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A Landscape of Surveillance. Investigating Hellenistic Fortifications and Potential Networks of Interaction in the Pergamon Micro-Region

aus / from

Archäologischer Anzeiger, 2022/2

DOI: https://doi.org/10.34780/d6lg-362f

Herausgebende Institution / Publisher:
Deutsches Archäologisches Institut

IMPRESSUM

Archäologischer Anzeiger
erscheint seit 1889/*published since 1889*

AA 2022/2 • 396 Seiten/*pages* mit 279 Abbildungen/*illustrations*

Peer Review
Alle für den Archäologischen Anzeiger eingereichten Beiträge werden einem doppelblinden Peer-Review-Verfahren durch internationale Fachgutachterinnen und -gutachter unterzogen./*All articles submitted to the Archäologischer Anzeiger are reviewed by international experts in a double-blind peer review process.*

Redaktion und Layout/*Editing and Typesetting*
Gesamtverantwortliche Redaktion/*Publishing editor*:
Deutsches Archäologisches Institut, Redaktion der Zentralen Wissenschaftlichen Dienste, Berlin
(https://www.dainst.org/standort/zentrale/redaktion), redaktion.zentrale@dainst.de
Für Manuskripteinreichungen siehe/*For manuscript submission, see*: https://publications.dainst.org/journals/index.php/aa/about/submissions
Redaktion/*Editing*: Dorothee Fillies, Berlin
Satz/*Typesetting*: le-tex publishing services GmbH, Leipzig
Corporate Design, Layoutgestaltung/*Layout design*: LMK Büro für Kommunikationsdesign, Berlin

Umschlagfoto/*Cover illustration*: E. Pontremoli – B. Haussoullier, Didymes. Fouilles de 1895 et 1896 (Paris 1904) Taf. 11;
Ausschnitt in Umzeichnung Zahra Elhanbaly, 2022

Druckausgabe/*Printed edition*

Druck und Vertrieb/*Printing and Distribution*: Dr. Ludwig Reichert Verlag Wiesbaden (www.reichert-verlag.de)

P-ISSN: 0003-8105 – ISBN: 978-3-7520-0727-5

Druck und Bindung in Deutschland/*Printed and Bound in Germany*

Digitale Ausgabe/*Digital edition*

Webdesign/*Webdesign*: LMK Büro für Kommunikationsdesign, Berlin
XML-Export, Konvertierung/*XML-Export, Conversion*: digital publishing competence, München
Programmierung Viewer-Ausgabe/*Programming Viewer*: LEAN BAKERY, München

E-ISSN: 2510-4713 – DOI: https://doi.org/10.34780/uc3c-2s3d

ABSTRACT

A Landscape of Surveillance

Investigating Hellenistic Fortifications and Potential Networks of Interaction in the Pergamon Micro-Region

Bernhard Ludwig – Daniel Knitter – Christina G. Williamson

This study presents a three-pronged landscape approach that combines visibility analyses, site location analyses, and the modeling of movement in an open-access environment as a comprehensive means of assessing degrees of surveillance and control of a territory. The study focuses on the Pergamon Micro-Region under the Attalid dynasty in the turbulent Hellenistic era. While unrestricted and permanent access to the surrounding core territory was vital to their success, our knowledge of the rural fortifications and the protection of this particular region is fragmentary. We have therefore carried out a full analysis of all the known fortifications in the Pergamon Micro-Region in terms of their function and ability to monitor and control the surrounding landscape from the city. The results yield new insights into Pergamon's strategic position as a regional center of power and communication through its deployment of rural fortifications to monitor, control and access areas of economic, strategic and military importance. The methodology shows how prominent locations were integrated into a system of defense that lost its functionality after Attalid rule. By also making the developed code of the analyses available alongside the study, we make our assumptions and decisions transparent and reproducible, encouraging readers to perform and test the analyses, or further develop them for their own specific research question.

KEYWORDS

Pergamon, landscape archaeology, fortification, visibility analysis, Topographic Position Index, geomorphons, isochrones, reproducible research

BERNHARD LUDWIG – DANIEL KNITTER – CHRISTINA G. WILLIAMSON

A Landscape of Surveillance

Investigating Hellenistic Fortifications and Potential Networks of Interaction in the Pergamon Micro-Region

Introduction

1 In order to understand the vitality of an ancient city one must focus on its wider environment[1]. Reliable accessibility and control of the essential landscape that provided fundamental resources, including food and routes of trade and communication, were basic requirements for the emergence and development of an urban center. The location within the landscape had to guarantee the security of the city itself and at the same time meet the above-mentioned needs. Compared to ancient coastal cities such as Ephesos or Smyrna, this posed a particular challenge for Pergamon, located about 25 km inland on a steep hill at the northern edge of the lower Bakırçay Plain (ancient Kaikos plain). The distance from the coast is generally seen as an economic disadvantage[2]. Nevertheless, the location offered a panoramic view of the vicinity as well as higher security[3], especially in the turbulent Hellenistic period[4]. The sheer number of known fortified settlements and military forts in the western lower Bakırçay Plain and the surrounding mountain ranges, which remained the heartland of Attalid territory throughout their rule, indicates the high importance of military presence at that time. The necessity of visual control over the territory of a city was already noted by Aristotle, who prescribed that a city should be able to oversee its territory in a single glance and that for secure communication, defense and access to resources, every part of the territory should be in visual contact with all the other parts[5]. The takeover and control of strategic locations allowed unrestricted and permanent access to the core-territory and was therefore essential for the stability of the Attalid dynasty.

2 Our knowledge regarding the protection of Pergamon's core territory is fragmentary and we can only provide general concepts as we await further investigations. Nonetheless, a close examination of the placement of fortifications in the landscape

1 Wallace-Hadrill – Rich 1991; Lang 1999; Zimmermann 2015; Zuiderhoek 2017.

2 Knitter et al. 2013; Radt 2016, 17–20.

3 Radt 2016; Radt 2018.

4 Marek – Frei 2017, 238–391.

5 Arist. Pol. 7.1327a; Koparal 2009, 501.

and the factors that commanded them will allow us to assess the potential of an interactional defense network with Pergamon as a central node. Our aim is to analyze these fortified places in their physical contexts in order to better understand their functions and to develop prognoses regarding the city's ability to control its surrounding landscape. The analyses are based upon digital elevation data and are employed in a script-based environment using free and open-source software to enable their reproduction[6]. The paper applies a novel combination of three different, landscape-based approaches: visibility analyses, site location analyses, and the modeling of movement, all of which are reproducible with the data provided.

3 A prerequisite for networking and communication is a simultaneous occupation of or at least access to the fortified places, which is assumed as a hypothesis in this study. Inter-visibility among these and with Pergamon would be necessary for any type of signaling to create a visual communication network, one that was surely much faster than physical travel and therefore more effective for surveillance[7]. Whether such visual relationships actually existed and whether they were intentionally created to establish a network of surveillance as part of an Attalid defense strategy will be assessed through various visibility analyses.

4 Visibilities within a landscape are highly dependent on topography and are not the only factor in the selection of site locations. Therefore, additional geomorphometric analyses will be conducted for a better understanding of the site locations in relation to strategic targets, such as roads, communities, and vital resources, as well as with the overall local topography.

5 Visual control of important areas such as valleys, roads or harbors is an important factor for the security of a region, but the ability to mobilize military resources in time is just as important. Besides a good overview, the ability to reach critical points in the monitored area would also have determined the site locations of fortifications. Due to the heterogeneous landscapes, regions in the Bakırçay Plain would have been more readily accessible than narrow tributary valleys, plateaus, or ridges. To objectively estimate travel times from the fortifications through their immediate surroundings, we calculated isochrones (lines of equal travel time), indicating all the areas that can be reached within a given time[8]. Based on these analyses, it can be assessed whether a lack of inter-visibility could be bridged with movement between fortifications in the context of communication. Furthermore, it can be determined to what extent the positioning of the fortifications was aimed at reaching strategic areas or targets, or how large their hypothetical area of control was. In addition, the isochrones show whether and to what extent all important places and areas in the Pergamon Micro-Region could be reached by one of the fortifications within a certain time.

6 By combining these landscape-based analyses with recent and ongoing field research[9], a comprehensive picture of the characteristics and structure of the command over the landscape around the Hellenistic royal seat of Pergamon will be drawn. The

6 Code and data are published on Zenodo (Knitter et al. 2021) and now also in the data repository iDAI.repo (https://doi.org/10.34780/jy6t-ad17).

7 E.g. Clark – Parker 1987.

8 Becker et al. 2017; Oltean – Fonte 2021.

9 »Elaia: Eine aiolische Polis als Subzentrum der hellenistischen Metropole Pergamon« (F. Pirson) and »Landstädte, Dörfer und Gehöfte in der Chora des hellenistischen Pergamon« (M. Zimmermann) were funded within DFG-Schwerpunktprogramm 1209 »Die hellenistische Polis als Lebensform. Urbane Strukturen und bürgerliche Identität zwischen Tradition und Wandel« (2006–2012); »The Maritime Topography of the Ancient Kane Peninsula: A Micro-Regional Approach to the Impact of Harbours and Anchorages on Politics, Economy and Communication of a Western Anatolian Landscape. Kane Regional Harbour Survey (KRHS) 2014–2018« (F. Pirson) was part of »Portus Limen – Rome's Mediterranean Ports« (S. Keay) and financed by the European Research Council (European Union's Seventh Framework Program FP7/2007–2013); »Die Transformation der Mikroregion Pergamon zwischen Hellenismus und römischer Kaiserzeit« (2019–today, F. Pirson, B. Schütt, T. Schulz-Brize) is an ongoing project funded by the German Research Foundation (DFG).

inclusion of results from current fieldwork and newly discovered sites is a great advantage in this study. Ongoing fieldwork also allows a better assessment and interpretation of the analyses. The transparency and traceability of our decisions and results are ensured by the publication of the code and data in the analyses.

Landscape, Fortifications, and Visual Relations in the Pergamon Micro-Region

7 Ancient Pergamon is situated on a steep hill some 25 km inland at the northern edge of the lower Bakırçay Plain (ancient Kaikos Plain) (Fig. 1). The surrounding landscape is very heterogeneous, characterized by several mountain ranges, flat and wide plains, isolated hills and the Aegean coastline. The center was the lower Bakırçay Plain, framed to the north by the Kozak and Madra Dağı Mountains (ancient Pindasos, 1,343 m), to the south by the Yunt Dağı Mountains (ancient Aspordenon, 1,076 m), and to the west by the Kara Dağı Mountains (ancient Kane, 772 m) on the Kane Peninsula. This region is defined as the Pergamon Micro-Region, a dynamic space of interaction between humans and their natural environment with an extent that varies according to the level of interaction as well as diachronic changes[10]. The Pergamon Micro-Region thus provided essential resources[11], ensured access to important transportation and communication routes[12], and had a high religious value as a sacred landscape through the creation of rural sanctuaries and tumuli as landmarks[13].

8 The landscape of the micro-region was included in the archaeological investigations from the early stages of systematic fieldwork on as an important context for understanding the history of the city. The geography and geology of the surrounding countryside were elaborately described and mapped in the early 20th century[14]. Even today, topography is seen as a determining factor in the placement of specific sites at specific locations within the landscape[15], which is why detailed studies on the relief of the micro-region and its dynamics are also structurally part of current research[16].

9 Based on the current state of research on the historical landscape and the archaeological record, this study focuses particularly on the western part of the Pergamon Micro-Region: the western lower Bakırçay Plain with the adjacent mountains, the Kane Peninsula and its coastline. The eastern part of the micro-region as well as the more mountainous regions will be included in future research, supported by new fieldwork. Our approach extends the work of Christina G. Williamson, who for the first time applied Geographic Information System (GIS)-based visibility analyses in the Pergamon Micro-Region to examine visual relationships of (fortified) sites and their relationship to their environment in the western Bakırçay Plain[17].

10 The Attalids, whose control over the area extended from the early 3rd century until the latter part of the 2nd century B.C.E., are known to have anchored their rule to Pergamon and its landscape. Their territorial claims were made manifest through the strategic placement of rural sanctuaries in Kapıkaya or Mamurt Kale and visually

10 Pirson 2017, 92; Pirson 2020, 158; cf. Horden – Purcell 2000; Zimmermann 2015; Schuler 2016.
11 Sommerey 2008, 159–169; Pirson – Zimmermann 2014; Laabs – Knitter 2021.
12 Tozan 2017; Feuser et al. 2020; Laufer 2020; Ludwig 2020; Ludwig 2022.
13 Wulf 1999; Agelidis 2009; Pirson et al. 2011, 123–126; Agelidis 2012; Pirson 2012a, 219–225; Ateş 2014; Williamson 2014a; Williamson 2016; Pirson 2017; Pirson – Ludwig in press.
14 Philippson 1902; Conze 1912, 43–59 (A. Philippson).
15 Reu et al. 2011, 3435.
16 Becker et al. 2020; Yang et al. 2021.
17 Williamson 2016; Williamson in press a; Williamson in press b.

1

Fig. 1: The Pergamon Micro-Region: Lower Bakırçay Plain and adjacent Madra Dağı, Kozak, Yunt Dağı, and Kara Dağı Mountains. The study area stretches between Pergamon and the coastline

significant funerary-monuments near the city[18]. These elements served as landmarks within the micro-region and created visual reference points within Pergamon's core territory. But in order to be able to assert and defend their territorial claims, especially in the transitional and volatile Hellenistic period[19], the Attalids installed military facilities at strategic locations surrounding the city and in its vital hinterland[20]. This is testified, for example, by an inscription mentioning a fortress in the Yunt Dağı Mountains near the present village of Yaylaköy[21]. Furthermore, it is attested that the area around Pergamon was under attack by the Gauls and rival rulers such as Philip V[22]. Fortifications at strategic locations enabled the control over the extensive territory while serving simultaneously as landmarks of Attalid presence. John Ma referred to Attalid Asia Minor as a »militarized landscape«, but this is noticed even at a regional level[23]. The first generation of researchers at Pergamon already discovered a large number of Hellenistic fortresses in the Kara Dağı Mountains and near the harbors of Kane[24] and Pitane[25] in the late 19th century[26]. In the following years, up to 14 watchtowers were postulated for the

18 Wulf 1999; Agelidis 2009; Pirson et al. 2011, 123–126; Agelidis 2012; Pirson 2012a, 219–225; Ateş 2014; Williamson 2014a; Williamson 2016; Pirson 2017; Pirson – Ludwig in press.

19 Marek – Frei 2017, 238–391.

20 Pirson 2012a, 225–229.

21 Müller 2010.

22 E.g. Polyb. 16.1.

23 Ma 2013, 73.

24 Pirson 2016, 175 f. (E. Laufer); Pirson 2018, 152–157 (S. Feuser – E. Laufer); Laufer 2020.

25 Pirson 2016, 181–184 (E. Laufer); Pirson 2018, 157–161 (S. Feuser – E. Laufer); Laufer 2020.

26 Schuchhardt 1887, 1209–1211; Conze 1912, 100 f. 108 f. (C. Schuchhardt).

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Kara Dağı Mountains, although not all of these can be located today[27]. Carl Schuchhardt was the first researcher to hypothesize a visual network in the region. He discovered, for example, that information on fleet movements in the area of the Arginusae Islands near Kane could be transmitted as signals to Pergamon via the fortresses on Kavaklık Tepe (Kabalyk)[28], Hatipler Kalesi[29] and Kalarga Tepe/Teuthrania[30]. Wolfgang Radt takes up the idea of a potential Hellenistic protection and communication system again in the context of a watchtower near Kapıkaya few kilometers north of Pergamon[31]. He also discusses the fortifications on the Kane Peninsula and concludes that this »watch and warn« system secured a smaller area than the actual borders of the Pergamene territory. In a contribution on the Hellenistic fortification of Pergamon and its regional strategic importance, Manfred Klinkott adopts the hypothesis of an extensive system of watch-towers and small fortresses and discusses their landscape positioning and orientation towards the plain of the Bakırçay River[32]. A network of military installations controlled from Pergamon was also assumed by Felix Pirson, in the context of Hellenistic fortresses in the vicinity of Atarneus[33]. Martin Zimmermann linked fortified settlements on the hills of the Bakırçay Plain and the adjacent mountains to the military protection of the *chora* of Pergamon[34], but at the same time, he argues against the military function of many sites and interprets them as centers of agricultural estates, so-called *Turmgehöfte*[35]. Due to the fortified character of the sites and their mostly spectacular view one cannot rule out an additional function for (local) surveillance. We therefore include these places in our analyses for a start, allowing for a more complex interpretation of their function.

Fig. 2: View from the western slope of the Acropolis of Pergamon with the present-day city of Bergama and the location of the fortresses on Büyüksofulu Tepe, Serhat Tepe, Eğrigöl Tepe/Halisarna, and Kalarga Tepe/Teuthrania

11 Pergamon itself was protected by its location on the city hill combined with a city wall[36]. 10 km southwest of Pergamon a Hellenistic fortification was situated on

27 Diest 1889, 8.

28 Schuchhardt 1887, 1210; Conze 1912, 119 (C. Schuchhardt); Pirson 2012b, 212 f. (M. Zimmermann); Zimmermann et al. 2015, 213.

29 Conze 1912, 118 (C. Schuchhardt); Pirson 2010, 181 f. (M. Zimmermann); Pirson 2011, 154–158 (M. Zimmermann); Pirson 2013, 119–121 (A. Matthaei); Zimmermann et al. 2015, 213 f.

30 Conze 1887, 149–160; Schuchhardt 1887, 1209 f.; Pirson 2013, 117–119 (A. Grüner); Zimmermann et al. 2015, 211 f.; Williamson 2016.

