsula) while to the West lay the more gradual Osogovo, Ograzhden, Maleshevska, and Belasitsa ranges (Zagorchev 2007). Furthermore, extensive tectonic and fluvial processes have shaped the valley into several distinct basins delimited by a series of natural gorges (Zagorchev 2007; Pernicheva-Perets et al. 2011). Based on these characteristics, the Struma River Valley can then be further divided into three defined sub-regions: The Upper, Middle, and Lower Struma Valleys.

The Upper Struma Valley lies in the north and is composed of four sub-basins. It is delimited by the Sofia Plain to the Western Balkan Mountains. The Middle Struma Valley, is composed of three sub-basins and is divided by the Kresna Gorge. Kresna Gorge is an especially worthy landmark for consideration, as it is the longest in the Struma Valley – reaching 16 km in length – and also formally marks the transitional border between the Mediterranean and Temperate climatic and vegetational zones (Pernicheva-Perets et al. 2011). Lastly, the Lower Struma Valley begins at Rupelski Gorge in the south where the river enters East Greek Macedonia, forms the wide Serres Lowlands, and joins with the Angitis River as the latter descends from the Drama Basin.

The compartmentalized nature of the terrain in question also appears to have acted on Neolithic settlement distribution and mitigated cultural contacts throughout the Valley (Pernicheva 1995). One hundred and seventeen distinct settlements from the Neolithic Period have been identified in the Struma Valley (see Chohadzhiev 2007; Grebska-Kulova 2009, Koukouli-Chryssanthaki et al. 2008; Pernicheva 1995; Pernicheva-Perets et al. 2011; Renfrew et al. 1986; figs. 2–4; Table 1). However, a notable complication exists regarding the chrono-cultural periodization system. Issues regarding the chronological placement of settlements along a comparable absolute time-scale arise mainly because



1. Divotino
2. Gabrov Dol
3. Pernik
4. Divlya
5. Priboi
6. Negovantsi
7. Galabnik
8. Shishkovtsi
9. Krainitsi
10. Saparevo
11. Kutugertsi
12. Dolistvovo-Ochilishteto
13. Sapareva Banya-Kremenik
14. Kjustendil-Kameni Bradvi
15. Piperkov Chiflik
16. Dupnitsa
17. Nevestino-Moshteni
18. Chetirtsi-Peshterata
19. Bersin
20. Dzherman-Bela Voda
21. Vaxevo-Studena Voda
22. Mursalevo
23. Kocherinovo-Quartal Levski
24. Kocherinovo-Lilacheto
25. Balgarchevo
26. Drenkovo-Ploshteko
27. Pokrovnik-Pepelnikov Chukar
28. Brezhani
29. Ilindentsi
30. Ploski
31. Vinogradi
32. Kovachevo
33. Kalimantsi

Fig. 2. Early Neolithic settlements in the Struma River Valley (after Whitford 2019)
Обр. 2. Ранно неолитни селища по долината на река Струма (по Whitford 2019)

		The Struma River Valley						
Period	Thrace (East Bulgaria)	Upper Struma	Middle Struma		Lower Struma (Greek Macedonia)	Serbia	Republic of Macedonia	Thessaly
			North	South				
Late Neolithic	IV B (Kalovanovets)	Sapareva Banya III (Kurilo)	Strumsko I B Balgarchevo III A	Petrovo III Promachon -Topolnitsa II Damyanitsa I	Sitagroi II	Vinca B	Angeltsi II Zelenikovo II Anza (Late)	Arapi
Middle Neolithic	Karanovo IV A III	Sapareva Banya II Vaxevo IV	Balgarchevo II B	Kovachevo II Dolna Ribnitsa Marchin	Dikili Tash I Sitagroi I	Vinca A IV	Anza IV Zelenikovo I	Tsangli Larissa
Early Neolithic	II I	Sapareva Banya I Vaxevo III Vaxevo II Vaxevo I	Balgarchevo I A	Kovachevo Id Ic Ib Ia		Starcevo III II I	Anza III Anza II Anza I	Sesklo ProtoSesklo Magulitsa

Table 2. Chrono-cultural periodization system (adapted from Perničeva 2007, republished from Whitford 2019)
Таблица 2. Хронологическо-културна периодизационна система (адаптирана по Perničeva 2007, повторно публикувана в Whitford 2019)

Period	Phase	Date Ranges (cal. B.C.)
Neolithic	Early Pottery	6300/6200 - 6000/5900
	Early	6000/5900 - 5550/5450
	Middle	5500/5450 - 5200/5100
	Late	5200/5100 - 4900/4850

