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Malaria Risk on Ancient Roman Roads: A Study and Application to Assessing Travel Decisions in Asia Minor by the Apostle Paul

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MALARIA RISK ON ANCIENT ROMAN ROADS: A STUDY AND APPLICATION TO ASSESSING TRAVEL DECISIONS IN ASIA MINOR BY THE APOSTLE PAUL

by

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ABSTRACT

This study models malaria risks for travelers on ancient Roman roads with the goal of providing a tool for historical assessment of travel accounts from antiquity. The project includes: identification of malaria risk factors and associated spatial datasets, malaria risk model construction, verification and validation against available pre-eradication data, overlay of ancient Roman road data, and an initial case-study application to the journeys of the Apostle Paul, as narrated in the New Testament book, Acts of the Apostles (Acts). The project is intentionally cross-disciplinary in bringing the technical capabilities of GIS to the task of evaluating nuanced textual sources for historical reconstruction.

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DEDICATION

To Felicia Jernigan Browning, my wife and lifetime partner, with love, for her support and long-suffering through the difficult times we shared together, during which this work came to fruition.

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LIST OF ABBREVIATIONS

AWMC	The Ancient World Mapping Center
DARE	*Digital Atlas of the Roman Empire*
DARMC	*The Digital Atlas of Roman and Medieval Civilizations*
DEM	Digital elevation model
DVS	Dominant vector species
EU	European Union
MAP	Malaria Atlas Project
MODIS	Moderate Resolution Imaging Spectroradiometer
RMSE	Root mean square error
Torelli map	*Carta della Malaria dell'Italia*

CHAPTER I - INTRODUCTION

General Description

This study models malaria risks for travelers on ancient Roman roads with the goal of providing a tool for historical assessment of travel accounts from antiquity. The project includes: identification of malaria risk factors and associated spatial datasets, malaria risk model construction, verification and validation against available pre-eradication data, overlay of ancient Roman road data, and an initial case-study application to the journeys of the Apostle Paul, as narrated in the New Testament book, Acts of the Apostles (Acts). The project is intentionally cross-disciplinary in bringing the technical capabilities of GIS to the task of evaluating nuanced textual sources for historical reconstruction.

Initial Impetus and Need for Study

The study arises from a long-term interest by the author in geographical and causation problems in the biblical account of Paul's so-called "Second Journey," described in Acts 15:36-18:21. After revisiting nascent Christian communities founded on his "First Journey" (Acts 13:13-14:28) in the southern portion of the Roman province of Galatia, Paul apparently intended to expand his work to the province of Asia and its capital Ephesus.

The biblical text relates "they went through the region of Phrygia and Galatia, having been forbidden by the Holy Spirit to speak the word in Asia" (Acts 16:6). Religious reading of the passage generally defaults to the assumption that Paul received definitive divine input directing him not to pursue his work in Asia. But the notion of unambiguous divine direction is belied by other details in the text: 1) Paul's ensuing false

start, in which he "attempted to go into Bithynia, but the Spirit of Jesus did not allow them" (Acts 16:7); 2) the apparent lack of any positive direction and default continuation to Alexandria Troas ("so, passing by Mysia, they went down to Troas") where the "Macedonian vision" finally occurs (Acts 16:8-9); 3) that the "vision" also involved the appearance of another person (indicated by the shift from third person to first person plural narrative) who participated in "concluding" that the group should go to Macedonia (Acts 16:10); and 4) Paul's immediate voyage to Ephesus after the Macedonian-Achaean detour, where he promised to return "if God wills" (Acts 18:19, 21). These details suggest practical "real world" influences on the decision-making and direction of Paul's efforts on his Second Journey and beg the question: what caused Paul—or the author of Acts—to conclude they were "forbidden by the Holy Spirit to speak the word in Asia" (Acts 16:6)?

Economic considerations or government influence may be suggested as reasons for Paul's inability to continue to Ephesus on the second journey, but these involve speculation and reading unmentioned factors into the biblical text. Meanwhile, the copious geographical detail of the account and Paul's own reference to health issues in his writings (2 Corinthians 12:7-9; Galatians 4:13-15) suggest another cause: the threat of malaria.