31 Radt 2016, 21.

32 Klinkott 1999, 204.

33 Pirson 2012a, 229.

34 Zimmermann et al. 2015, 211.

35 Pirson 2008a, 121 f. (M. Zimmermann); Pirson 2012b, 211–213 (M. Zimmermann); *Turmgehöfte* in general: e.g. Haselberger 1979; Konecny 1997; Pimouguet-Pédarros 2000; Lohmann 2015.

36 On the city wall most recently Lorentzen 2010; Lorentzen 2014; Pirson 2017. On Pergamon in general Pirson – Scholl 2014; Radt 2016; Pirson 2017; Scholl – Schwarzmaier 2018 among others.

the prominent Eğrigöl Tepe/Halisarna[37] in the plain (Fig. 1. 2). The highest and most prominent elevation in the plain west of Pergamon was Kalarga Tepe/Teuthrania (Fig. 1. 2). It is assumed that the Hellenistic fortification on the summit served for the military protection of the plain due to its exceptional location. A smaller fortification from the Hellenistic period is situated on Memeli Tepe[38], a less imposing hill just 5 km west of Kalarga Tepe/Teuthrania. Another 5 km to the north a fortification is located on Dede Tepe[39] in the southern foothills of the Kozak Mountains. The settlement of Atarneus[40], already fortified in Hellenistic period, was also located in the southwestern foothills of the Kozak Mountains at the northwestern entrance of the Bakırçay Plain. On the opposite side of this narrow passage a small fortress (Site 2011/DIK01)[41] was situated in the northern foothills of the Kara Dağı Mountains. Both the fortified settlement of Hatipler Kalesi and the small fortress at Deliktaş[42] in the western area of the Kara Dağı Mountains face the Bakırçay Plain. As previously mentioned, early researchers identified many other fortifications scattered throughout the Kane Peninsula. Many must be considered lost today, with the exception of a few recently rediscovered sites in the western and southern areas of the Kara Dağı Mountains: In the south of this peninsula, there are two probable fortifications near Pitane (Site 2017/PIT01)[43] and on Yazılı Taş Tepe[44], as well as the fortified settlement of Kemikliburun[45] and the watchtower above present-day Denizköy (Site 2017/05)[46]. The two sites of Söğütlü Kalesi[47] and Asarlık Tepe[48] are located on plateaus of Kara Dağı. So far, they have been interpreted as centers of agricultural estates, but with their expansive and strategic views, a military securing function should not be ruled out. Remains of another fortification were found 4 km south of Bademli (Site 2017/06)[49] near Asarlık Tepe. The most elevated fortification in the Kara Dağı Mountains is located on Kavaklık Tepe. This site offers an impressive view both to the coast and to the Bakırçay Plain. Besides several bays and landing sites, two harbor cities were located along the coast of the Kane Peninsula in the Hellenistic period: Kane in the northwest of the peninsula and Pitane on a headland in the south. In both places a city wall can be traced for the Hellenistic period. The same applies to the harbor city of Elaia[50], which as the main harbor of the Attalids had the greatest importance for Pergamon[51]. The harbor city was located on a strategically important place at a narrow point between the foothills of the Yunt Dağı Mountains and the coast at the southwestern entrance to the Bakırçay Plain. The harbor and the coastal road running through this narrow space were additionally secured by the fortress on Sakarkaya[52] 3.3 km southeast of Elaia. Similar fortresses on Zindan Kayası[53] and Gavur

37 Conze 1912, 116 f. (C. Schuchhardt); Pirson 2012a, 225 f.; Pirson 2012b, 215 f. (M. Zimmermann); Zimmermann et al. 2015, 211 f.

38 Pirson 2009, 181 f. (M. Zimmermann); Pirson 2010, 181 f. (M. Zimmermann).

39 Dörpfeld 1928, 154–156; Pirson 2012b, 215 f. (M. Zimmermann); Zimmermann et al. 2015, 212.

40 Conze 1912, 120 f. (C. Schuchhardt); Pirson 2012b, 208–211 (M. Zimmermann); Pirson – Zimmermann 2014, 153–160; Zimmermann et al. 2015, 193–207.

41 Zimmermann et al. 2015, 213.

42 Conze 1912, 100 f. (C. Schuchhardt); Pirson 2010, 168. 182 (M. Zimmermann).

43 Unpublished project report 2017.

44 Pirson 2019, 120 (B. Ludwig).

45 Pirson 2019, 118–120 (B. Ludwig).

46 Pirson 2018, 161–164 (S. Feuser – E. Laufer).

47 Conze 1912, 119 (C. Schuchhardt); Pirson 2012b, 211 f. (M. Zimmermann); Zimmermann et al. 2015, 213.

48 Schuchhardt 1887, 1210; Conze 1912, 119 (C. Schuchhardt); Pirson 2012b, 212 f. (M. Zimmermann); Zimmermann et al. 2015, 213.

49 Pirson 2018, 163 f. (S. Feuser – E. Laufer).

50 Most recently Pirson et al. 2015; Feuser et al. 2018; Seeliger et al. 2019; Feuser et al. 2020.

51 Pirson 2014; Pirson et al. 2015; Feuser et al. 2018; Feuser et al. 2020.

52 Pirson 2010, 201; Pirson 2011, 172 f.

53 Pirson 2010, 201; Pirson 2012b, 222–225; Pirson 2017, 53.

Evleri[54] were located in side valleys a few kilometers south of Sakarkaya. These types of fortifications are also known from other valleys in the northwestern foothills of the Yunt Dağı Mountains in Hellenistic period. The Kuyulu Kaya[55] fortress was located on a high rock in the middle of the Tekkedere Valley. A similar situation can be observed in the small and narrow Değirmendere Valley where a small fortress (Site 2017/04)[56] was situated on a hill near present-day Karahıdırlı. In contrast, the fortresses on Büyüksofulu Tepe[57] and Serhat Tepe[58] were both located on high peaks in the northwestern Yunt Dağı Mountains, offering a wide view of the Bakırçay Plain and the surrounding mountains.

12 The landscape in this area near Pergamon was thus punctuated with watch-towers and strongholds. Even if they were not all simultaneously occupied, their frequency (cf. Fig. 1), indicates an intensive web of defense systems throughout the landscape.

13 The integration of visibility-based approaches into the study of Pergamon and its micro-region however, is neither new nor exclusive to GIS. C. Schuchhardt already considered visibility as a location factor for sites on the Kane Peninsula more than a century ago[59]. Vincent J. Scully and Wolfram Hoepfner outlined visual axes between major Hellenistic buildings on the city hill, the monumental tumuli in the plain, and the surrounding landscape[60]. Visual connections between the city hill of Pergamon and the extra-urban sanctuaries at Mamurt Kale and Kapıkaya were observed by Alexander Conze and Paul Schazmann as well as Klaus Nohlen and W. Radt[61]. Based on this observation, Ulrike Wulf correlated the orientation of the city's road system with visual axes between city hill and sites in the surroundings[62]. These relations were most recently revised by F. Pirson[63]. His studies of Pergamon's territory as a perceptual space[64], or its role as the visual-aesthetic center of the dominion[65], were extended by C. G. Williamson[66] by the concept of a ›visual region‹ for the lower Bakırçay Plain and GIS-based visibility analyses. Most recently, such analyses have been applied by F. Pirson and Bernhard Ludwig[67] in the study of urban-landscape interactions and by Daniel Knitter and B. Ludwig[68] to demonstrate a completely reproducible work-flow in landscape archaeological research.

14 The examples mentioned here illustrate that seeing and being seen can be associated with religious ideas or political motives. In this study, however, we focus on the need for surveillance, communication, or control and its impact on the positioning of places within a landscape.

54 Conze 1912, 114 f. (C. Schuchhardt); Pirson 2010, 200 f.
55 Pirson 2019, 115 f. (B. Ludwig); Pirson 2020, 210–212 (B. Ludwig).
56 Pirson 2018, 167 f. (B. Ludwig – F. Pirson).
57 Pirson 2019, 117 f. (B. Ludwig).
58 Pirson 2012b, 213 f. (M. Zimmermann); Pirson 2013, 121 f. (A. Matthaei); Zimmermann et al. 2015, 212 f.
59 Schuchhardt 1887.
60 Scully 1979, 194–198; Hoepfner 1990, 282.
61 Conze – Schazmann 1911 on Mamurt Kale and Radt 1978, 71 on Kapıkaya.
62 Wulf 1999.
63 Pirson 2017, 61 f.
64 Pirson 2008b, 45.
65 Pirson 2012a, 219–225.
66 Williamson 2016.
67 Pirson – Ludwig in press.
68 Knitter – Ludwig 2021.

Archaeological and Topographic Data

15 Archaeological data used in this study includes a data set of 27 archaeological sites assembled and published through various survey projects managed by the Pergamon Excavation Project[69].

16 The analyses conducted in this study are based predominantly on topographic data (derived from a digital elevation model DEM). These models usually represent the present-day terrain surface and only in rare cases can the ancient topography be reconstructed. Nevertheless, modern elevation models form the basis for these analyses and their horizontal and vertical accuracy as well as their resolution significantly influence the calculated results. Therefore, it is essential to mention this information and take them into account when comparing and interpreting the results.

17 In this study we use an open-access DEM to guarantee reproducibility. The elevation data are provided by the EU Copernicus project as EU-DEM v1.1. This provides a digital surface model that fuses SRTM and ASTER GDEM data using a weighted average approach. The EU-DEM v1.1 has a pixel resolution of 25 m × 25 m and a vertical accuracy of 7 m[70].

Methods

18 This study follows a landscape approach most recently proposed by Sylvian Fachard[71] and is based upon quantitative spatial analyses to assess the networking potential of rural fortifications and Pergamon's ability to control its micro-region. These phenomena depend on numerous factors, necessitating an approach that integrates analyses from the perspective of topography, visual perception, and mobility.

19 All analyses conducted in this study are based solely on open-source software. Basic processing, reading, writing, and reprojection of spatial data are conducted using GDAL[72]. R software is used as general entry point to more advanced geomorphometric methods conducted via GRASS GIS[73].

Relief

Topographic Position Index

20 The Topographic Position Index (TPI) is a measure of the difference between the elevation of a point on a DEM and the mean elevation of the neighboring cells within a predetermined radius[74]. In this study, the point represents the location of the site and the neighboring cells represent the landscape. Sites with positive TPI values are located higher than the average of their surrounding landscape and sites with negative TPI values are located lower, meaning that positive TPI values indicate an exposed location within a landscape while negative TPI values indicate a valley or depression-like location. TPI values around 0 correspond to flat areas or constant slopes. Using this method, we can classify the topographic positions of the sites relative to the local landscape. This allows us to draw conclusions about the individual function of a site. And by comparison

69 See also footnote 9.
70 Copernicus Programme 2021.
71 Fachard 2016a; Fachard 2016b.
72 GDAL/OGR Contributors 2021.
73 GRASS Development Team 2017; R Core Team 2021. For our computational code and further details see Knitter et al. 2021.
74 Cf. Weiss 2001; Lindsay et al. 2015.

with other sites and results, we may be able to identify commonalities, connections, and relationships that indicate a higher-level role within a system or network.

21 For the calculation of the TPI we employ the r.neighbors tool in GRASS GIS that calculates each cell of a raster file (the DEM) as a function of the values assigned to the cells around it (i.e., in its user-defined neighborhood). In our case, the function is the difference from mean elevation between the pixel and the mean of all pixels in its neighborhood. Small-scale topographic features can be revealed using small neighborhood sizes and large-scale features such as ridges or valleys can only be highlighted through large neighborhood sizes. This illustrates the scale dependence of TPI. The term scale can have two meanings that should be considered. On the one hand, it refers to the extent in space, i.e., the size of neighborhood, and on the other hand, to the resolution, in this case the pixel size of the DEM[75]. Marzieh Mokarram and Dinesh Sathyamoorthy described scale as »the window of perception, and hence, it has a direct influence on the landform type on a specific location«[76]. In this study, we want to investigate both the local topography surrounding each site and its position within the landscape from a more general perspective. To account for both scenarios, we calculate the TPI with both a neighborhood size of 5 cells (125 m) and 11 cells (275 m).

Geomorphons

22 In order to put our site-based investigations into the wider topographic context, we additionally compute geomorphons. This concept was introduced by Tomasz F. Stepinski and Jaroslaw Jasiewicz, who define geomorphons as »a relief-invariant, orientation-invariant, and size-flexible abstracted elementary unit of terrain«[77]. Thus, geomorphons are much less sensitive to scale. Instead of a fixed neighborhood size, e.g., a specific number of immediate neighboring cells, this method uses pixels determined from the line-of-sight principle along the eight compass directions. The search radius represents the maximum allowable distance for calculation of their zenith and nadir angles. All pairs of zenith and nadir angles are converted into a pattern and assigned to a geomorphon[78]. Using the r.geomorphon algorithm in GRASS GIS the ten most common landform types (flat, summit, ridge, shoulder, spur, slope, hollow, foot slope, valley, and depression) were derived from the DEM. We set the flatness threshold to 1 degree and the flatness distance to 100 m to take care of modern noise, e.g., caused by small dams for traffic and agricultural purposes. To obtain a differentiated result, we use five different search radii: 100 m, 500 m, 1,000 m, 1,500 m, and 2,000 m. These represent both a local and a regional perspective.

Visibility

23 Visibilities are highly dependent on the topography of a landscape. Prominent sites, for example, rise out of the landscape, are visible from a distance, and are »related to visual and physical control«[79]. Visibilities and the relative topographic position of archaeological sites are thus closely related and must be studied together.

24 The study of visibility has numerous applications in archaeological research today[80]. Especially in landscape archaeology, visibility is considered a structuring

75 Goodchild 2011, 5.

76 Mokarram – Sathyamoorthy 2018, 653.

77 Stepinski – Jasiewicz 2011, 109.

78 Jasiewicz – Stepinski 2013, 152.

79 Llobera 2001, 1007.

80 E.g. Brughmans et al. 2018; Fábrega-Álvarez – Parcero-Oubiña 2019; Lewis 2020 among many others, and with an overview and further reading Gillings – Wheatley 2020.

element of past landscapes and important factor in the location of sites[81]. Since the emergence of GIS software, the application of visibility analysis is a regular feature of many archaeological studies. As long as the difficulties in the application, both in the computational process and in the interpretation of the results, are not disregarded, computer-based visibility analyses are supportive tools in the study of ancient human-environment relationships.

Single Viewsheds of Each Site

25 Viewsheds are the areal extent of visibility from a designated place. In GIS one can calculate a viewshed based on the surface values in a digital elevation model (DEM). Using a defined observer location, the viewshed function will assign a value of 1 or 0 to each raster cell. The result is a binary map with the values ›visible‹ and ›not visible‹. In GIS analyses the observer's field of vision is infinite, restricted only by the extent of the applied terrain model or curvature of the earth, although other parameters can be applied, such as observer or target height, visual range, or scope. In practice, however, seeing and recognizing is determined, for example, by the size of the object, the contrast to its surroundings, its brightness, color and shape. To compensate for this, David Wheatley and Mark Gillings[82] introduced the Higuchi viewshed analysis[83] to archaeological research, which classifies the range of visibility to distance values. Dennis Ogburn[84] further adapted this method by integrating environmental (haze, light conditions, etc.) and object-related (size, contrast, etc.) factors into the calculation. In these ›fuzzy‹ viewsheds, degrees of visibility between 1 (clearly visible) and 0 (not visible) are assigned. However, visual perception is a complex phenomenon that cannot yet be fully modeled in GIS. Most of the common issues were summarized by D. Wheatley and M. Gillings[85] and should be considered in the calculation, but especially discussed in the interpretation process of visibility analyses.

26 We compute the viewsheds using the r.viewshed algorithm in GRASS GIS. Generally, they are calculated from a single observation point. This approach however, is unsuitable for larger sites such as hilltops or fortified settlements. One alternative is to create random points in a defined area surrounding the site and calculate a viewshed for each of these points. Another alternative, that integrates the assumption of several hilltop sites, is to use the most exposed points as defined by the TPI values in the surrounding of a site. We followed this approach and used a radius of 100 m around a site as search radius. Our basic observer height is set to 10 m, taking into account both the observer's eye level and the potential height of towers. For eye level, we refer to Wolf-Rüdiger Teegen[86] who gives an average height of 1.52 m (± 3 cm) for women and 1.57 m (± 3 cm) for men in Hellenistic-Roman Pergamon. For the height of towers, we refer to John H. Young, Josiah Ober and Hans Lohmann[87] and consider 10 m for both tower and observer's eye level to be a conservative height assumption. Since we cannot exclude smaller or larger tower heights due to the often-poor preservation of the archaeological sites we additionally include observer heights of 5 m, 7.5 m, 12.5 m and 15 m in our study. Another parameter is the maximum calculation radius around each site. This maximum range of visibility is set at 40 km, based on known local conditions – for example, the Mediterranean Sea, at c. 30 km away, may be seen from the city hill of Pergamon but only during very clear atmospheric conditions. Consequently, all the

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81 Doneus 2013, 301–306.
82 Wheatley – Gillings 2000.
83 Higuchi 1983.
84 Ogburn 2006; also Llobera 2007.
85 Wheatley – Gillings 2000.
86 Pirson 2020, 234–237 (W.-R. Teegen); cf. Angel 2013 for the Hellenistic Mediterranean.
87 Young 1956; Ober 1987; Lohmann 1993; Lohmann 2015.

fortified sites are within the search radius, but whether they would actually be visible or not must be assessed in the second step, based on the results and the authors' own experience from the field (›ground-truthing‹).

27 To consider the decreasing visibility of objects with distance, i.e., Higuchi (see above), we calculate the visible areas by the distance from the observer location, using a triangular fuzzy membership function to create Higuchi-like viewsheds with values ranging between 1 (visible at the location of the site) and 0 (theoretically visible but too distant to be recognizable), with 40 km as maximum radius. We employ the R package FuzzyLandscapes for these calculations[88].