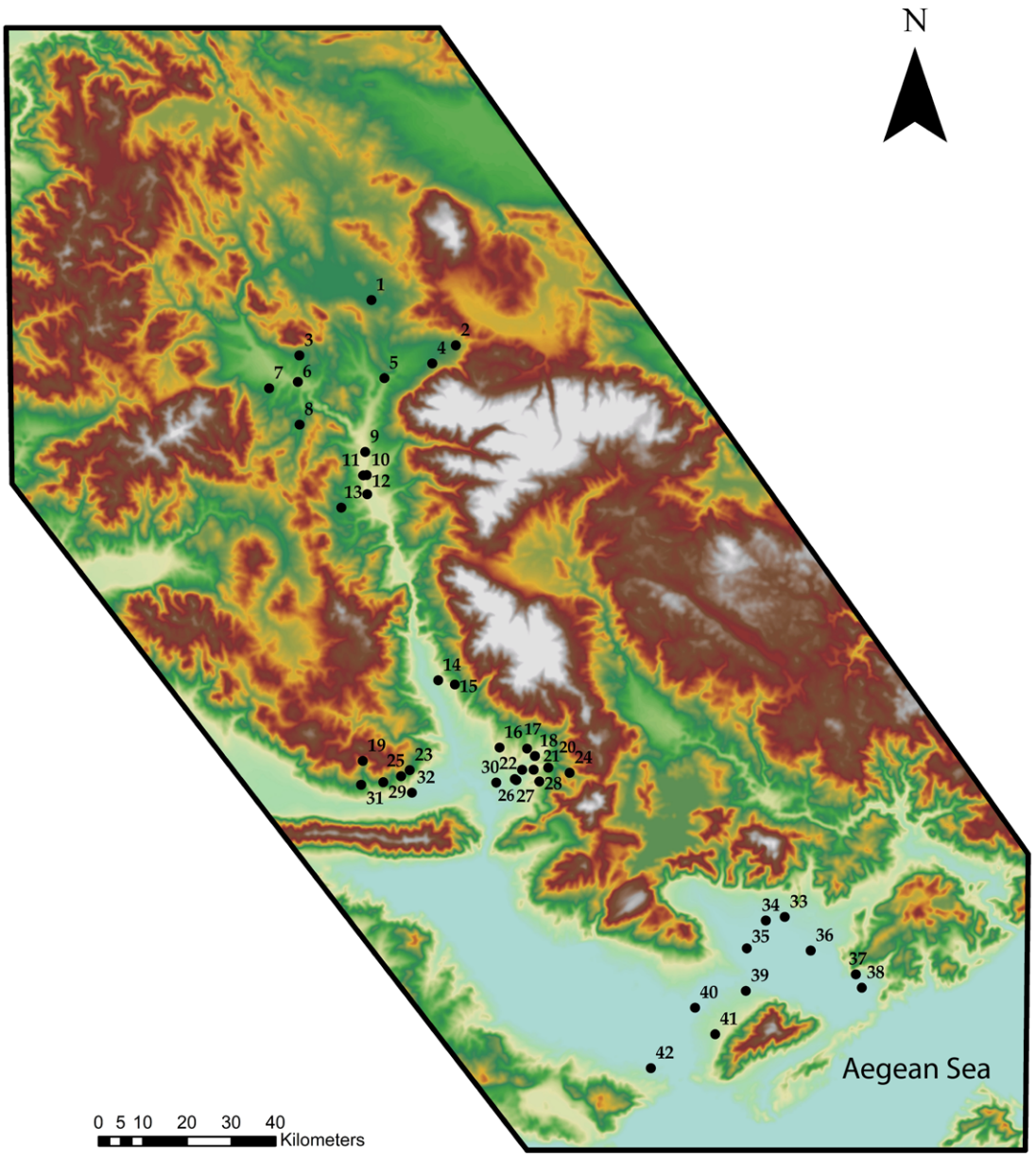
Table 3. Absolute date ranges (after Boyadziev 1995, republished from Whitford 2019)
Таблица 3. Абсолютни дати (по Boyadziev 1995, повторно публикувана в Whitford 2019)

the characteristic finds of the region are not wholly isolated to Southwest Bulgaria alone. In most cases, these have also been found geographically and chronologically distributed in parts of Eastern Bulgaria, North Macedonia, Serbia, Mainland Greece, and beyond (Demoule 2009; Pernicheva-Perets et al. 2011; Tsirtsoni 2016), emphasizing connections with the neighbouring regions. Very different chronological periodization systems are in use for each of the regions in question complicating any attempt at a supra-regional synthesis (Pernicheva-Perets et al. 2011; Tsirtsoni 2016). For the purposes of this study, I utilize a variant of the periodization system first suggested by Georgiev (1961) – with regards to the stratigraphy at Tell Karanovo in Eastern Bulgaria – and later by Pernicheva (1995) in relation to the Struma River Valley. Due to the very limited amount of radiocarbon dates for the Neolithic of the region in general, the periodization system is primarily defined by the detailed sequencing of pottery types and in their association across key settlements (Perničeva 2007; Table 2). All absolute dates reported here are from Boyadzhiev (1995; Table 3).

Early Neolithic (6200–5450 cal BC)

In total, 33 settlements represent the Early Neolithic Period in the Struma River Valley. Notably, not a single Early Neolithic settlement has been discovered in the Lower Struma Valley (Demoule, Perlès 1993; Pernicheva 1995; Pernicheva-Perets et al. 2011). All throughout the Early Neolithic Period, the placement of settlements generally remains the same as they are situated along the first and/or second terraces of the Struma River and its principal tributaries (Pernicheva-Perets et al. 2011). In terms of settlement locations, no significant differences are immediately noted between the first and second halves of the Early Neolithic.