A Cumulative Viewshed of All Sites

28 We assume that the fortifications and fortified settlements in the western part of the Pergamon Micro-Region form a potential network based on visibility. Combining the calculated viewsheds into a cumulative viewshed[89] of all the sites gives an impression of the entire area that could be visually monitored; the Higuchi-like viewsheds moreover indicate the quality of visibility in different areas, and the importance of favorable atmospheric conditions. It is also possible to identify areas that either could not be viewed or where there could theoretically be other strongholds that are still undiscovered.

Line-of-Sight Connections/Inter-Visibility Network

29 Mutual communication is essential for a potential surveillance and fortification network and can be ensured through connections of inter-visibility. By deliberately placing or using specific sites within the landscape, inter-visibility connections are created and sites are linked together, creating a network based on visibility. Line-of-sight analysis assesses these inter-visibility connections and obstacles along a given line between two locations, and is therefore a useful tool. In performing the analysis, we set both the observer and target heights to 5 m, 7.5 m, 10 m, 12.5 m, and 15 m according to our previously mentioned assumptions (see § 25–27).

Natural Visuality

30 To gain insights into the relationship between visibility in the landscape and the location of the fortified places, we examine the natural visuality of the western micro-region. The term ›visuality‹ implies the qualitative potential of visibility provided by certain areas and the degree to which the studied places were themselves naturally prominent in the landscape, as well as the views which they afforded[90]. It also references the area of visual interaction between those places. Connected with this is the concept of ›visual regions‹, areas that are included within a single frame of viewing which implicitly gives them a logical coherence, at least in the eyes of the beholder[91]. This visual sense of belonging readily extends towards a conceptualization of territory and governance, as Aristotle had prescribed[92].

31 For the area of the Pergamon Micro-Region this extends beyond land. A distinctive feature of this area is the long coastline to the west. Given the maritime and naval activities, this was certainly not a boundary for historical interaction processes and therefore we incorporated the offshore coast in our area of study. However, the range of visibility widely differs between land and sea surfaces and so we generated 9,999

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88 Hamer – Knitter 2018.

89 Wheatley 1995.

90 Llobera et al. 2010.

91 Williamson 2014b; Williamson 2016 with references.

92 Arist. Pol. 7.1327a.

randomly distributed on-shore and 2,000 off-shore observation points in the study area for our calculations of cumulative viewsheds. This allows us to better identify and interpret phenomena along the coastline that arise from this edge location. To compensate for edge effects[93], we extended the modeling area, corresponding to the bounding box of the catchment-based complementary region presented by Julian Laabs and D. Knitter[94] that was further extended by 10 km on each side. For visualization reasons the maps show a smaller area.

Isochrones

32 A prominent or elevated position within the landscape can increase the ability to survey the environment and communicate over greater distances, but at the same time the accessibility of the monitored area must be ensured to control this particular area. Movement through the immediate vicinity of the sites thus constitutes another factor to be considered in this study. Movement usually takes place along paths, but their traces in the study area are very sparse. In order to determine the potential area of influence through movement, we have calculated isochrones[95]. They show the anisotropic cumulative time of moving from a defined location, comparable to least-cost paths[96] without a defined target. The resulting isochrones can be mapped indicating an area that can be reached in a given timeframe. This assists in (a) estimating travel times from the fortifications through their immediate surroundings, in (b) assessing where lack of inter-visibility could be bridged with movement between fortifications to communicate, and in (c) determining whether and to what extent strategic places and important areas in the Pergamon Micro-Region could be reached by one of the fortifications within a certain time.

33 We use the r.walk algorithm in GRASS GIS for the calculations. The cost of movement is determined by the slope and different cost parameters, affecting the movement speed. While the original algorithm employs parameters defined by Eric Langmuir[97], we use updated values following analyses of Joaquín Márquez-Pérez et al. as well as Ian J. Irmischer and Keith C. Clarke[98] to calculate cumulative movement costs, i.e., time in seconds it takes to walk for 1 meter a flat surface (1/walking speed): 0.8 (r.walk default: 0.72); additional walking time in seconds, per meter of elevation gain on uphill slopes: 5.0 (r.walk default: 6.0); additional walking time in seconds, per meter of elevation loss on moderate downhill slopes: -3.25 (r.walk default: 1.998); additional walking time in seconds, per meter of elevation loss on steep downhill slopes: -5.5 (r.walk default: -1.998).

93 Gillings – Wheatley 2020.

94 Laabs – Knitter 2021. See Knitter et al. 2021 for the data and corresponding code.

95 Becker et al. 2017; Oltean – Fonte 2021.

96 On the application of least-cost path analyses in archaeological research see most recently Herzog – Schröer 2019; Parcero-Oubiña et al. 2019; Verhagen et al. 2019; Herzog 2020 among many others. For the calculation of least-cost paths in the Pergamon Micro-Region see Knitter – Ludwig 2021; Ludwig 2020.

97 Langmuir 1984.

98 Márquez-Pérez et al. 2017; Irmischer – Clarke 2018.

Place name	TPI		Geomorphons				
	125 m	275 m	100 m	500 m	1,000 m	1,500 m	2,000 m
Kalarga Tepe/Teuthrania	4.459	20.750	spur	summit	summit	summit	summit
Site near Dikili (Site 2011/DIK01)	2.553	13.203	ridge	summit	summit	summit	summit
Asarlık Tepe	2.392	12.445	ridge	summit	ridge	ridge	ridge
Dede Tepe	2.310	12.566	ridge	ridge	summit	summit	summit
Sakarkaya	2.252	12.733	spur	ridge	ridge	ridge	ridge
Serhat Tepe	2.121	11.079	spur	ridge	ridge	ridge	ridge
Pergamon	1.992	10.656	spur	summit	summit	summit	summit
Eğrigöl Tepe/Halisarna	1.950	10.797	summit	summit	summit	summit	summit
Büyüksofulu Tepe	1.846	10.492	spur	summit	summit	summit	summit
Hatipler Kalesi	1.403	8.241	spur	summit	summit	summit	summit
Atarneus	1.354	8.035	spur	summit	summit	summit	summit
Site near Pitane (Site 2017/PIT01)	1.252	6.547	slope	spur	spur	spur	spur
Memeli Tepe	1.162	5.320	ridge	ridge	summit	ridge	ridge
Site near Denizköy (Site 2017/05)	0.902	5.276	slope	spur	spur	spur	spur
Deliktaş	0.897	4.639	spur	spur	spur	spur	spur
Kavaklık Tepe	0.610	3.614	slope	ridge	summit	summit	summit
Yazılı Taş Tepe	0.584	2.751	slope	slope	slope	slope	slope
Söğütlü Kalesi	0.526	2.760	spur	ridge	slope	slope	slope
Pitane	0.398	2.357	ridge	summit	summit	summit	summit
Kemikliburun	0.343	2.021	slope	slope	ridge	ridge	ridge
Zindan Kayası	0.319	0.430	slope	hollow	hollow	hollow	hollow
Kuyulu Kaya	0.291	0.516	slope	hollow	valley	valley	valley
Elaia	0.245	1.167	spur	slope	slope	hollow	hollow
Kane	0.207	0.763	footslope	footslope	slope	slope	slope
Site near Karahıdırlı (Site 2017/04)	0.001	-0.555	slope	hollow	valley	valley	valley
Site near Bademli (Site 2017/06)	-0.253	-1.487	slope	spur	slope	slope	slope
Gavur Evleri	-0.379	-2.286	slope	valley	valley	valley	valley

3

Fig. 3: Results of TPI and geomorphon analyses sorted in descending order by TPI 125 m

Results

Geomorphometric Analyses

Topographic Position Index

34 The Topographic Position Index provides information on the relative topographic position of the fortifications. Positive values indicate exposed or prominent locations, while negative values indicate valleys or hollows. As may be expected, fortresses will in most cases be located in exposed or well defensible locations. This is demonstrated in the calculated TPI values (Fig. 3).

35 All but a few of the values are positive. Kalarga Tepe/Teuthrania has by far the highest value, which can be explained by its location in the middle of the western lower Bakırçay Plain. Its exceptional location, prominence and importance for the region between Pergamon and the coast have already been recognized[99]. More sites have positive values, but there are also some with negative values that deserve attention. The harbor cities of Elaia, Pitane, and Kane have negative values, due to their location in

99 Williamson 2016.

bays with little exposure. Pitane, located on a headland at the southern Kane Peninsula, should be more exposed than the other harbors, but the difference in elevation between the headland and the sea is negligible. With the exception of site 2017/06 near Bademli, all other sites with low TPI values are located on small hills in very narrow and deeply incised valleys of the Yunt Dağı Mountains. This topographical situation is the reason why the TPI value decreases significantly with larger radii, especially at the Gavur Evleri.

36 In short, the Topographic Position Index generally appears to correctly represent topographic locations, but we need additional data and information to validate this observation.

Geomorphons

37 Geomorphons were calculated for the study area to analyze the sites in their wider topographic context. Since the investigated sites are located in a very heterogeneous landscape and to represent both a local and a regional perspective, we set five different search radii: 100 m, 500 m, 1,000 m, 1,500 m, and 2,000 m. The results show that there are almost no differences between 1,000 m, 1,500 m, and 2,000 m (Fig. 3). We can identify high hills in the flat and wide western lower Bakırçay Plain (e.g., Eğrigöl Tepe/Halisarna or Kalarga Tepe/Teuthrania) with values between 100 m and 1,000 m. The location of small hills in narrow valleys (e.g., Kuyulu Kaya or Site 2017/04 near Karahıdırlı) is not well represented.

38 From the perspective of a regional surveillance or communication system, information can be derived from the combination of TPI and geomorphons (Fig. 3). Half of the sites are located in elevated positions within the landscape with TPI values above 1 (125 m) and 5 (275 m) and corresponding geomorphons (summit, ridge, spur). They have a high potential to form a higher-level system. These sites also predominantly have direct proximity to the western lower Bakırçay Plain (Fig. 1). The other half of the sites has a low TPI and is located in more differentiated topographic units. Their potential to be part of a higher-level system is lower and they may have had more local functions.

39 The advantages of combining multiple geomorphologic analyses can be seen when considering the harbor places of Elaia, Pitane, and Kane. If the TPI indicated little difference in values despite their different locations in bays or on a peninsula, the result of the geomorphons is more meaningful (Fig. 3). The particular position of Pitane on a peninsula on the southern coast of the Kara Dağı Mountains is highlighted by its assignment to the topographic unit of ridge and summit. This result emphasizes the exposed location within the area, which is relevant to the study of monitoring and control.

Visibility Analyses

Single Viewsheds of Each Site

40 The individual viewsheds of each location indicate which areas in their surroundings could be seen and monitored. Orientation, size and range of the visible area allow conclusions to be drawn about the potential for a surveillance function. Higuchi viewsheds also provide information on the quality of visibility.

41 The viewshed of Pergamon shows a good visibility of the southern Bakırçay Plain up to the foothills of the Yunt Dağı Mountains (Fig. 4). The view extends to the coast and the Kara Dağı Mountains, but the quality of visibility decreases significantly. However, fortresses such as Kalarga Tepe/Teuthrania, Eğrigöl Tepe/Halisarna or Serhat Tepe are still located in the highly visible area (Fig. 2).

42 The visible area of Kalarga Tepe/Teuthrania, the fortress on a prominent hill in the middle of the plain, is exceptionally extensive (Fig. 5). Due to its special position,

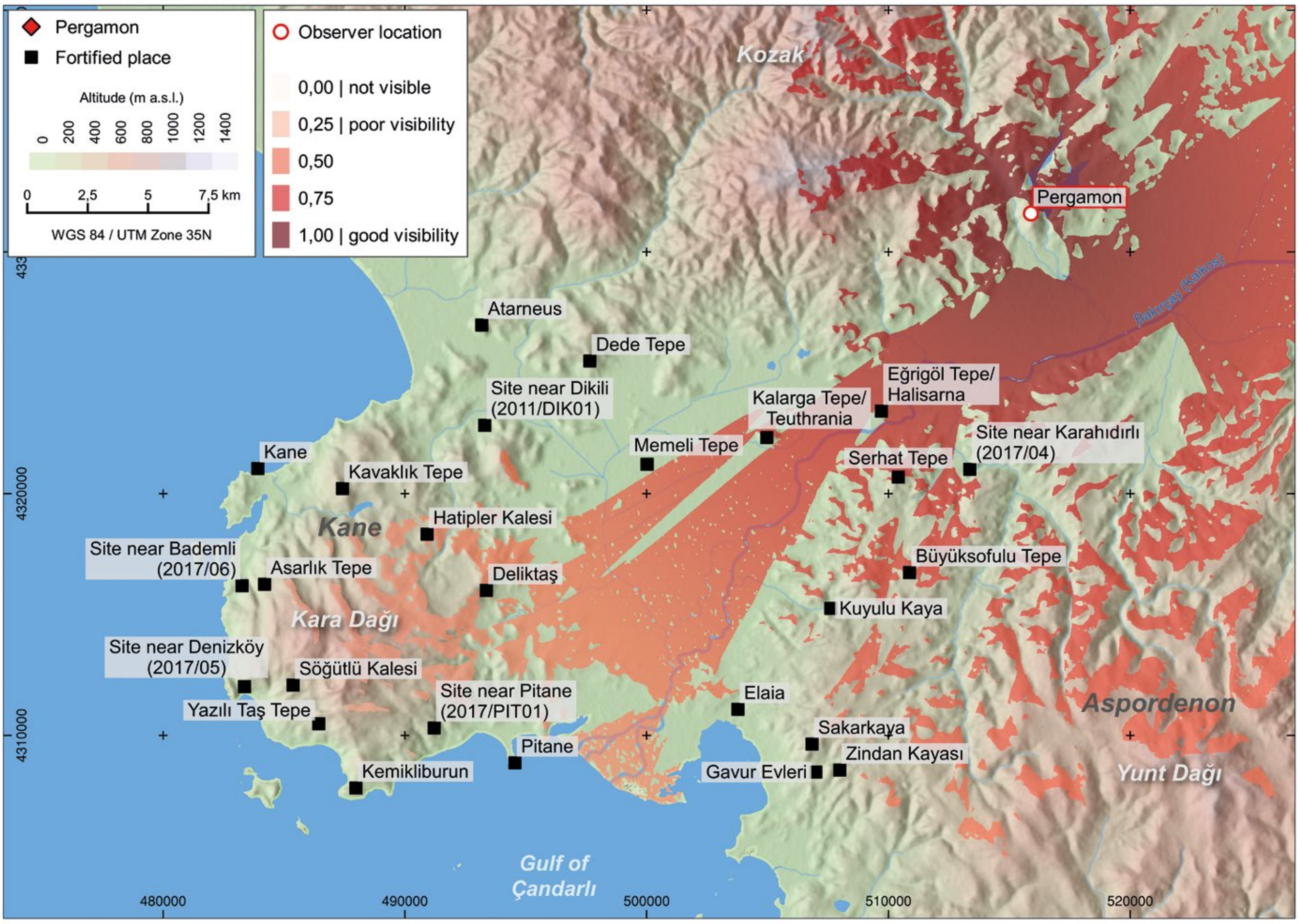

Fig. 4: Higuchi viewshed from Pergamon (10 m observer height)

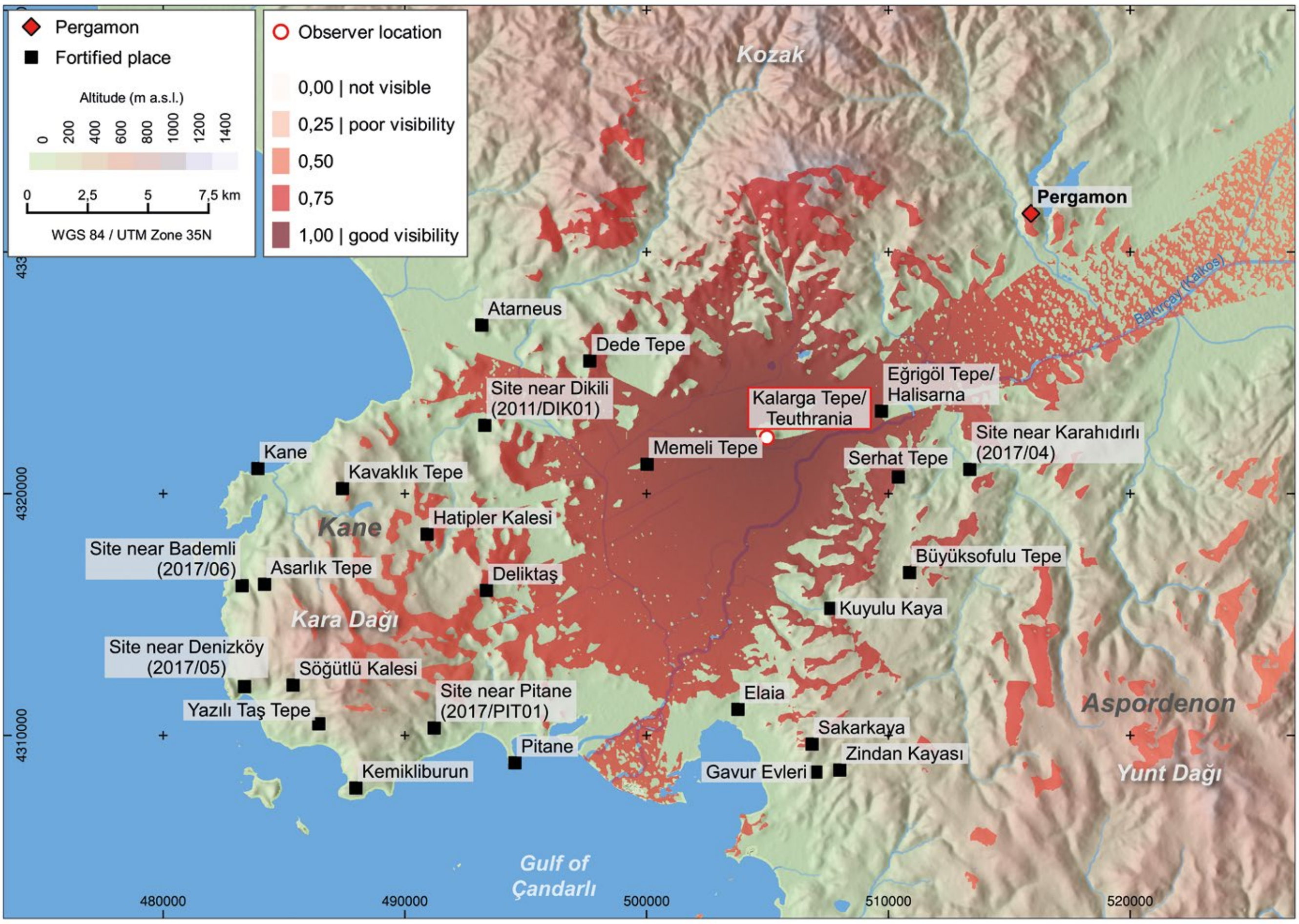

Fig. 5: Higuchi viewshed from Kalarga Tepe/Teuthrania (10 m observer height)

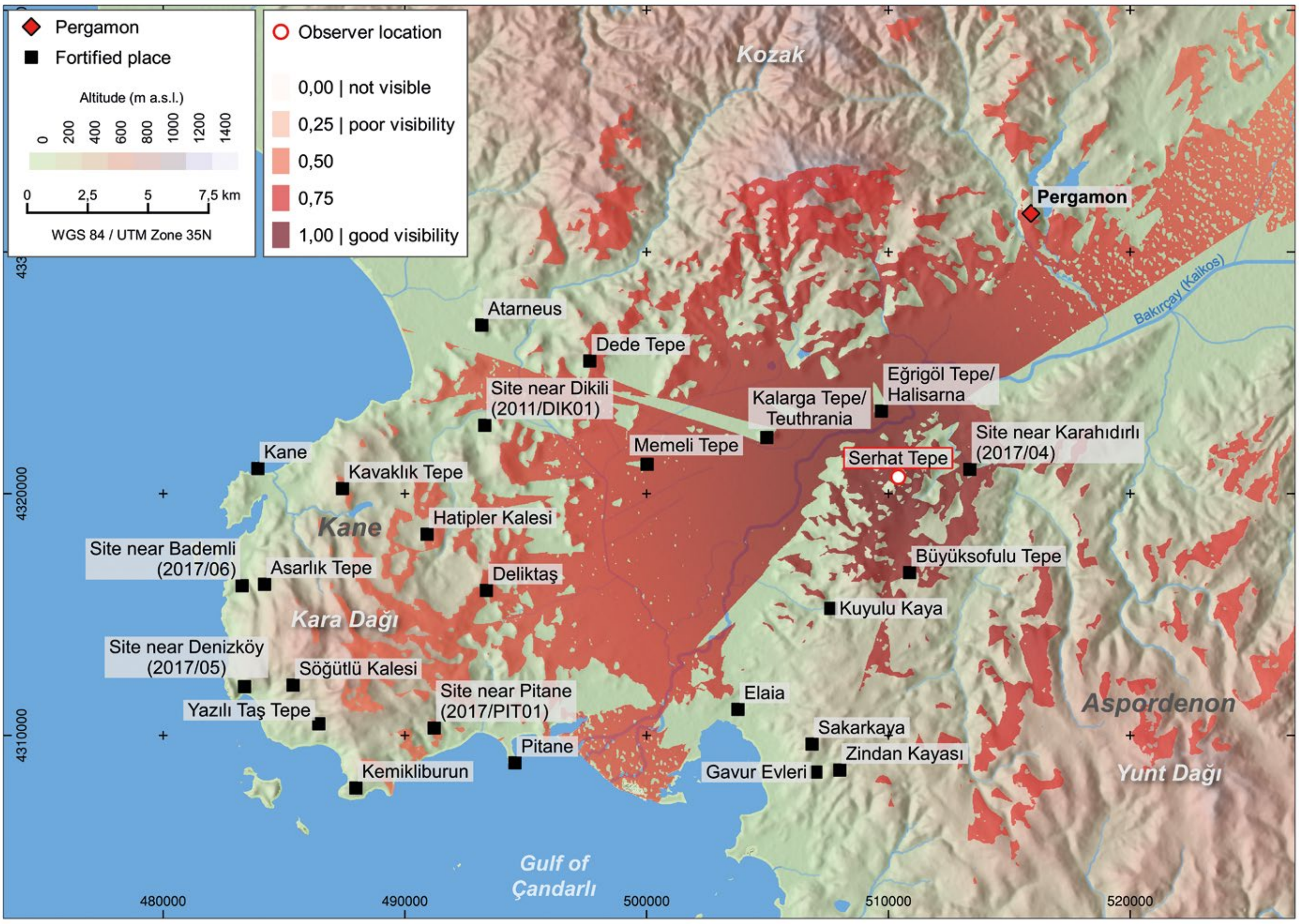

Fig. 6: Higuchi viewshed from Serhat Tepe (10 m observer height)

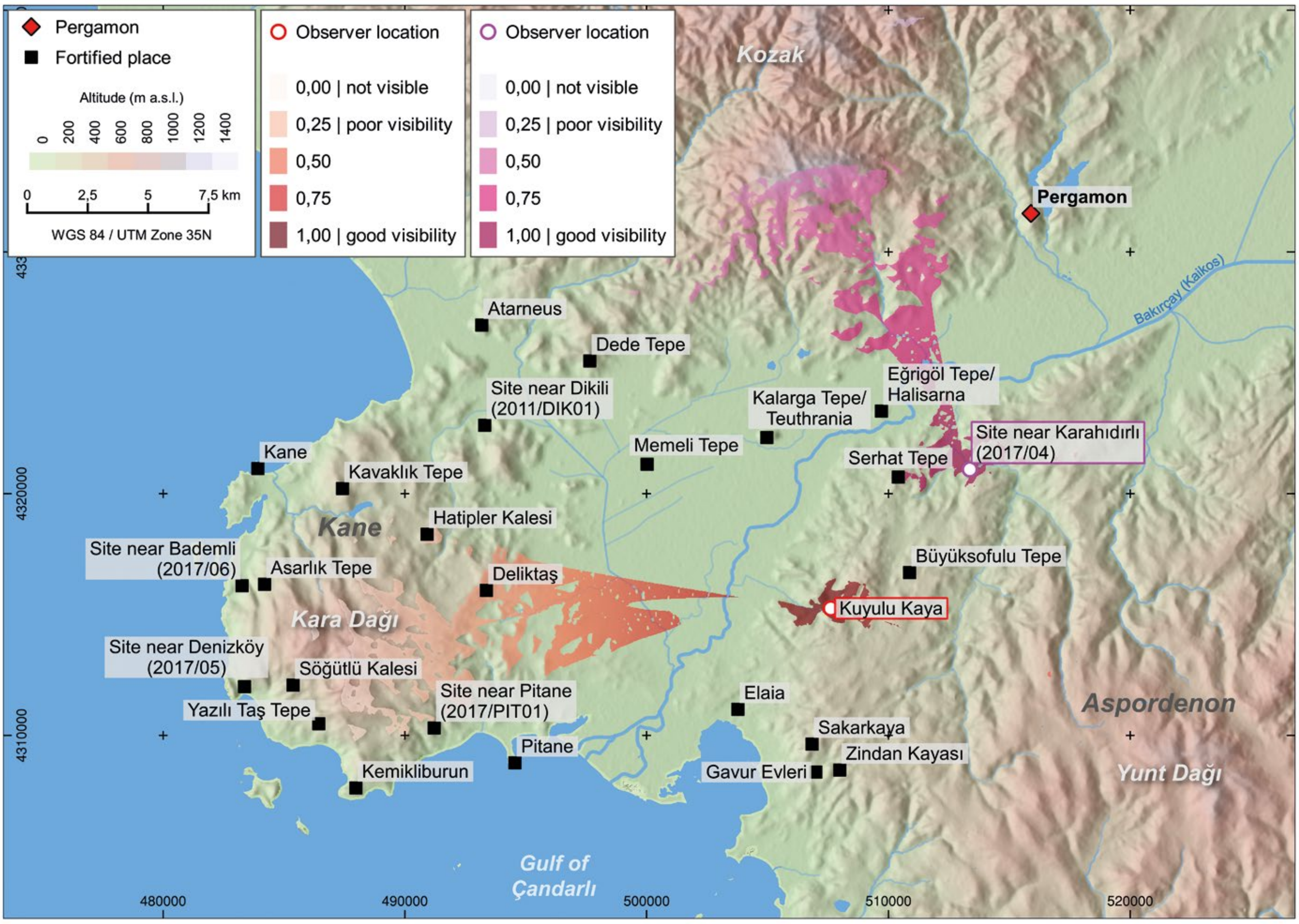

Fig. 7: Higuchi viewshed from Kuyulu Kaya (red) and the site near Karahıdırlı (2017/04) (violet) (10 m observer height)

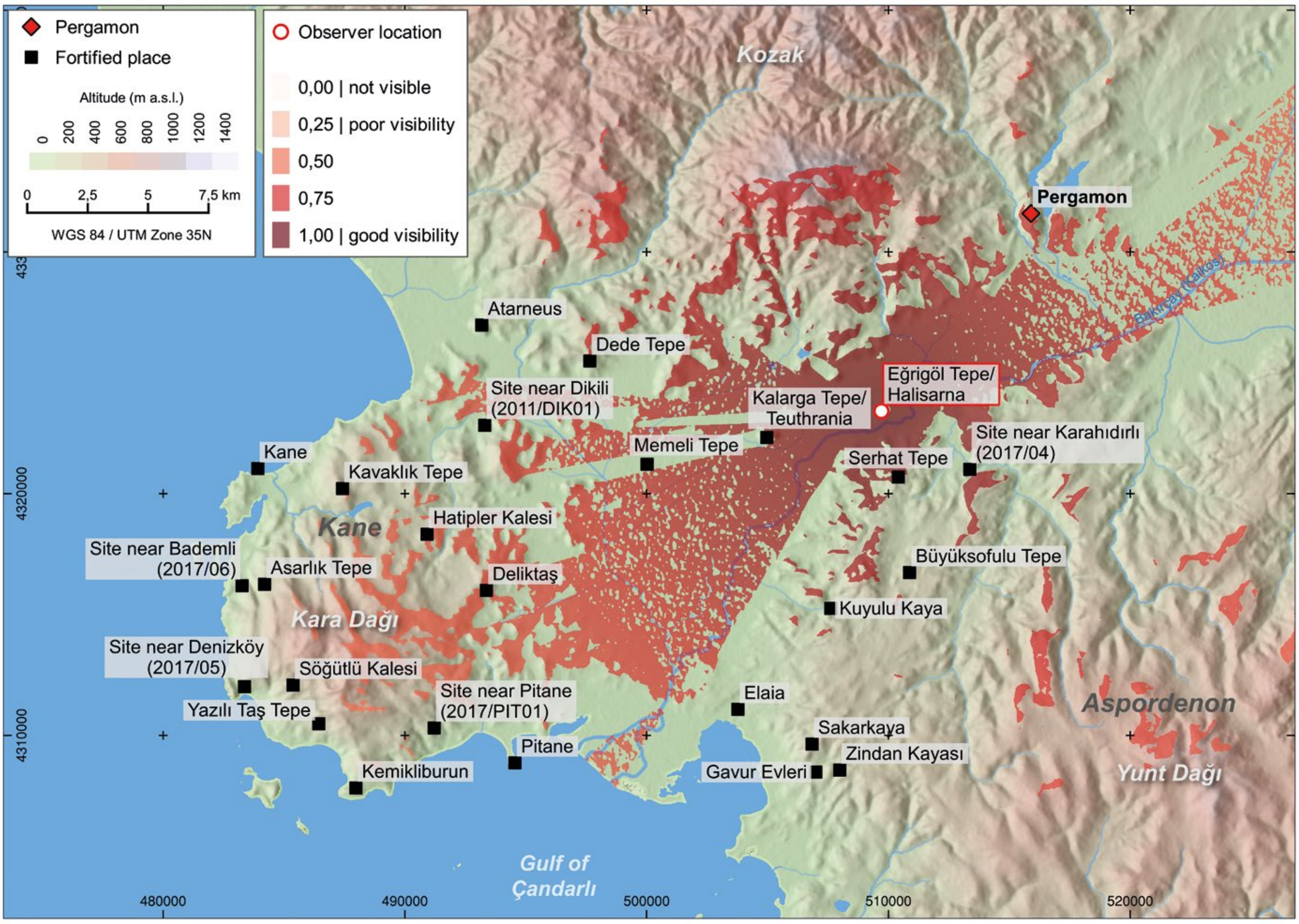

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Fig. 8: Higuchi viewshed from Eğrigöl Tepe/Halisarna (10 m observer height)

parts of the eastern lower Bakırçay Plain, Pergamon, the entire western lower Bakırçay Plain, the surrounding mountain ranges, and parts of the coastline between Elaia and Pitane are visible. The fortress on Serhat Tepe has a similarly extensive visible area (Fig. 6). From this point, parts of the Yunt Dağı Mountains range with its side valleys leading to the plain, the transition between the mountains and the plain, can be monitored. This is especially true for the intramontane basin framed by the forts on Serhat Tepe and Büyüksofulu Tepe (Fig. 6), an intensively used agricultural area in the immediate vicinity of Pergamon[100]. Also, smaller side valleys could apparently be monitored by their own fortresses, which could serve as a retreat in troubled times. A good example of this is the viewshed of Kuyulu Kaya (Fig. 7). The visible area is almost exclusively limited to the Tekkedere Valley. The fortress near Karahıdırlı (2017/04) in a narrow valley in the foothills of the Yunt Dağı Mountains has a similarly small visible area (Fig. 7). It probably had a local function, such as monitoring or controlling the route that led from the mountains through the valley to the Bakırçay Plain and Pergamon[101]. Eğrigöl Tepe/Halisarna, on the other hand, has already been interpreted as an outpost of the city monitoring and controlling of the main traffic route through the western lower Bakırçay Plain and an ancient bridge over the Kaikos River next to the hill[102]. The viewshed from this place, covering large parts of the plain, supports this hypothesis (Fig. 8). Further visual relations can be identified along the coastline. The viewsheds from Sakarkaya (Fig. 9) and the

100 Pirson 2020, 223–227 (F. Becker – D. Knitter – X. Yang – B. Schütt); Pirson 2020, 212–214 (B. Ludwig); Pirson 2020, 220–223.

101 Cf. Ludwig 2020.

102 Pirson 2012a, 225 f.

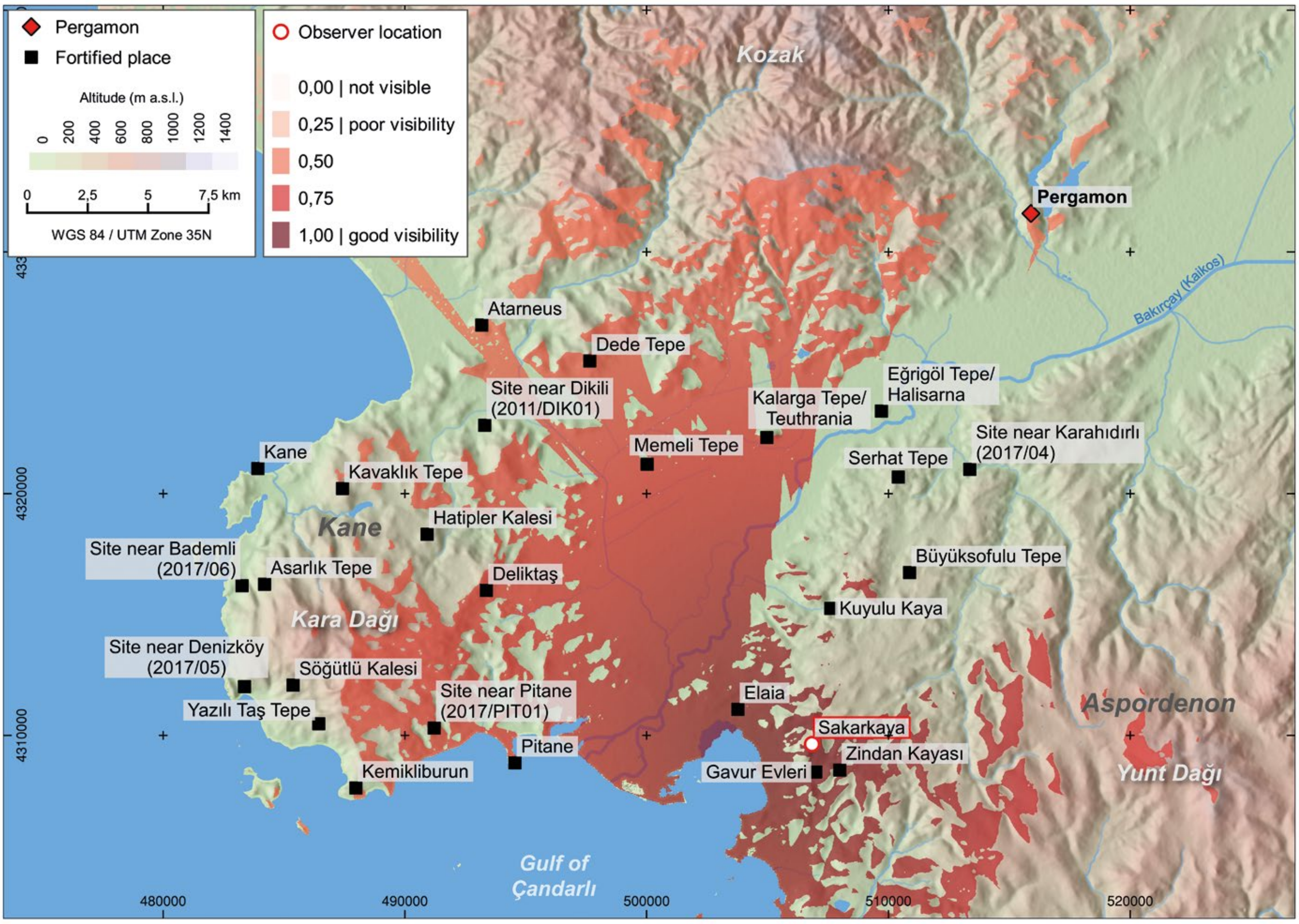

Fig. 9: Higuchi viewshed from Sakarkaya (10 m observer height)