From a typological point of view, the settlement of Krainitsi in the Upper Struma Valley represents the oldest known phase of the Early Neolithic, comprising a monochrome ceramic stage



1. Galabnik
2. Saparevo
3. Tavalichevo-Gigan
4. Sapareva Banya-Kremenik
5. Dupnitsa
6. Nevestino-Moshteni
7. Bersin
8. Vaxevo-Studena Voda
9. Mursalevo
10. Kocherinovo-Quartal Levski
11. Kocherinovo-Lilacheto
12. Balgarchevo
13. Drenkovo-Gurleshki Nivi
14. Ilindentsi
15. Ploski
16. Vinogradi
17. Chereshnitsa II
18. Kovachevo
19. Baskaltsi
20. Petrovo I
21. Kalimantsi
22. Katuntsi III
23. Churichene
24. Goleshovo
25. Dolna Ribnitsa
26. Katuntsi I
27. Katuntsi II
28. Yanovo
29. Vishlene
30. Harsovo
31. Gega
32. Parvomai
33. Arkadikos
34. Chorla
35. Sitagroi
36. Doxaton
37. Dikili Tash
38. Polystylon
39. Nea Baphra
40. Dimitra
41. Mikro Souli
42. Kryoneri

Fig. 3. Middle Neolithic settlements in the Struma River Valley (after Whitford 2019)
Обр. 3. Средно неолитни селища по долината на река Струма (по Whitford 2019)

that parallels that of the earliest Neolithic in Thessaly (Čohadžiev 1998). To this point in time, it is the only known settlement that provides evidence for such an early stage of development in the region. During the first half of the Early Neolithic (c. 6200–5850 cal BC), following the monochrome stage – as evidenced also by the stratigraphy at Krainitsi – a white on red painted ceramic tradition emerges near homogeneously across the Middle and Upper Struma Valleys (Pernicheva 1995). During the second half of the Early Neolithic (c. 5850–5450 cal BC), north of Kresna Gorge a dark on red painted ceramic tradition (i.e. classic Starčevo), having close affiliates in the Vardar Valley (see Anza; Gimbutas 1974), progressively supplants the white on red painted tradition (Pernicheva 1995). However, the white on red painted tradition continued to persist to the south of Kresna Gorge. Material culture diversification was thus possibly mitigated in local geographic-ecological terms beginning by at least the second half of the Early Neolithic.

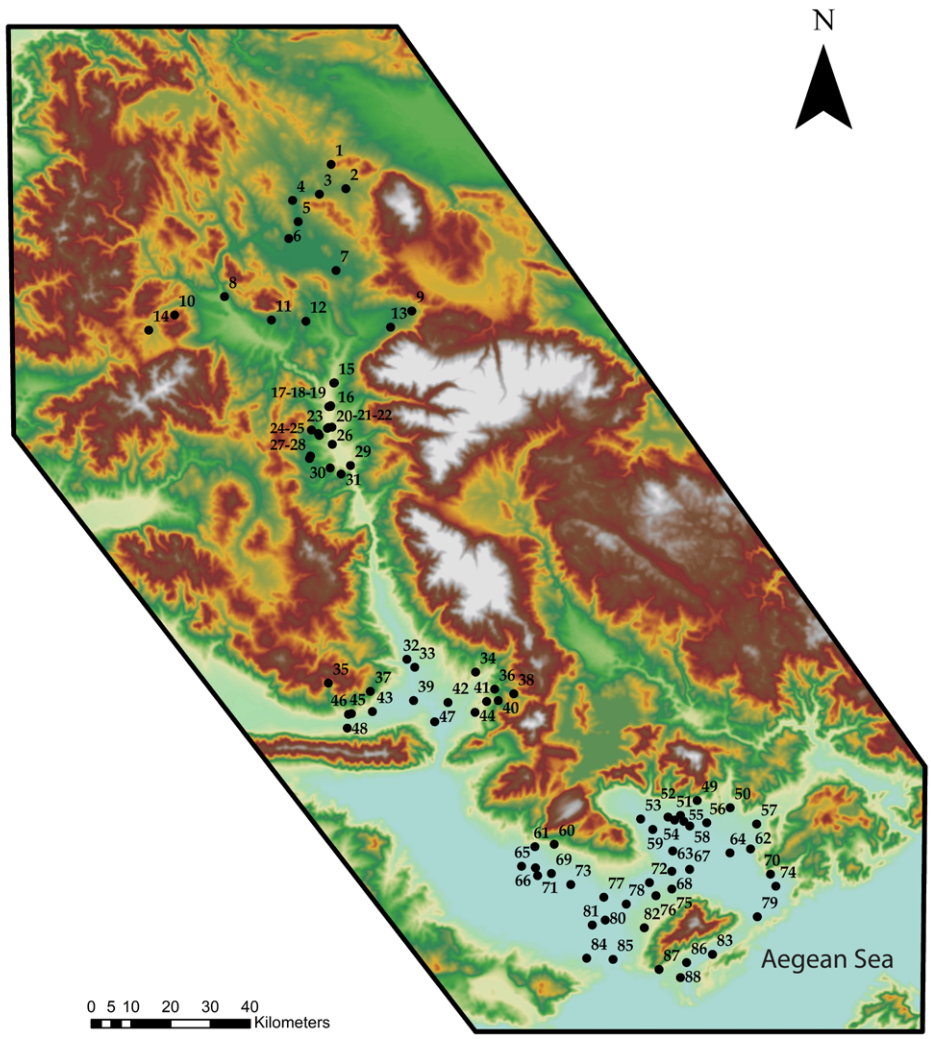
Middle Neolithic (5450–5200 cal BC)