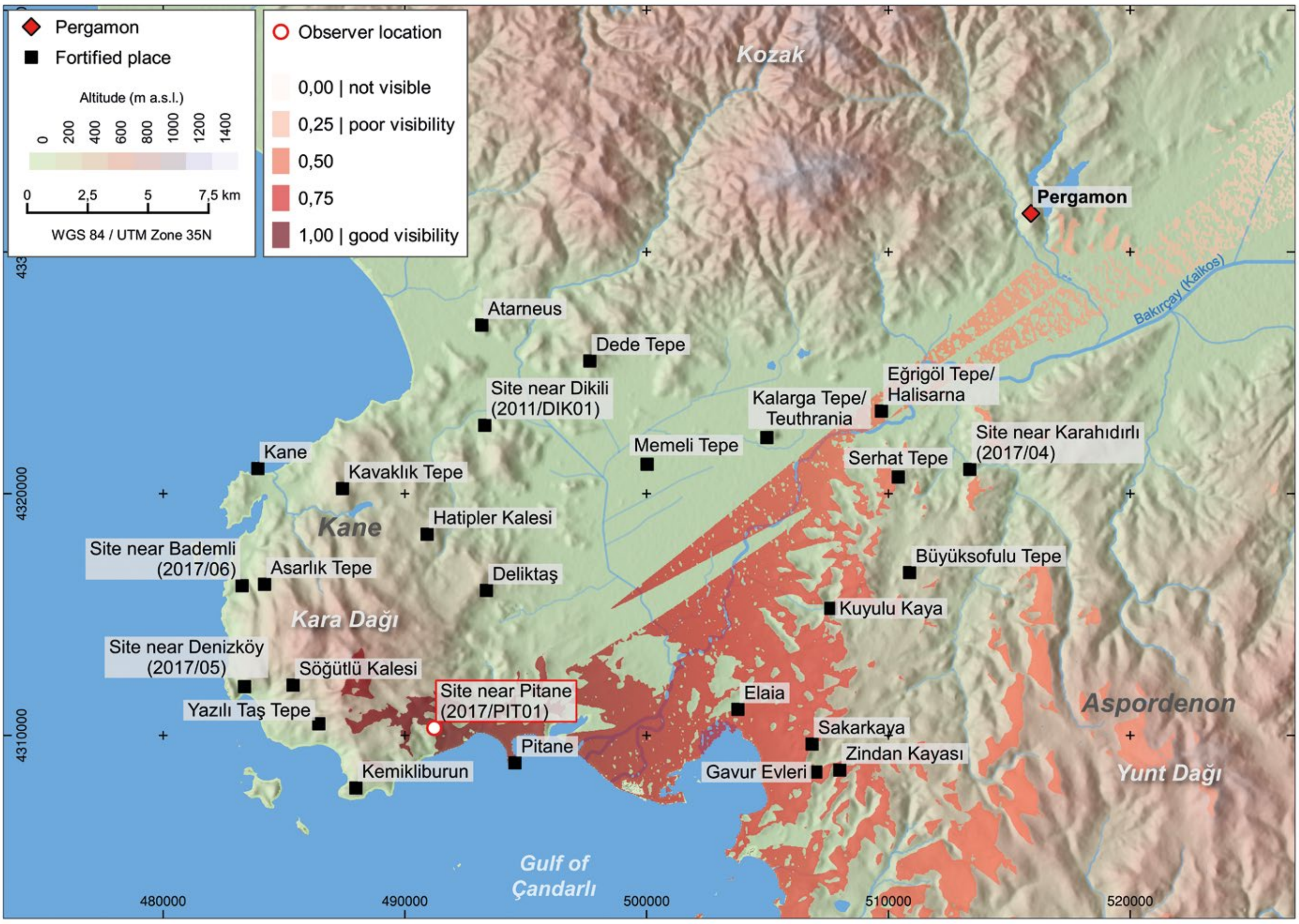

Fig. 10: Higuchi viewshed from the site near Pitane (2017/PIT01) (10 m observer height)

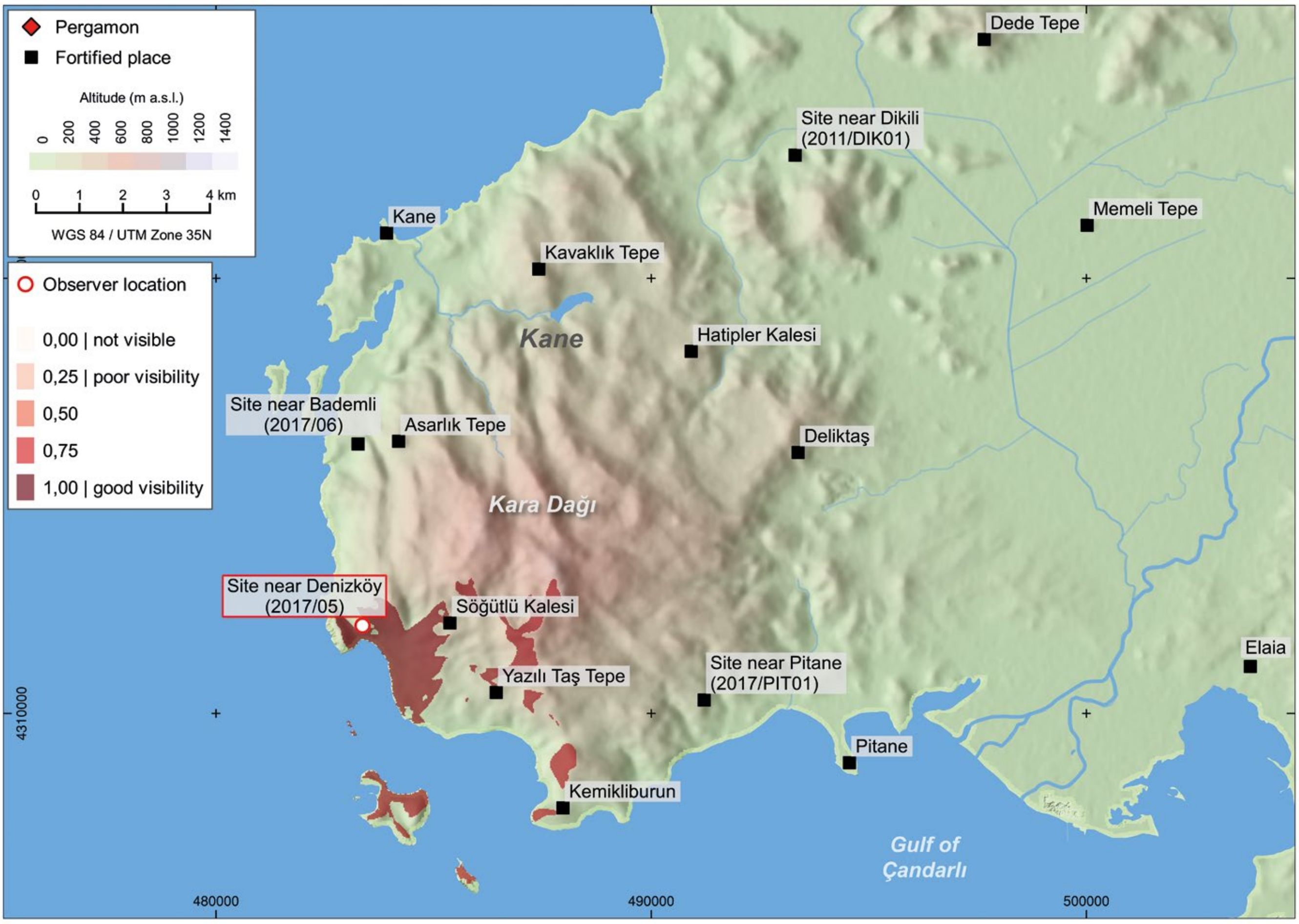

Fig. 11: Higuchi viewshed from the site near Denizköy (2017/05) (10 m observer height)

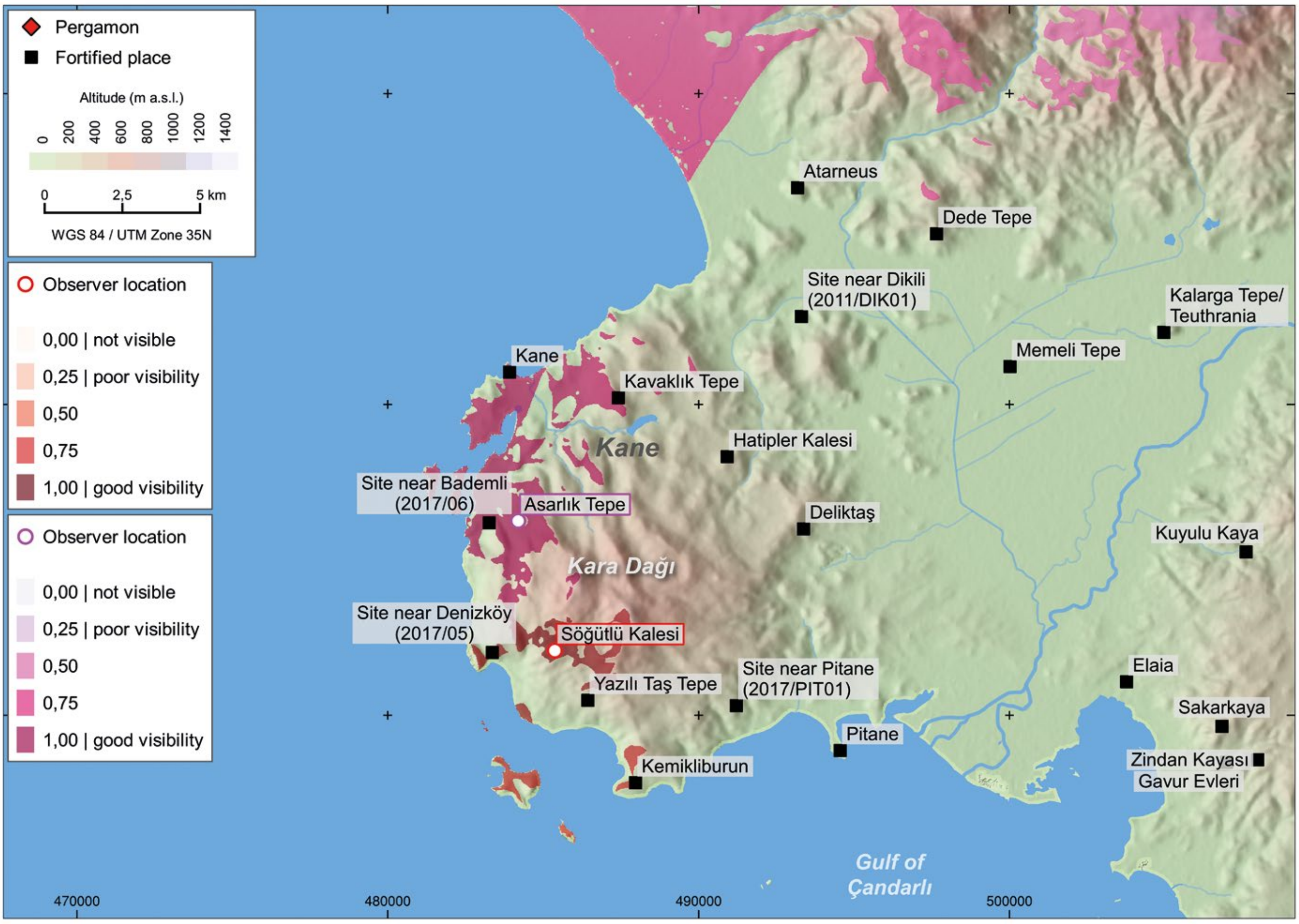

Fig. 12: Higuchi viewshed from Söğütlü Kalesi (red) and Asarlık Tepe (violet) (10 m observer height)

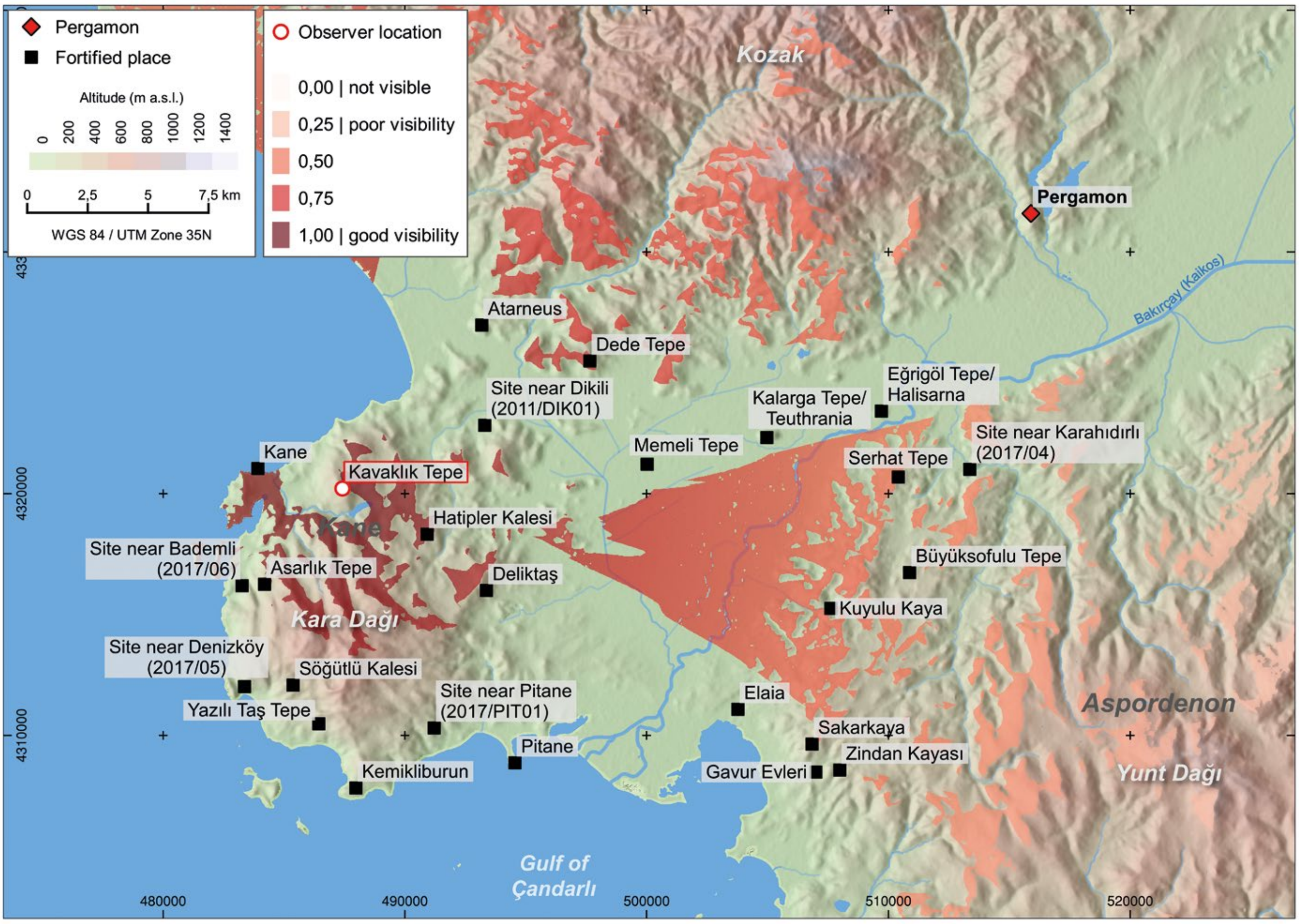

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Fig. 13: Higuchi viewshed from Kavaklık Tepe (10 m observer height)

fortress near Pitane (2017/PIT01) (Fig. 10) are both oriented toward the Gulf of Çandarlı and have a direct relationship to the ancient harbors of Elaia and Pitane. Due to these visual relationships and their positioning on exposed locations, a monitoring or control function for these sites was outlined earlier[103]. A surveillance relationship to individual bays, which served as temporary landing sites along the coast[104], can also be seen in the viewshed from the fortress near Denizköy (2017/05) (Fig. 11).

43 For Asarlık Tepe and Söğütlü Kalesi in the western Kara Dağı Mountains no convincing interpretation as a watchtower or as part of an agricultural estate has been presented so far. The viewshed from Söğütlü Kalesi is limited to a few small and disjointed areas in the southwestern Kara Dağı Mountains (Fig. 12). In contrast, the visible area of Asarlık Tepe includes not only Kane but also the Arginusae Islands and the only coastal strip along the Kane Peninsula that does not consist of steep cliffs (Fig. 12). Based only on their viewsheds, we can assume a surveillance function for Asarlık Tepe and a retreat or agricultural character for Söğütlü Kalesi. The fortress on Kavaklık Tepe is also located in the Kara Dağı Mountains, but has very different visual characteristics. The viewshed illustrates the commanding view, which covers the coastline in the area of Kane and the Arginusae Islands, the coast north of Atarneus, and large areas of the Bakırçay Plain (Fig. 13). The view across the mountains both into the plain and to the coast, already highlighted by the place's discoverers, clearly speaks of geostrategic motives in the selection of this spot.