Considering the entire Struma Valley 42 settlements have been recorded for the Middle Neolithic Period. The Middle Neolithic is uniformly characterised by black polished pottery and emphasized bi-conical shapes and in some instances by the Dolna Ribnitsa decorative technique consisting of double or more rarely single rowed punctations located above the carination (Pernicheva 1995). Overall, there is a reduction of known sites in the Upper Struma Valley alongside a proliferation of settlements in the Middle and Lower Struma Valleys. In all cases, Middle Neolithic settlements in the Upper Struma Valley were also occupied in the Early Neolithic Period, suggesting a strong degree of local continuity in the selection of settlement location. In the Middle and Lower Struma Valleys, however, many new settlements emerge in areas that were not previously occupied (Perničeva 1983). In the Lower Struma Valley in particular, all Middle Neolithic settlements are located over previously uninhabited terrain as no Early Neolithic settlements to date have been found in the area. The sub-regional continuity in the Upper Struma Valley, paired with the proliferation of settlements in the Middle Struma Valley and Lower Struma Valley thus suggests that a more southward oriented settlement pattern progressively developed at this time.

Late Neolithic (5200–4900 cal BC)

During the Late Neolithic Period, the Struma River Valley witnesses a drastic increase in the number of settlements in all three of its sub-regions (Grębska-Kulowa, Kulow 2007). The total number of settlements more than doubles from just 42 in the previous period, now reaching 88 in total. Furthermore, with the exception of just a few sites, most of the Late Neolithic settlements are situated over previously uninhabited terrain (Pernicheva-Perets et al. 2011). With regards to settlement distribution, there is now a noticeable distinction between the types and locations of settlements. Some settlements begin occupying vast areas near the terraces of the Struma River and its principal tributaries – reaching upwards of 200 000 m^2 – while others occupy more hilly terrains farther away from the main river systems (Pernicheva-Perets et al. 2011; Genadieva 2007).

The Late Neolithic is characterized primarily by the appearance and broad distribution of black-topped ceramics of the Karanovo III type, alongside the appearance of the more geographically restricted Vinča B type ceramics, the Akropotamos brown on cream painted style, and the Topolnitsa black on red painted style (Grębska-Kulova 2003; Boyadziev 1995; Pernicheva-Perets et al. 2011; Vajsov 2007). Vinča B type ceramics, for example, are largely confined to the Upper Struma Valley, but also appear in the Middle Struma Valley. The Akropotamos style, on the other hand, is by far most prevalent in the Lower Struma Valley, with specimens from the North represented only in minor quantities and interpreted as imports (Pernicheva-Perets et al. 2011). Lastly, the Topolnitsa variant originates in the Middle Struma Valley and appears as a local imitation of the southern Akro-



1. Divotino
2. Pernik
3. Krakra
4. Batanovtsi
5. Radomir
6. Priboi
7. Galabnik
8. Shipochano
9. Saparevo
10. Dozdevitsa
11. Tavalichevo-Gigan
12. Shatrovo-Golemi Vrum
13. Sapareva Banya-Kremenik
14. Dolno Selo
15. Slatino-Karo
16. Slatino-Tchardako
17. Slatino-Guerena
18. Mursalevo
19. Dragodan
20. Kocherinovo-Quartal Levski
21. Kocherinovo-Lilacheto
22. Buchino-Golio Rid
23. Buchino-Lisieska Chuka
24. Buchino-Nivite
25. Buchino-Suhata Cheshma
26. Balgarchevo
27. Drenkovo-Ploshteko
28. Logodazh-Berova Kitka
29. Strumsko
30. Pokrovnik-Grobishtartsi
31. Moshtanets -Popovska Mahala
32. Sandanski
33. Damyanitsa
34. Chereshnitsa II
35. Baskaltsi
36. Petrovo I
37. Churichene
38. Goleshovo
39. Mitino
40. Petrovo II
41. Yanovo
42. Harsovo
43. Parvomai
44. Piperitsa
45. Drenovitsa I
46. Drenovitsa II
47. Promachon-Topolnitsa
48. Kamena
49. Xeropotamos
50. Kallyphitos
51. Bunar Bashi
52. Mikri Toumba
53. Kali Vryssi
54. Petroussa
55. Mylopotamos
56. Arkadikos
57. Adriani-Agora
58. Chorla
59. Megalokampos
60. Agio Pnevma
61. Agrianitsa
62. Kephalari
63. Sitagroi
64. Doxaton
65. Monovrisis
66. Fakistra
67. Kourovo
68. Symvoli
69. Toumba Seron
70. Dikili Tash
71. Sidirodromikos Strathmos
72. Paliokastra
73. Tholos
74. Polystylon
75. Nea Baphra
76. Kéramidès
77. Aïri Baïri
78. Dimitra
79. Paliambela Eleftheroupolis
80. Myrkinos
81. Fidokorifi
82. Mikro Souli
83. Moustheni
84. Kryoneri
85. Hill 133
86. Gialimia-Podochori
87. Galepsos
88. Akropotamos