103 Pirson 2012a, 226; Ludwig 2022.
104 Ludwig 2022.

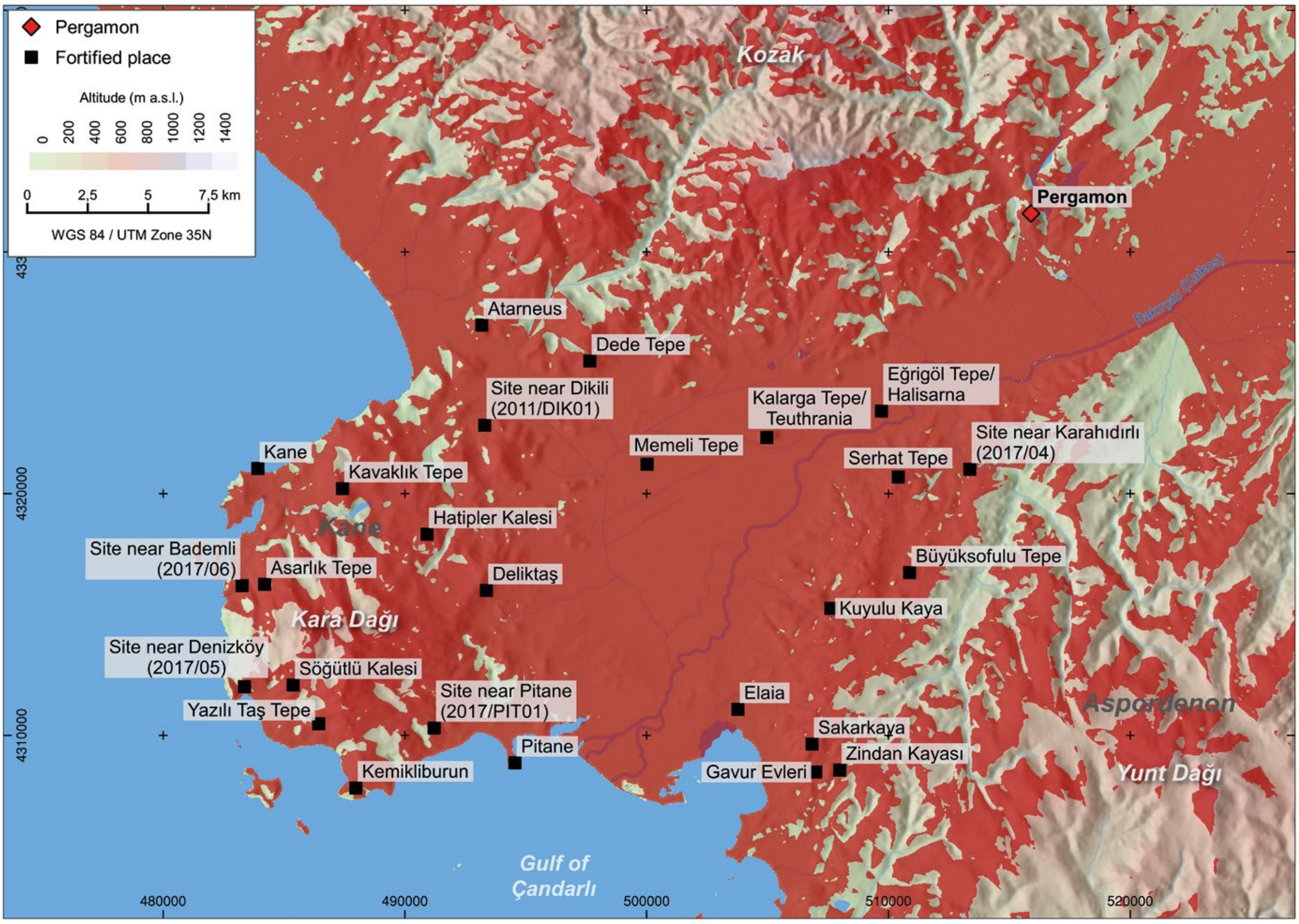

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Fig. 14: Cumulative viewshed from all fortified places

A Cumulative Viewshed of All Sites

44 The individual viewsheds were combined into a cumulative viewshed representing the entire area that could be viewed from all sites (Fig. 14). It is obvious that the western lower Bakırçay Plain and the foot slopes of the surrounding mountains are very well covered. However, large valleys in the Kozak and Yunt Dağı Mountains are not visible. In particular, two valleys (Sınır or Değirmen Valley and Gümüşova Valley) a few kilometers south of Pergamon are ›blind spots‹. Given the troubled times, it would be highly unusual if one could approach Pergamon ›unseen‹ so close. Further field research in the area may well reveal more fortifications that could visually cover these areas. Another possibility, which also applies to the Kara Dağı and Kozak Mountains, are temporary camps, the remains of which we have no evidence of today. Based on the results of this study, potential places where targeted fieldwork would be necessary can be narrowed down in the end.

Line-of-Sight Connections/Inter-Visibility Network

45 We assumed 10 m as the theoretical observer height from a potential tower or building at all sites. Fig. 15 shows the individual results of calculated observer heights 5 m, 10 m, 15 m, and a combination of all results. If there is a mutual line of sight between two locations, a line was drawn. There are only minor differences between the calculations with 5 and 15 m observer heights, so 10 m can serve as a good basis for interpretation.

46 The result is an inter-visibility network extending from Pergamon to the coast and including all sites used in this study. Pergamon had up to eight visual connections to other fortresses and was thus exceptionally well connected.

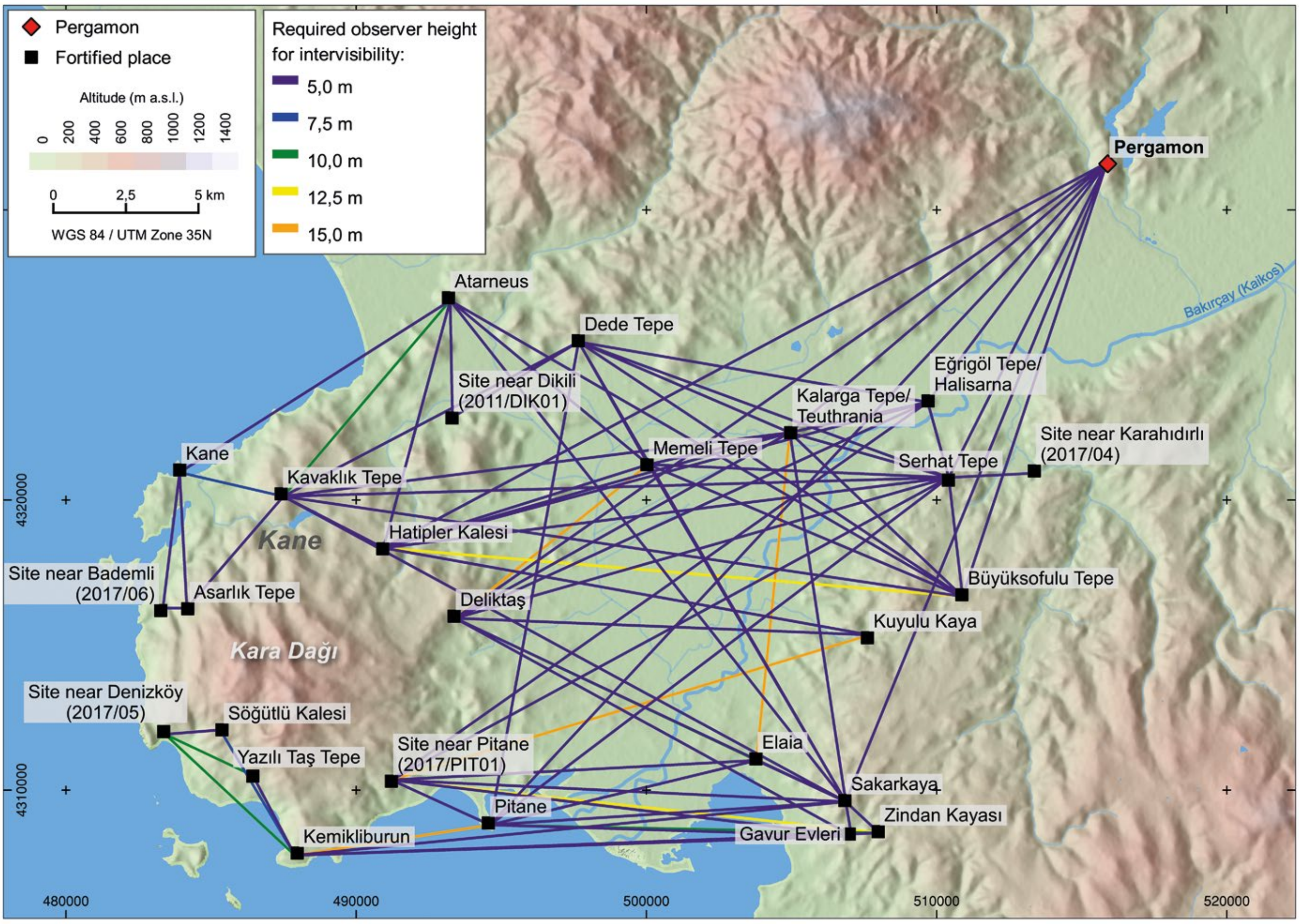

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Fig. 15: Network of inter-visibility between fortified places in the western Pergamon Micro-Region combined from different observer heights: 5 m, 7.5 m, 10 m, 12.5 m, and 15 m

47 There are several nodes essential to the network. From their isolated location within the plain, these are of course Eğrigöl Tepe/Halisarna, Memeli Tepe, and Kalarga Tepe/Teuthrania, the latter certainly being key due to the multiplicity of its connections. The same is true for Serhat Tepe and the fortress on Sakarkaya, each of which provides connections in all directions.

48 The special role of the fortress on Kavaklık Tepe in the Kara Dağı Mountains as a visual hub between Kane, the coastline and the Bakırçay Plain can be confirmed. This fortress creates a visual link between these two completely different landscape units. It also connects Kane and Asarlık Tepe, which in turn can see large parts of the coastline there, among others, with Kalarga Tepe/Teuthrania and thus also with Pergamon. The other two major harbor cities, Pitane and Elaia, are also well integrated into the visual network.

49 On the southern Kane Peninsula, Kemikliburun has the role of a visual hub. However, there are no direct connections between Kemikliburun and Pitane or the fortress near Pitane (2018/PIT01). In addition, sites connected in the southwest of the Kane Peninsula can be assigned more of a local function, such as the site near Denizköy (2017/05) visually covering only the adjacent bay. If one also dismisses the stronghold function of Söğütlü Kalesi, one can conclude that the southwestern part of the Kane Peninsula, which has no major port city, was part of a defense network only to a limited extent.

50 The results show a dense network of mutual visual connections between all fortified sites in the Hellenistic period. To what extent this existing inter-visibility network was used for communication and surveillance by the Attalid rulers of Pergamon will further be discussed at the end.