Fig. 4. Late Neolithic settlements in the Struma River Valley (after Whitford 2019)
Обр. 4. Късно неолитни селища по долината на река Струма (по Whitford 2019)

potamos type (Grębska-Kulova 2003; Boyadziev 1995; Vajsov 2007). The Late Neolithic Period can then most readily be described as a certain time of dynamic cultural differentiation and of settlement proliferation.

Data and methods

The topic of this paper is to characterize the distribution of early agricultural settlements in the Struma River Valley during the Neolithic Period and to assess how the human ecological niche changed over time. To that regard, Phillips et al. (2006; 2008) developed a maximum entropy species distribution modeling method (Maxent) that I adapted for use in the analyses. Maxent utilizes presence-only data and samples a restricted background to generate a random set of pseudo-absences from which to assess the distribution of presence points against a user defined set of independent ecological variables. I produced one model each for the Early Neolithic (33 presences), Middle Neolithic (42 presences), and Late Neolithic (88 presences), effectively determining the extent and characteristics of what may be interpreted as the human ecological niche for each period. The locations of the archaeological sites were identified via a rigorous review of paper maps and archaeological site registries housed within the relevant regional museums, offered to the author by the regional coordinators M. Grębska-Kulowa (for the Blagoevgrad area), V. Genadieva (for the Kyustendil area), A. Bakamska (for the Pernik area), and D. Malamidou (for the Serres and Drama areas), respectively. The absolute coordinates listed in Table 1 were subsequently obtained from Google Earth.

I selected 10 climate and terrain variables that arguably would have impacted the location selection of early agricultural settlements, particularly in relation to the composition of their respective crop and livestock assemblages and for the purposes of construction (O'Donnell & Ignizio 2012). These are annual mean temperature, temperature annual range, temperature seasonality, annual precipitation, precipitation seasonality, elevation, slope, terrain roughness, topographic wetness index, and soil typological unit (fig. 5). All climate variables were compiled and freely obtained from the WorldClim Present day bioclimatic dataset (Worldclim.org). Terrain variables were computed in ArcGIS 13.1 and derived from the version 2 ASTER Global Digital Elevation Model (Aster GDEM v2; asterweb.jpl.nasa.gov).

The first step in the species distribution modeling procedure involves checking for statistical collinearity between all independent variables (see Peterson 2011). Statistical collinearity is defined as a ridged association between different independent variables, such that the value of one changes relative with the value of another. Once identified, one or more of the collinear variables should be removed from further analysis so as not to unintentionally bias the model in favour of particularly related sets of ecological conditions. By pairing all continuous variables, examining their scatterplots/histograms, and determining their Pearson product-moment correlation coefficient (R^2), I determined significant instances of collinearity ($R^2 > 0.8$; fig. 6) and removed 4 of the independent variables from the analyses—temperature seasonality, annual precipitation, elevation, and terrain roughness. Annual mean temperature, temperature annual range, precipitation seasonality, slope, topographic wetness index, and soil typological unit were each retained. Notably, the soil types dataset was withheld from the test for statistical collinearity as soil types are here represented as categorical data and therefore cannot be collinear in Euclidean space. Collectively, the remaining independent variables adequately represent ecological variability in the Struma River Valley.

The second step in the Maxent procedure regards the selection of suitable modeling parameters. Barbet-Massin et al. (2012) determined that for GLM species distribution models (a methodology similar to that of Maxent) the increase in accuracy of the model reaches an asymptote when the number of presences is equal to 10% or less the number of pseudo-absences. Therefore, I changed