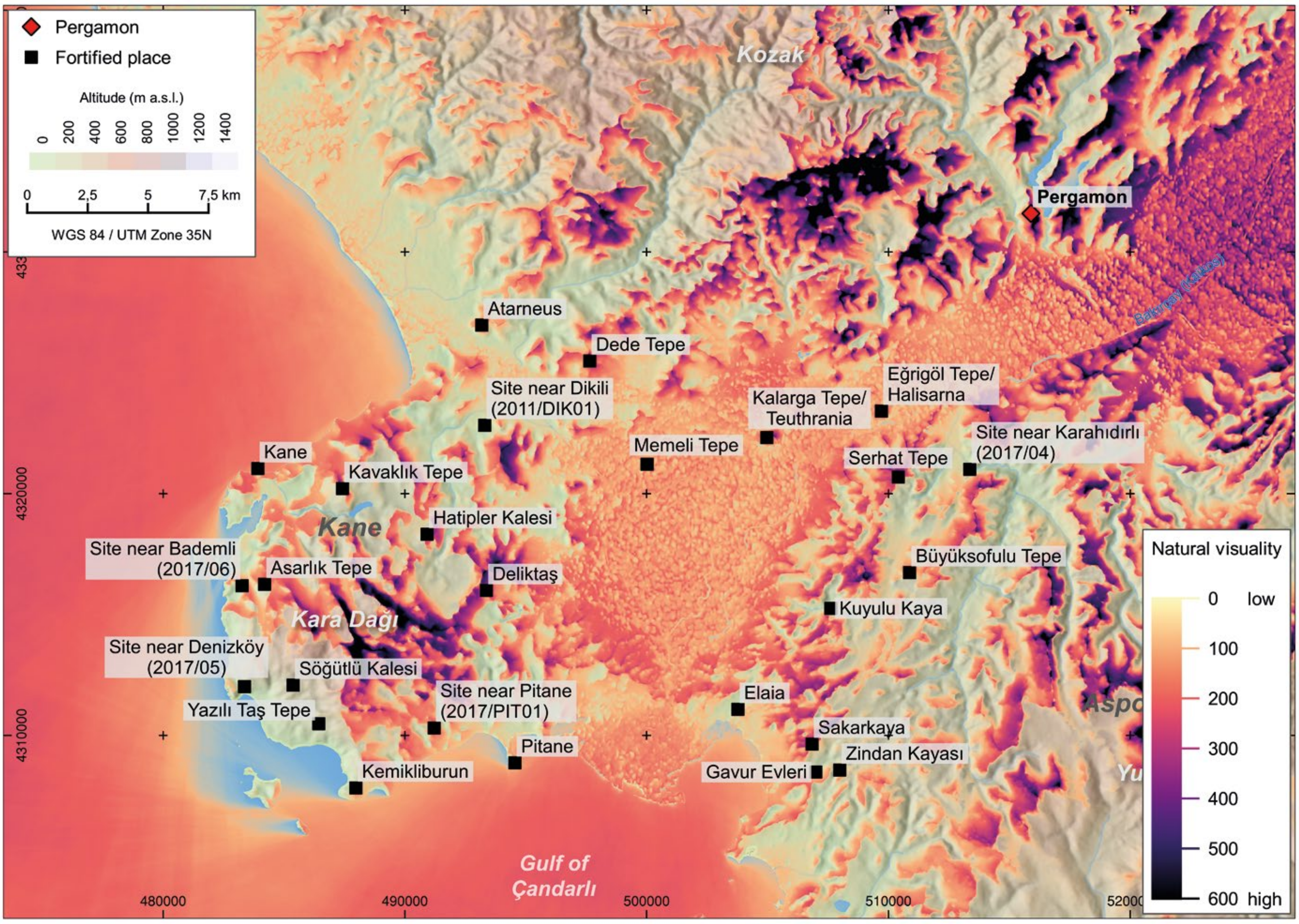


Fig. 16: Natural visuality of the western micro-region from land perspective

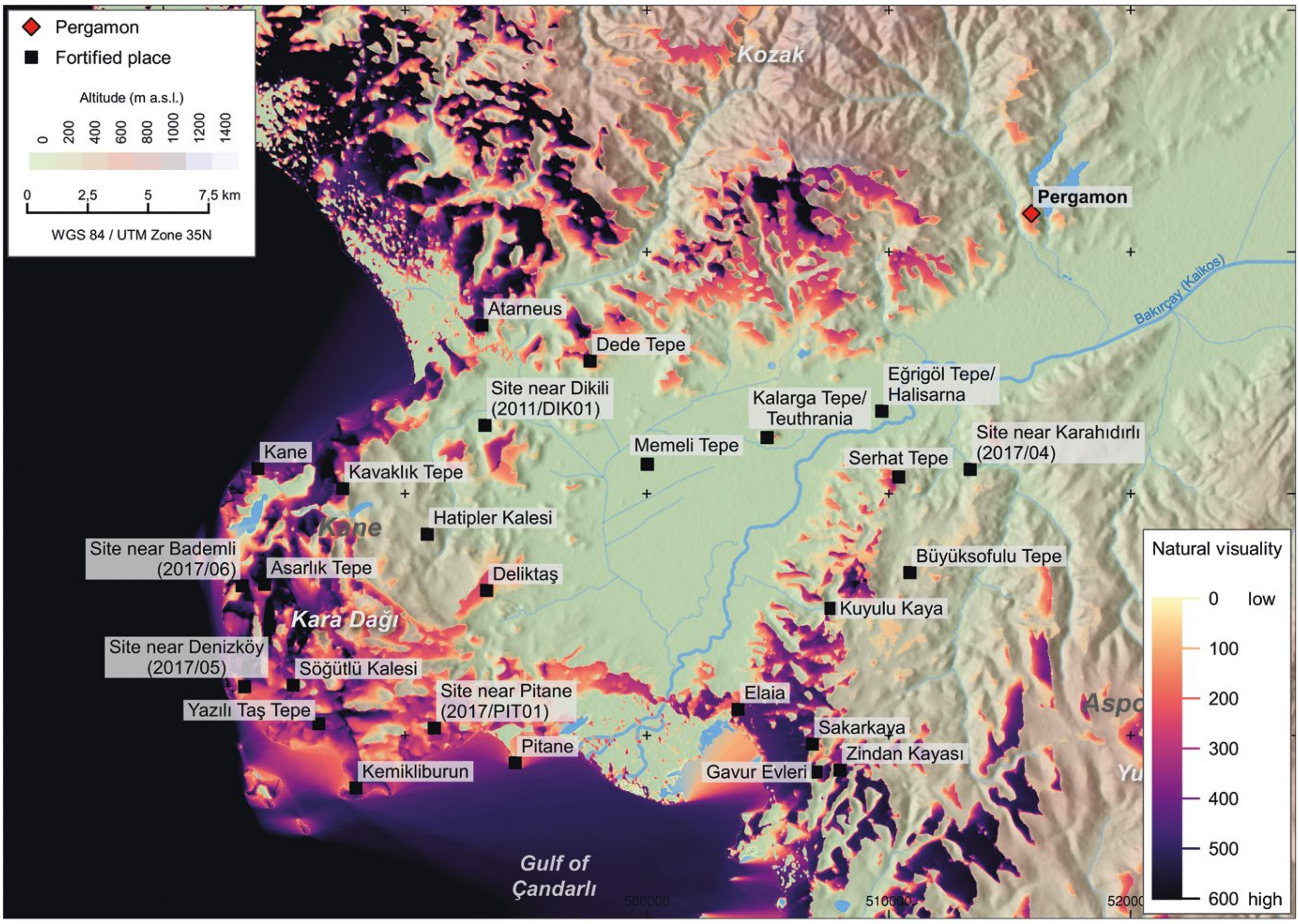


Fig. 17: Natural visuality of the western micro-region from sea perspective

Land view			Sea view		
Place name	**Hit count**	**%**	**Place name**	**Hit count**	**%**
Pergamon	711.9	7.1	Atarneus	524.3	26.2
Serhat Tepe	496.8	5.0	Sakarkaya	504.8	25.2
Sakarkaya	404.8	4.0	Asarlık Tepe	501.4	25.1
Eğrigöl Tepe/Halisarna	395.0	4.0	Dede Tepe	468.2	23.4
Dede Tepe	381.3	3.8	Yazılı Taş Tepe	421.3	21.1
Kalarga Tepe/Teuthrania	379.6	3.8	Kane	364.0	18.2
Deliktaş	353.8	3.5	Site near Denizköy (Site 2017/05)	358.2	17.9
Büyüksofulu Tepe	317.6	3.2	Site near Pitane (Site 2017/PIT01)	304.4	15.2
Hatipler Kalesi	303.1	3.0	Site near Bademli (Site 2017/06)	238.2	11.9
Site near Pitane (Site 2017/PIT01)	227.5	2.3	Söğütlü Kalesi	227.5	11.4
Kavaklık Tepe	197.7	2.0	Kalarga Tepe/Teuthrania	225.3	11.3
Kane	170.0	1.7	Gavur Evleri	223.3	11.2
Memeli Tepe	166.9	1.7	Deliktaş	212.1	10.6
Atarneus	164.5	1.6	Elaia	201.5	10.1
Pitane	156.2	1.6	Serhat Tepe	199.2	10.0
Site near Dikili (Site 2011/DIK01)	110.3	1.1	Pitane	181.7	9.1
Asarlık Tepe	107.9	1.1	Kemikliburun	171.2	8.6
Gavur Evleri	64.7	0.6	Büyüksofulu Tepe	140.9	7.0
Elaia	51.6	0.5	Zindan Kayası	84.2	4.2
Kemikliburun	44.4	0.4	Kavaklık Tepe	54.9	2.7
Kuyulu Kaya	44.2	0.4	Eğrigöl Tepe/Halisarna	46.8	2.3
Site near Karahıdırlı (Site 2017/04)	32.4	0.3	Pergamon	30.2	1.5
Zindan Kayası	16.2	0.2	Memeli Tepe	8.6	0.4
Yazılı Taş Tepe	8.0	0.1	Site near Dikili (Site 2011/DIK01)	4.1	0.2
Söğütlü Kalesi	4.5	0.0	Hatipler Kalesi	1.2	0.1
Site near Denizköy (Site 2017/05)	3.4	0.0	Kuyulu Kaya	0.0	0.0
Site near Bademli (Site 2017/06)	1.8	0.0	Site near Karahıdırlı (Site 2017/04)	0.0	0.0

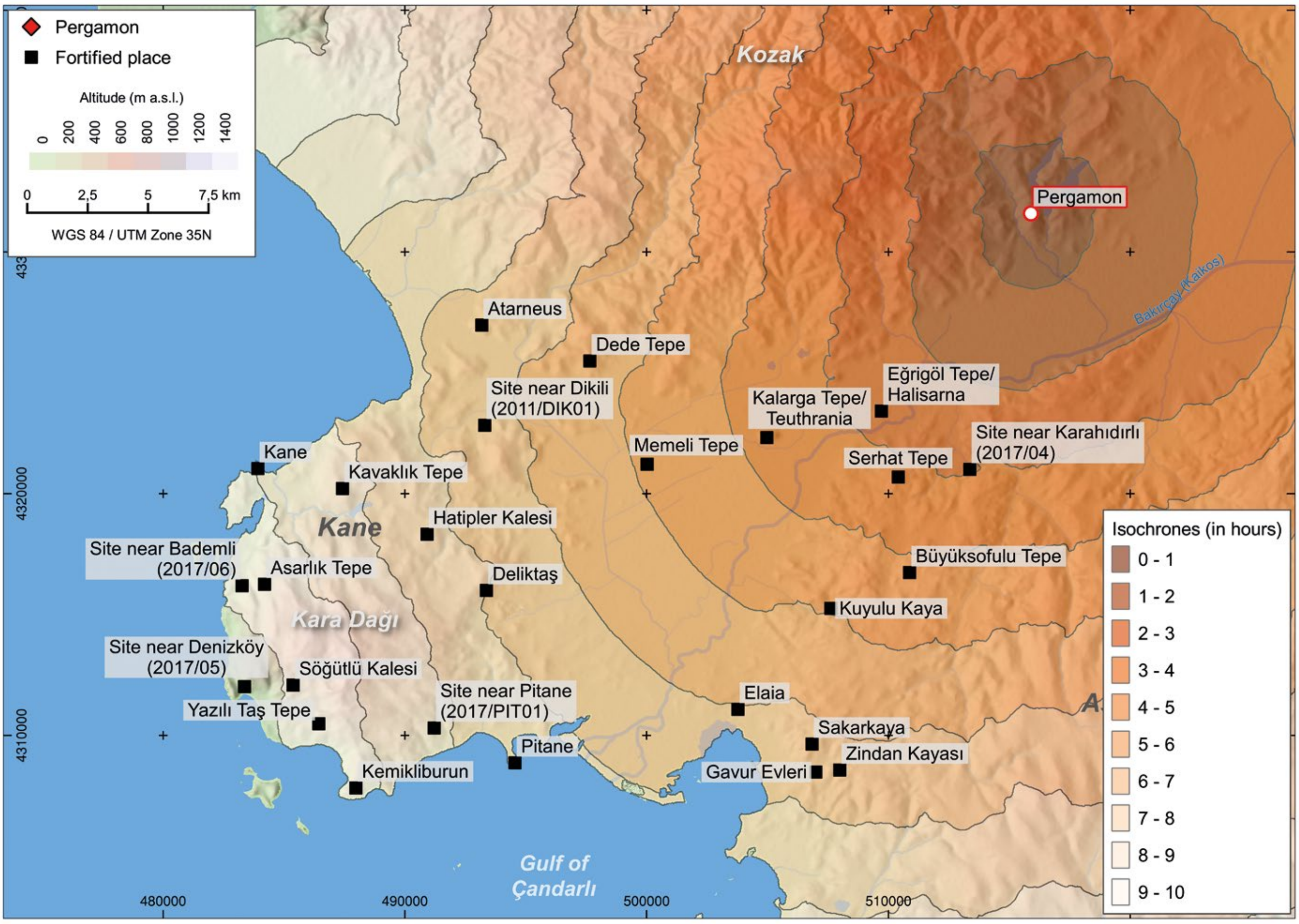
18

Fig. 18: Sites and their degree of natural visuality expressed in hit counts sorted in descending order. Average hit count land view: 196.9 = 2 % of all sample points (9,999) and sea view: 211 = 10 % of all sample points (2,000)

Natural Visuality

51 The mostly exposed location of the studied fortresses not only allowed a view into the landscape. Due to their position, the sites also formed visual reference points for the people living in or moving through the micro-region. Especially in this heterogeneous landscape, the sites may have served as landmarks or places of retreat for the local population. At the same time, they represented regional landmarks that both defined the local landscape while marking Attalid claims of territory and control beyond the confines of the city.

52 The results of the cumulative viewsheds indicate a tight visual connection among the features seen from land. As mentioned in the beginning, the Kane peninsula, the Kozak Mountains, and the crests of the Yunt Dağı together frame the western lower Bakırçay (ancient Kaikos) Plain. The analyses show this as their peaks and foothills are the darkest shade, indicating that they are viewed the most frequently (Fig. 16. 18). But the analysis also shows a consistency of visibility in the Bakırçay Plain itself, with the fortifications generally on naturally prominent features. This internal coherence actually increases further inland, becoming darker in the upper Bakırçay Plain, and east of Pergamon. Moreover, much of the sea is also consistently visible from land, proving that integrated connection especially with the gulfs of Çandarlı and Dikili. Yet from the opposite perspective, the plain of the Bakırçay is virtually hidden from the sea, whereas the western fringes of the Kane peninsula, the Kozak Mountains, and the Yunt Dağı, are



19

Fig. 19: 10-hour isochrones from Pergamon

prominently in view (Fig. 17. 18). In terms of a visual region, we may see two distinctive perspectives. The land view shows a highly integrated coherent region that connects most of the Bakırçay Plain and the surrounding hills with the sea, whereas the sea view largely stops at the coastal heights. These heights therefore serve as pivotal ›hinges‹ that can connect the view over land and sea, thereby potentially extending the sense of territory that would naturally be afforded by the strong visual region of the landscape, whether or not they were crowned with fortifications or other landmarks[105].

Isochrones

53 A prominent position within the landscape increases the possibilities for monitoring the surroundings and for communication. At the same time, however, it must be possible to reach the monitored area in as short a time as possible. We therefore examined the potential radius of activity or movement around the fortifications. The isochrones indicate the area that can be reached in a given time. We assume a pedestrian with a speed of 5 km/h and so each isochrone marks one hour of walking.

54 From Pergamon one could reach Eğrigöl Tepe/Halisarna in less than 3 hours and Elaia in about 6 hours (Fig. 19). But a fortress also has a great influence on its immediate surroundings. Who or what in the vicinity was of importance or worth protecting? Which routes, resources, settlements, borders or other fortresses are in near walking distance?

105 Williamson 2016.

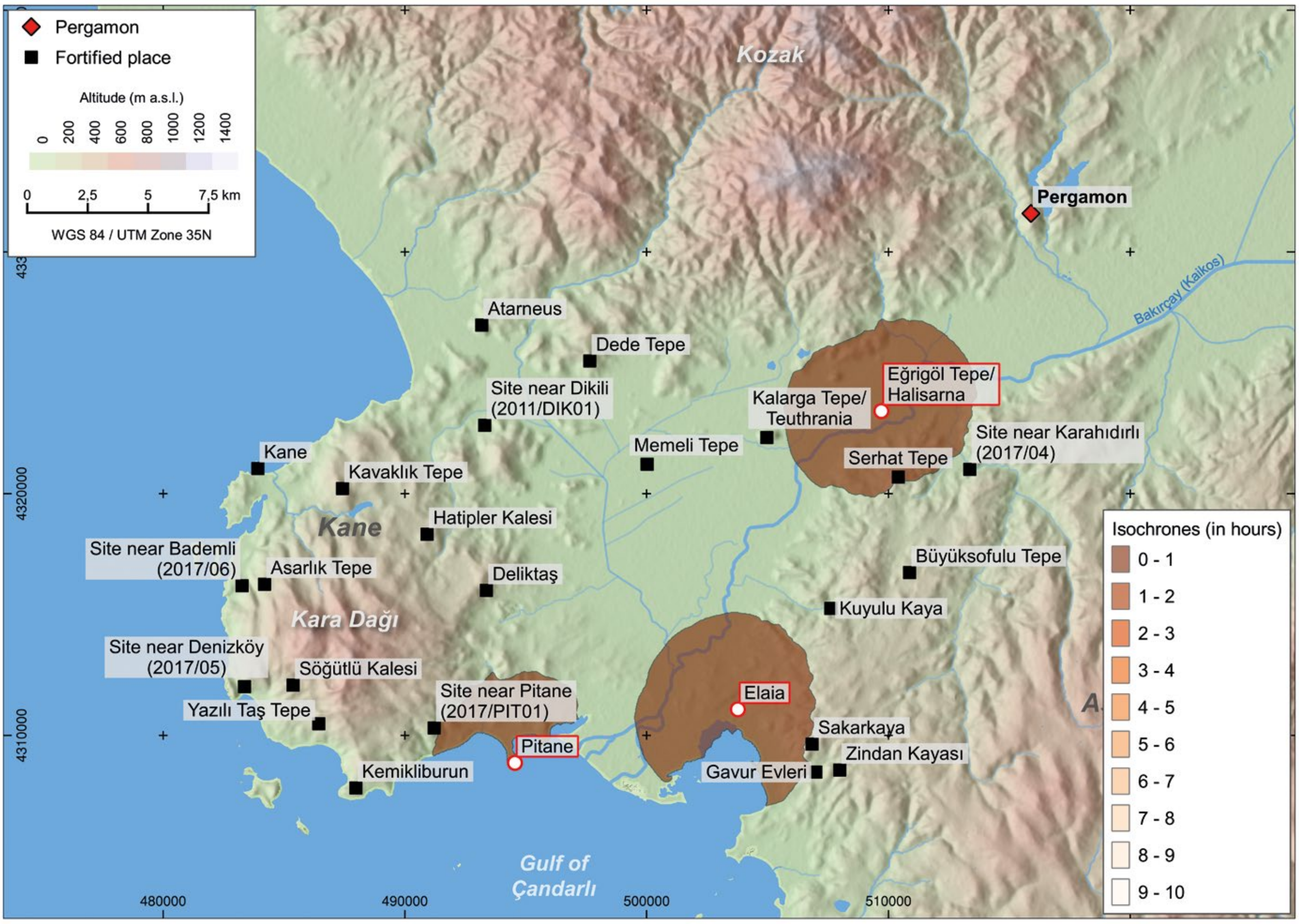


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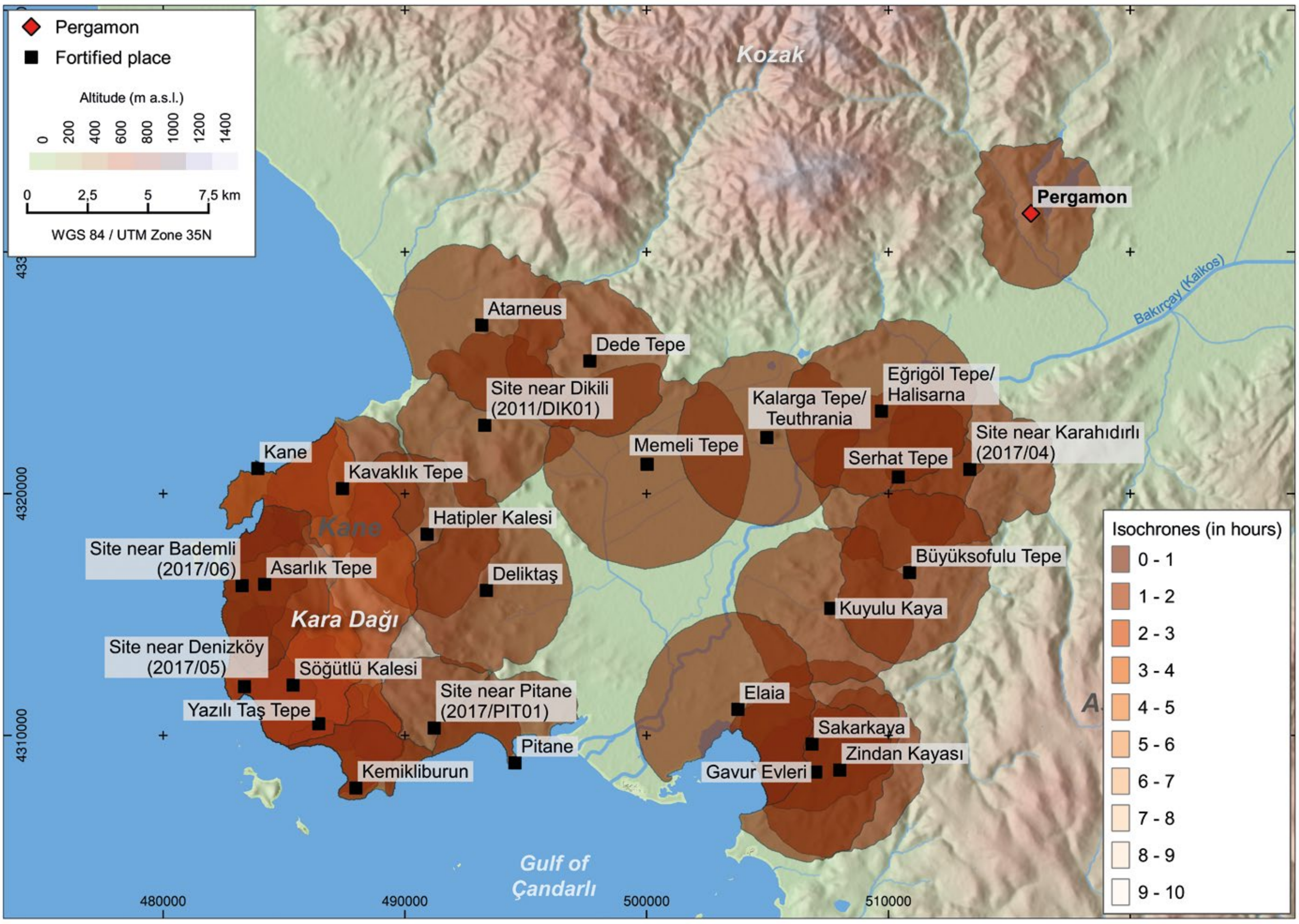
Fig. 20: 1-hour isochrones from Eğrigöl Tepe/Halisarna, Pitane, and Elaia

55 The one-hour isochrone of Eğrigöl Tepe/Halisarna, a steep and very prominent hill in the plain, covers the narrowest part of the western lower Bakırçay Plain (Fig. 20). The main road to the coast and to Elaia was vital for the city and ran through this area[106]. The crucial bridges over the river were also located in this same area, which underlines the importance of this fortress as an important outpost of Pergamon[107].