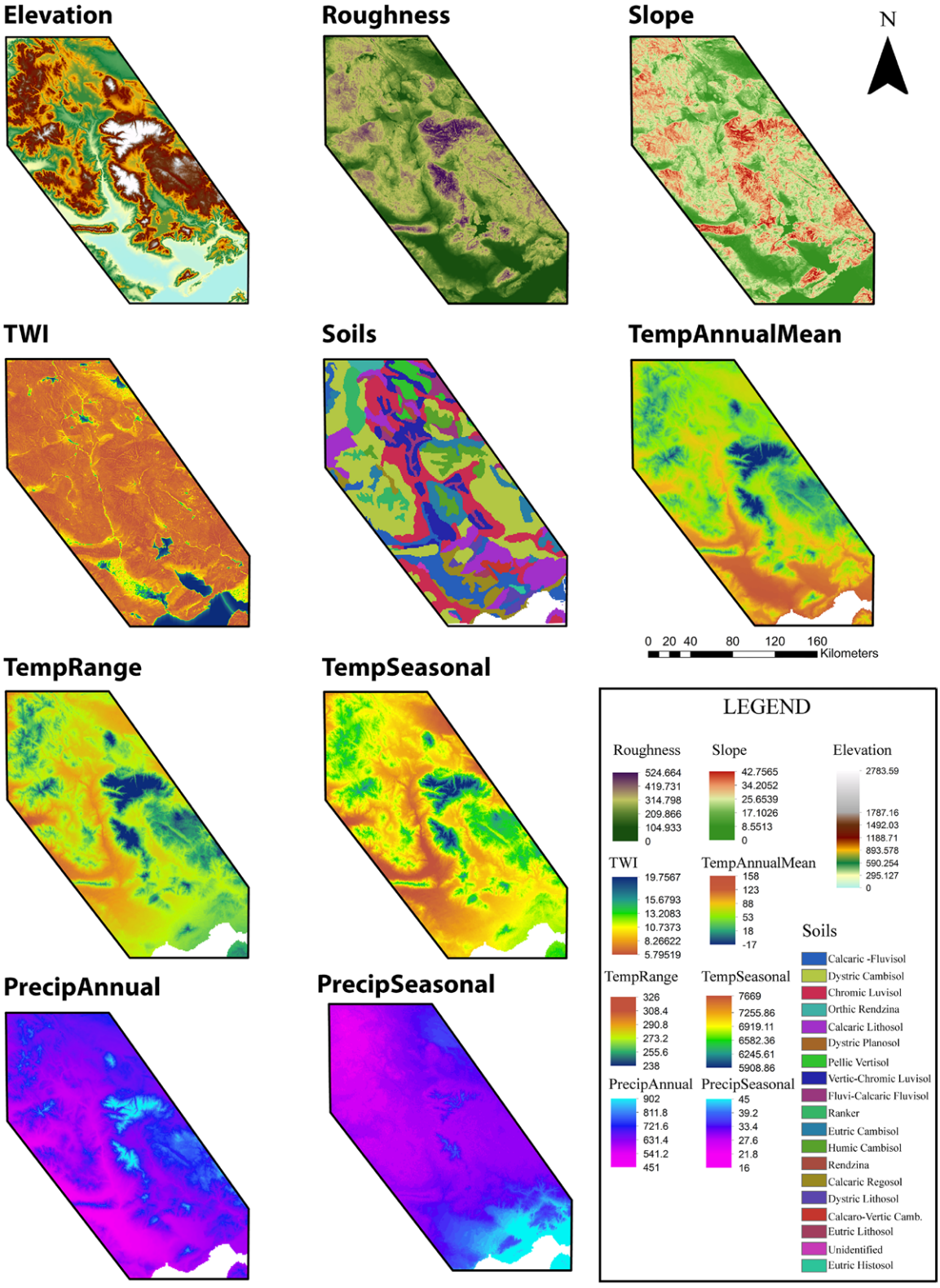


Fig. 5. Ecological variables (after Whitford 2019)
Fig. 5. Екологични променливи (по Whitford 2019)

the functional parameters of Maxent from their default setting (10 000 pseudo-absences) to sample only 1000 pseudo-absences due to the relatively small sample size of archaeological settlements. The geographic extent of the background from which the pseudo-absences are sampled encompasses the entire catchment area of the Struma River Valley (~10 800 km^2) and includes a significant portion of the surrounding region, accounting for a total surface area of approximately 38 000 km^2. I intentionally selected such a broad boundary so as not to restrict the model too severely and risk model overfit. The identified archaeological sites in the region (33 Early Neolithic, 42 Middle Neolithic, and 88 Late Neolithic) were each recorded as a presence point. The Maxent procedure utilizes a defined percentage of the presences (i.e. archaeological sites) in training the model to determine the ecological values at those locations based on the distribution of the background independent ecological variables. The remaining presences are then retained as test points used in verifying the model's predictive accuracy (measured as AUC; Phillips et al. 2006). I selected a cross-validation method at 500 iterations per run for the training and testing procedure of the models. I determined the additional modeling parameters (i.e. types of feature classes and regularization multiplier) in accordance with the enmevaluation function of the ENMeval package for R (see Muscarella et al. 2014; Whitford 2019).

Results

The Maxent cross-validation procedure produces a cumulative mean model compiled from every single presence point having in turn been retained as a test in verifying the model's predictive accuracy. The logistic output of the procedure projects habitat suitability values (ranging from 0% to 100%) onto the study region, effectively identifying the extent and characteristics of what may be interpreted as the human ecological niche of the archaeological period in question. One model each was produced for the Early, Middle, and Late Neolithic Periods (fig. 7).

Discussion

The results of the Maxent species distribution models for the Early, Middle, and Late Neolithic Periods of the Struma River Valley provide some valuable insight towards interpreting diachronic shifts in the location selection of early agricultural settlements, especially with regards to changes in the ecological niche.

Regarding the Early Neolithic, the probability for settlement is largely confined to particular portions of the Middle and Upper Struma Valleys. These regions can be characterized by temperate to sub-Mediterranean type climates having extended periods of frost and by a lesser precipitation seasonality consisting of slightly wetter winters over summers. Settlements are preferentially located on very gently sloped or flat terrains with a moderate to high topographic wetness index and on easy to work agricultural soils (i.e. fluvisols and luvisols). Interestingly, the Lower Struma Valley was not identified by the model as having any probability for settlement during the Early Neolithic, which is consistent with the current state of research and the absence of any known Early Neolithic settlements in the region. The general characteristics of the Early Neolithic ecological niche then coincide with more temperate areas of excellent agricultural potential generally located near the valley bottoms and in proximity to major river systems.

The distribution of Middle Neolithic settlements, on the other hand, although generally conservative and aligned with the characteristics of the Early Neolithic niche, is more varied in several important manners. Most of the similarities between the Early and Middle Neolithic ecological niche can be accounted for by the fact that all the Middle Neolithic sites located to the north of Kresna

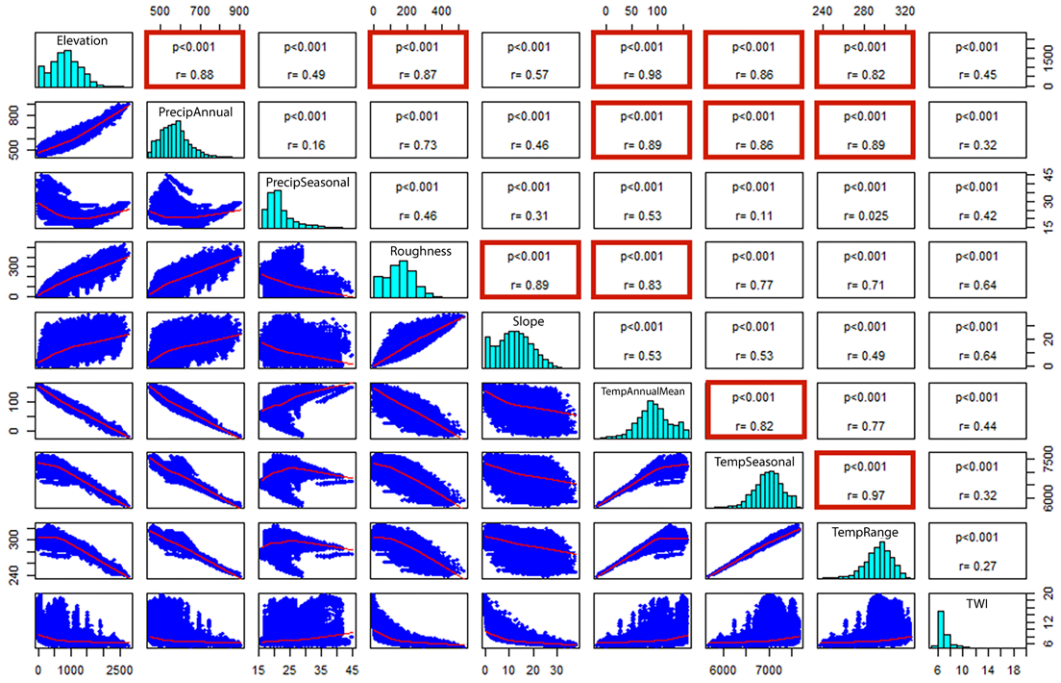


Fig. 6. Test for collinearity; instances of collinearity (R2 > 0.8) outlined in red (after Whitford 2019)
Обр. 6. Тест за колинеарност; случаи на колинеарност (R2> 0,8), очертани в червено (по Whitford 2019)

Gorge are situated over the previous Early Neolithic settlements, suggesting a strong degree of niche conservatism in the sub-region. To the south of Kresna Gorge, however, the majority of Middle Neolithic settlements are located over previously uninhabited terrain. This expansion to new terrains during the Middle Neolithic is associated with an increase in the occupation of warmer climates, in regions having a marked precipitation seasonality, located on sloped terrains, and situated farther away from easily worked agricultural soils (represented by the strong probability for settlement on regosols and cambisols, which are less suitable for agriculture without the use of the plough or irrigation).

Lastly, during the Late Neolithic, the vast majority of settlements are situated over previously uninhabited terrain and collectively cover a significant portion of the Struma River Valley's geographic breadth and ecological variability, excluding only the alpine and sub-alpine regions. Although habitat suitability is greatest in areas having a high mean annual temperature, the latter is contrasted by the probability for settlement also in areas having a high annual temperature range. Settlement in locations covering a wide range of different precipitation seasonality values is also attested. With regards to soil types, the Late Neolithic settlement distribution has expanded to include nearly all the available soils in the Struma Valley except for only two (calcaric lithosols and dystric cambisols, which are largely isolated to the alpine and sub-alpine regions). Areas with flat terrains and moderate to high topographic wetness indexes are preferred, though settlement in areas with sloped terrains are also found to a significant degree. Essentially, by the Late Neolithic Period settlements are located on all the inhabitable terrain available in the Struma Valley.