56 C. Schuchhardt[108] mentions more than a dozen Hellenistic watchtowers that form a belt around the harbor city of Pitane at the beginning of the 20th century. The fortress west of Pitane (2017/PIT01), one hour away, was probably part of this local fortification system (Fig. 20). Further remains of this fortification are lost today or remain undiscovered, but future fieldwork may focus on the area of the one-hour isochrone. The same phenomenon can even be observed for the harbor of Elaia, whose protection by the fortress on Sakarkaya has been previously outlined. These two places are also within an hour's walk of each other (Fig. 20).

57 The combination of the one-hour isochrones shows that from almost all fortresses one could reach the respective neighboring fortress in about one hour on foot (Fig. 21). Riding a horse, one would even be faster still[109]. Due to the positioning of the fortresses, it was not only possible to communicate with each other and with Pergamon, but also to reach almost the entire western lower Bakırçay Plain in a relatively short time. Only the gap in the immediate vicinity of Pergamon raises the question whether

106 Ludwig 2020.
107 Pirson 2012a.
108 Schuchhardt 1887.
109 Busby – Rutland 2019, 119.



21

Fig. 21: Combined 1-hour isochrones of all sites

there are other, so far undiscovered, fortresses there. Perhaps, however, this was intentional, so that especially in the immediate vicinity of the city no fortresses were available that could be controlled by attackers in a siege of the city.

Discussion

58 The aim of the study was to investigate whether and to what extent the Hellenistic rulers of Pergamon were able to monitor and control their core territory from the acropolis on the northern edge of the Bakırçay Plain. This study therefore focused on fortified places being of central importance for the surveillance of this region. Following a landscape approach and based on a digital elevation model, we carried out analyses focusing on the aspects of visibility, relative topographic site location and the modeling of movement. These analyses also enabled us to assess the potential of the fortified places forming a communication network with Pergamon as part of a state-run defense strategy.

59 For access to the resources of the micro-region and for military protection of the city and its supply routes, the establishment and control of the immediate territory of the city would have been of utmost importance to the Attalid rulers. The boundaries of the Pergamene *chora* however are only known in very fuzzy outlines[110]. The term boundary does not mean a defined state (border) line in this context, but how ancient inhabitants may have perceived the territorial claim of Attalid power in the land-

110 Sommerey 2008.

scape[111]. According to F. Pirson, C. G. Williamson and U. Wulf the perception of Attalid presence in the landscape was represented by rural sanctuaries at Kapıkaya in the Kozak Mountains and Mamurt Kale in the Yunt Dağı Mountains and expressed through their visual connections to the city[112]. This notion can now be enhanced by the analyses of fortified places, which were also positioned at prominent points within the micro-region and linked through visual connections. They were also visible from many areas of the landscape expressing Attalid power.

60 The results of the calculation of natural visuality show that the mountains surrounding the Bakırçay Plain lead to the perception of a closed and bounded landscape (Fig. 16). The western lower Bakırçay Plain, the foothills of the adjacent mountains and parts of the Kane Peninsula have a high natural visuality. An impression of enclosure is simultaneously evident from the coastal perspective (Fig. 17). This region, bounded by physical barriers, has also been described as a ›visual region‹ by C. G. Williamson[113] in the context of Kalarga Tepe/Teuthrania serving as a visual hub (Fig. 5. 15). Center of power and communication in the region however was Pergamon, whose strategic location is illustrated by its outstanding natural visuality (Fig. 18) and commanding view (Fig. 2. 4). Thanks to these topographical conditions and the additional placement and use of the fortified places in the vicinity, the described region could be monitored and controlled from the acropolis. Following a spatial strategy, visual relationships were thus created between Pergamon and these specific spots in the landscape stating the claim of territorial power and simultaneously enabling intra-territorial interaction and communication (Fig. 15). Approaching enemies, armies, mobile tribes, and even natural threats such as forest fires could be spotted across the entire region (Fig. 14). Information could then be rapidly transmitted from Pergamon to the region and vice versa (Fig. 15). Considering the dynamic political and military conflicts in the turbulent Hellenistic period, a working communication network offered great advantages. Since we were able to prove the existence of such a network, we can assume that the Attalids used these places as parts of their surveillance system in the context of a state-run defense strategy.

61 Some places, such as Eğrigöl Tepe/Halisarna or Büyüksofulu Tepe for example, already existed in the Archaic period and continued to be used in Hellenistic times. Many others, such as Atarneus, Kalarga Tepe/Teuthrania, Hatipler Kalesi and several fortified places along the coastline, however, did not survive the transformative Hellenistic period and the integration of the Attalid kingdom into the Roman state. Some sites seem to be razed in the aftermath of warlike conflicts[114], while others may have become obsolete due to the changing political conditions in the Roman Imperial period. In any case, a transformation of geopolitical power across the Pergamon Micro-Region is evident. Localized power slowly diminished and a network of state (sponsored) defenses began to appear under Attalid rule. This system enabled surveillance and control of their existential core territory and set a stable foundation for the development and success of the city of Pergamon. In the Roman Imperial period, changing political conditions finally led to the abandonment of many fortified places and thus to the end of the surveillance network.

62 For the supply of the city, permanent access to resources, such as timber, firewood or fresh water, as well as their exploitation and transport to Pergamon had to be ensured. Especially the fertile plain of the Bakırçay, whose agricultural resources

111 Sommerey 2012.
112 Wulf 1999, 33–49; Pirson 2008b, 36 f.; Williamson 2014a.
113 Williamson 2014a, Williamson 2016.
114 Pirson 2017, 92–95.

ensured the basic food supply of the city was of primary importance[115]. The arable land and its farmsteads could be monitored and controlled by fortifications on Kalarga Tepe/Teuthrania or Eğrigöl Tepe/Halisarna in the plain (Fig. 5. 8. 15) as well as fortified places located on the slope facing the plain, such as Serhat Tepe or even Pergamon itself (Fig. 4. 6. 15). Apart from being visible from afar, garrisons were able to reach large parts of the plain in a very short time (Fig. 21). The fortress on Serhat Tepe and Büyüksofulu Tepe visually dominating a mountainous region of the Yunt Dağı could have encouraged people to settle also in this fertile intramontane basin (Fig. 6). Small and narrow side valleys, such as the Tekkedere Valley northeast of Elaia, were also settled and used for agriculture in Hellenistic times. The Kuyulu Kaya was a central place of this small valley. From its elevated position, the entire valley could be monitored (Fig. 7) and the fortress also served as a retreat for the local community.

63 A more differentiated situation is evident for the Kane Peninsula. The harbors and other fortified places along the entire coastline had close (visual) relations to the sea, to individual bays and landing sites which were already addressed in other contexts[116]. Their close connection to the sea is additionally evident from their natural visuality calculated from the sea perspective (Fig. 17. 18).

64 On the contrary, the towers of Söğütlü Kalesi and Asarlık Tepe, whose function has not yet been clearly identified, are situated away from the coastline in the Kara Dağı Mountains. They have been interpreted as *Turmgehöfte*, i.e., towers as part of a private agricultural estate[117]. However, a primarily military function of the towers cannot be excluded either. At present, there is no regional and differentiating settlement typology that would allow distinguishing fortified towers and *Turmgehöfte*[118], but some more precise and differentiated suggestions for interpreting them can now be made, based on our results: Both Söğütlü Kalesi and Asarlık Tepe, and even Kavaklık Tepe further north, are surrounded by plateaus and agricultural terraces. However, their topographical location and visibility characteristics differ greatly. Söğütlü Kalesi has a very low TPI value and is situated on the slopes of the Kara Dağı Mountains (Fig. 3). The view from this place is largely limited to the surrounding hillsides (Fig. 12). Direct lines of sight to the fortresses near Denizköy (2017/05) and Yazılı Taş Tepe exist (Fig. 15), but features characterizing a fortification, i.e., an exposed position or a commanding view, are missing. It is most likely that the tower at Söğütlü Kalesi was a private *Turmgehöft*, being part of an agricultural estate, serving residential or storage purposes and as a place of retreat for the local community in case of emergency.

65 Asarlık Tepe, on the other hand, is located on a ridge and has relatively high TPI values compared to the other fortifications (Fig. 3). Furthermore, the calculated viewshed is not limited to the immediate surroundings, but includes a large coastal strip with the Arginusae Islands, Kane and the fortress on Kavaklık Tepe (Fig. 12). A clear functional assignment is not possible, but both an agricultural and a military function seem possible. The visual and topographical characteristics, as well as the easy accessibility of the harbor of Kane in a little more than an hour and via a documented ancient road section[119], can be interpreted in both ways. The tower of Asarlık Tepe is representative for the difficulties of functional classification of such places and reveals the wide range of factors and decisions related to the choice of a location. A tower originally built as part of a private farmstead may have been used as a state military base during the changing and uncertain political times in the Hellenistic period. Even a

115 Pirson – Zimmermann 2014; Laabs – Knitter 2021.

116 Laufer 2020; Ludwig 2022.

117 Zimmermann et al. 2015, 213.

118 Schuler 1998, 83–90.

119 Pirson 2016, 184 f. (E. Laufer); Ludwig 2020, 27 f.

simultaneous use for agricultural and military purposes does not seem to be excluded here and more research is needed.

66 Kavaklık Tepe has been interpreted as a fortress since its discovery at the end of the 19th century. In fact, geomorphological calculations show that the site is not as exposed as assumed (Fig. 3). Plateaus and terraces in the immediate vicinity of the place could have been used for agriculture. Its viewshed, however, illustrates the favorable strategic position that allows a wide view ranging from the coast to the Bakırçay Plain (Fig. 13). At least eight direct lines of sight to other sites make the fortress a visual hub that provided (visual) communication across the rough and mountainous northern Kane Peninsula (Fig. 15). The fortress probably also served as an observation point for the security of the route leading from Kane into the Bakırçay Plain[120]. A primary military use can therefore be assumed. This does not however exclude an agricultural function, which may have been practiced to a limited extent on the mentioned plateaus for the supply of the stationed garrison.

67 These examples show that the differentiation between military and agricultural function must be answered individually for each of the fortified places. A decision is not always possible, but an integrative approach that examines the places in the context of their surrounding landscape allows more profound interpretations.

68 Kavaklık Tepe is not the only fortress that can be associated with securing routes. The strategic position of Elaia and the fortress on Sakarkaya for securing the coastal road and the southwestern access to the plain has already been discussed in other contexts[121]. A similar situation is evident near Atarneus with the fortified places near Dikili (2011/DIK01) and on the Dede Tepe at the northwestern entry to the plain. But smaller side valleys with roads leading into the core of Pergamene territory were secured by fortresses. One example is the fortress near Karahıdırlı in the Değirmendere Valley, which, due to its topographical and visual characteristics, can only be associated with the control of the route leading through the narrow valley (Fig. 3. 7). There is no suitable land for agriculture in the immediate vicinity of the site, making the placement of buildings for storage and residential purposes highly unlikely.

69 In addition to the fortified places included in this study, scattered settlements in the Pergamon Micro-Region are assumed to have existed during the Hellenistic period[122]. Some names of these settlements have survived from the Pergamene ephebe lists[123], but little is known about their location, size, or density. A promising avenue for further research would be to investigate the relationships of the fortified places in the Pergamon Micro-Region with such local settlements, pending further field surveys.

70 The presented findings and insights are strongly determined by the employed algorithms and raw data. We use high quality open-access data, established and reliable free and open-source software[124], and provide our developed code in order to encourage readers to execute and test our analyses on their own[125]. Besides, we aimed at creating robust results by choosing a variety of thresholds[126]. The results for these different thresholds show similar trends, thus proving the dependability of the presented findings. Nevertheless, a thorough analysis of the robustness of the results would need to employ different input data (e.g., another DEM) and alternative algorithms, a task that is beyond the scope of this study.

120 Ludwig 2020, 27 f.
121 Ludwig 2020; Pirson 2012a.
122 Sommerey 2008.
123 Sommerey 2008, 152–155.
124 Cf. Fortunato – Galassi 2021.
125 See Knitter et al. 2021 for a description and explanation.
126 See employed observer heights in the visibility analyses or the different radii in the geomorphometric analyses.

Conclusions

71 In this study we present a novel combination of quantitative spatial analyses to assess the networking potential of ancient rural fortifications and the ability of an ancient city to control its micro-region. This innovative approach offers the opportunity to integrate different fields of research (e.g., Archaeology, Landscape Archaeology and Geography) and thereby provides new perspectives and opportunities in studying historical phenomena and ancient human-environment interactions. The analyses are based on high quality open-access data and were conducted using established and reliable open-source software. By also making the developed code of the analyses available alongside the study, we make our assumptions and decisions transparent and reproducible, encouraging readers to perform and test the analyses, or further develop them for their own specific research question.

72 In the scope of our research, this landscape approach, allowed for the first time a comprehensive analysis of all known fortifications in the Pergamon Micro-Region in terms of their function and the city's ability to monitor and control its surrounding landscape.

73 The results of our study highlight Pergamon's strategic position as a center of power and communication by its outstanding natural visuality and commanding view. Based on these particular capabilities, visual relationships between Pergamon and fortified places in the micro-region were created. These places commanded by the Attalids, served to monitor, control and reach strategically and military important areas (e.g., resources, transport infrastructure, and harbors). Located at prominent spots within the landscape, they also stated the claim of territorial power and simultaneously enabled intra-territorial interaction and communication. Considering the dynamic political and military conflicts in the turbulent Hellenistic period, it is most likely that the Attalids used these places as parts of a surveillance system in the context of a state-run defense strategy. This system was not static, however, but changed over time. Looking at the fortified places and their settlement history in a diachronic perspective reveals a transformation of geopolitical power across the Pergamon Micro-Region. Localized power slowly diminished and a network of state (sponsored) defenses began to appear under Attalid rule, which in turn seems to disappear in the Roman Imperial period.

74 This study and its landscape approach further illustrate the variety of individual functions, the factors governing the placement of fortified places and the complexity of their distribution. The landscape surrounding Pergamon was shaped by various kinds of fortifications: individual towers with a surrounding wall, towers as parts of rural estates (*Turmgehöfte*) or small settlements or even fortified settlements and harbors. Holding power over these places and using them to monitor and control the micro-region enhanced the level of security and was thus essential for the development and stability of the Pergamene kingdom during the Hellenistic period.

75 Even these results do not have to remain static, however, but can be continuously supplemented and refined in the light of new evidence and discoveries in the future thanks to our open and transparent approach.

Availability of Data and Material

76 Any data and material required to reproduce this study is provided in our data repository at Zenodo https://zenodo.org/record/5115942 or https://doi.org/10.5281/zenodo.5115942 (Knitter et al. 2021) and also in iDAI.repo via https://doi.org/10.34780/jy6t-ad17 or available open-access.

Code Availability

77 The code to reproduce the presented analyses is available here: https://zenodo.org/record/5115942 or https://doi.org/10.5281/zenodo.5115942 (Knitter et al. 2021) and also in the data repository iDAI.repo (https://doi.org/10.34780/jy6t-ad17).

Acknowledgements

78 The research was conducted and financed in the context of the project »Die Transformation der Mikroregion Pergamon zwischen Hellenismus und römischer Kaiserzeit (TransPergMikro)« of the German Research Foundation (DFG, German Research Foundation – project number 419349690) and supported by the Pergamon Excavation Project of the Istanbul Department of the German Archaeological Institute (DAI). D. Knitter is furthermore grateful to the CRC1266 »Scales of Transformation« for supporting his work (DFG, German Research Foundation – project number 290391021). C. G. Williamson is grateful to the Dutch Research Council (NWO) and the Joukowsky Institute for Archaeology and the Ancient World at Brown University, for sponsoring the NWO Rubicon project »Commanding Views. Monumental landscapes and the territorial formation of Pergamon, 3rd to 2nd centuries BC« (446-13-003).

79 The authors thank Brigitta Schütt and Felix Pirson for their careful reading of the manuscript and their comments and suggestions that improved the paper.

Funding

80 This research was funded by Deutsche Forschungsgemeinschaft (German Research Foundation) grant numbers 419349690 as well as 2901391021.

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ILLUSTRATION CREDITS

Title Page: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 1: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 2: DAI Pergamongrabung (Ulrich Mania)
Fig. 3: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 4: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 5: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 6: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 7: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 8: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 9: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 10: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 11: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 12: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 13: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 14: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 15: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 16: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 17: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 18: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 19: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 20: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)
Fig. 21: DAI Pergamongrabung (Bernhard Ludwig – Daniel Knitter – Christina G. Williamson)

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METADATA

Titel/*Title*: A Landscape of Surveillance. Investigating Hellenistic Fortifications and Potential Networks of Interaction in the Pergamon Micro-Region

Band/*Issue*: AA 2022/2

Bitte zitieren Sie diesen Beitrag folgenderweise/ *Please cite the article as follows*: B. Ludwig – D. Knitter – Ch. G. Williamson, A Landscape of Surveillance. Investigating Hellenistic Fortifications and Potential Networks of Interaction in the Pergamon Micro-Region, AA 2022/2, § 1–80, https://doi.org/10.34780/d6lg-362f

Online veröffentlicht am/*Online published on*: 05.05.2023

DOI: https://doi.org/10.34780/d6lg-362f

Schlagwörter/*Keywords*: Pergamon, landscape archaeology, fortification, visibility analysis, Topographic Position Index, geomorphons, isochrones, reproducible research

Bibliographischer Datensatz/*Bibliographic reference*: https://zenon.dainst.org/Record/003033543