Diachronic considerations of change to the ecological niche

Considerations of change to the human ecological niche during the Neolithic Period of the Struma River Valley demonstrate that a strong degree of niche conservatism is observed. The tendency for change is rather inclined towards niche expansion rather than towards total niche replace-

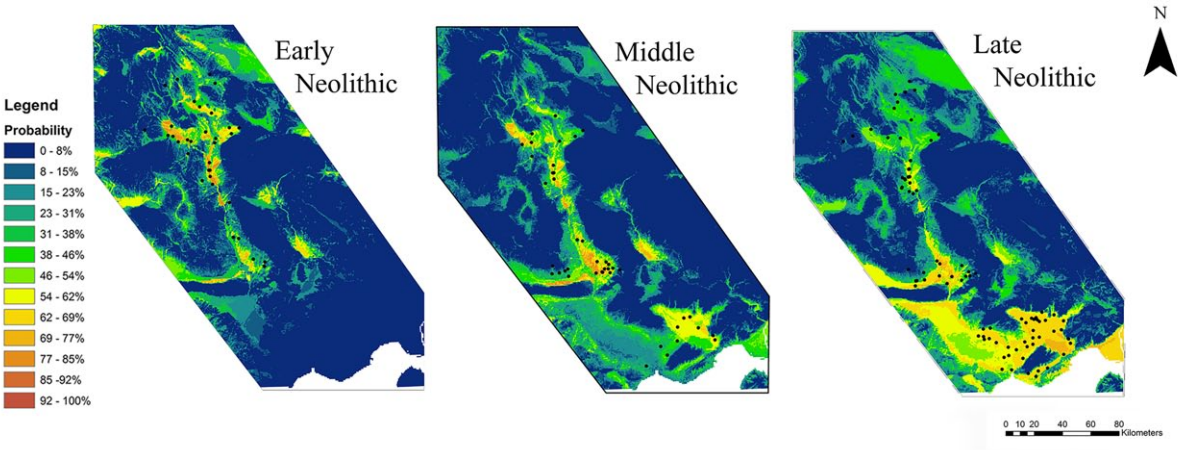


Fig. 7. Maxent species distribution models; Neolithic ecological niches
Обр. 7. Модели с максимална ентропия на разпространение на видове; Неолитни екологични ниши

ment. The progressive occupation of more agriculturally marginal soils and in locations providing more varied types of climate and terrain bears evidence of a need to expand and settle in locations that are less agriculturally suitable over time. The latter niche expansion can then possibly be corelated with population growth, large-scale social reorganizations, improvements in agricultural practices, and/or an increase in the importance of animal husbandry. Additionally, each period is characterized by more frequent episodes of cultural diversification, beginning with a relatively undiversified cultural base during the Early Neolithic and ending with the emergence of three distinct cultural traditions located near exclusively in each of the Struma Valley's sub-regions by the Late Neolithic. It therefore appears that episodes of cultural diversification during the Neolithic Period of the Struma River Valley are strongly correlated with an expansion in the ecological setting of human settlement over time. However, whether cultural diversification was the cause or the result of expansion to the ecological niche during the Neolithic Period remains to be determined.

Conclusion

As demonstrated by the analyses, there is in fact considerable benefit to further adapting species distribution modeling techniques towards addressing archaeological problems. More specifically, such an approach can shed some light on the assessment of human settlement distributions and, when paired with the archaeological record, can help in evaluating diachronic considerations of cultural change. When applied to the spread of early agriculture in the Struma River Valley, the techniques presented here determined to what degree different ecological variables acted as significant factors in the location selection for Neolithic settlement and how these changed (or did not change) over time. Furthermore, considering the relative expansion of the human ecological niche in the Struma River Valley, the results may be tentatively interpreted as evidence for demographic expansion, improvements in agricultural practice, an increased reliance on animal husbandry, and/or of large-scale social reorganizations in association with episodes of cultural diversification. Arguments regarding diachronic change in subsistence strategies, material culture diversification, and/or of land-use practices may then be further addressed considering this new and complimentary evidence.

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Неолитът (с. 6200–4900 BC) по долината на река Струма: Характеризиране на промяна в човешката екологична ниша според модели на разпространението на видовете

Брент Уинфорд

(резюме)

През неолита (около 6200–4900 г. BC) ранните популациите на ранните земеделци се установяват постепенно в района по долината на река Струма, докато достигнат максимална заетост в късния неолит. Екологичните характеристики на долината на река Струма са разнородни, особено по нейния градиент север-юг, а също и вертикално по склоновете на долината. Това предполага, че ранните селскостопански популации са се приспособили към тази екологична обстановка. В настоящата статия е прилижен подход, основан на моделиране на разпределението на видовете максимална ентропия (Maxent), за да се направи характеристика на диахронната промяна в екологичното разпределение на неолитните селища. Процедурата Maxent по същество определя характеристиките и степента на това, което може да се тълкува като човешка екологична ниша. Диахронната интерпретация на резултатите показва, че има значителна степен на консерватизъм в нишата през целия неолитен период. Повечето селища обикновено са разположени на благоприятни за земеделие терени. Въпреки това, се забелязват и други варианти на разполагане на селища, които водят до разширяване на човешката екологична ниша, в която, с течение на времето, се включват и по-неблагоприятни за земеделие площи. Обсъдени са потенциалните последици от подобна експанзия, сред които решаваща роля вероятно са играли демографското увеличение и подобренията в селскостопанските практики.