Over a century ago William M. Ramsay, the eminent geographer and inveterate explorer of Asia Minor, suggested Paul's movements there (especially in Acts 13:13) were dictated by recurrent malaria and the realities of the physical terrain (Ramsay 1920, 92-97). Paul's references to his own physical infirmities (2 Corinthians 10:9, 12:7; Galatians 4:13) are consistent with the idea. Ramsay makes particular note of Paul's

statement to the Galatians that "you know it was because of a bodily ailment that I preached the gospel to you at first" (Galatians 4:13) to support his theory.

A few Pauline scholars of divergent approaches accept the idea that Paul suffered from malaria (e.g., Robertson 1920, 13, 27; Borg and Crossan 2009, 63-64). More cautiously, others concede that sickness contributed to changes in his plans (e.g., Murphy-O'Conner 1996, 162). Nevertheless, despite much research on the apostle's use of known Roman roads and actual routes taken (French 1994), no studies have taken up Ramsay's connection between geography and Paul's illness in analysis of routes chosen or—more tellingly—declined. This fact is arguably due to an inability on the part of most biblical scholars to conduct a GIS-based analysis such as the one described here. This study and resulting tool provide evidence-based reasoning in a field heretofore dominated (and necessarily so) by *a priori* assumptions.

Wider Application

Beyond Pauline or biblical studies, the study promises application to wider fields of historical geography and ancient history. Climate change and pandemic threats in the contemporary world have engendered an interest in the role of disease in ancient history, resulting in new and seminal studies (e.g., Sallares 2002; Harper 2017). The threat of vector-borne disease is well-established for certain regions, such as the Pontine Marshes and Campania in Italy, but no attempts at spatial modeling of that threat have appeared to date.

Further, the effect of malaria on travelers has escaped serious study. To illustrate, malaria and other disease threats are not mentioned in the leading synthesis on ancient travel (Casson 1994), despite textual evidence highlighting the problem. Literary data on

the geographical movements of individual travelers as well as entire armies may be enlightened by modeling malaria or other disease threat along listed routes. Finally, in a broader sense, this project helps bridge the gap of research methodology between humanities and STEM disciplines.

Statement of Thesis and Approach of This Study

This study explores a multipart thesis as follows: Construction of a viable model for malaria risk prediction is possible for the ancient world; such a model can be extended to predict those hazards for travelers on ancient Roman roads; and its application to certain text sources with spatial data can add meaningfully to discussion toward historical reconstruction. The study proceeds according to the following steps:

1. **Identify relevant aspects of the malaria disease process and its manifestation in antiquity.** Chapter II examines the epidemiology and ecologies of malaria. Particular attention is given to aspects of the disease relevant to modeling considerations. Review of awareness and descriptions of malaria follows in order to identify potential references in surviving text sources.
2. **Construct a risk model for malaria in antiquity.** Strategies for construction of contemporary malaria risk assessment models are reviewed in Chapter III and aspects applicable to a model for antiquity identified. Resulting risk layers and sources are established and documented, and model construction outlined. Methodology and a baseline for model calibration and validation are identified and described. Next, study areas are established for calibration and validation, and results presented. The chapter concludes with anecdotal and scientific support for

validation drawn from sources extending from the time of validation observation data into antiquity.

3. **Extend risk model to Roman roads and apply to the travel decisions of Paul as a case study.** Chapter IV identifies datasets and the procedure for extending the ancient malaria risk to Roman roads. Text source examples within the validation area are again used for anecdotal support and described as precursors for other application. For the case study application to Paul's travel decisions in Asia Minor, the problem is reviewed through a brief history of affected issues, varying opinions to date, and specific notes on the relevant text passages. The model is then applied to western Asia Minor, the location of the texts in question, and extended to the Roman roads there. Results and discussion follow.

CHAPTER II – MALARIA IN ANTIQUITY

Malaria: Epidemiology and Ecologies

Malaria is caused by a parasitic infection of the victim's blood by various species of protozoans of the genus *Plasmodium*. The parasites are transmitted between victims during blood meals by female mosquitos of the genus *Anopheles* (Carter and Mendis 2002, 565). The latter are conventionally called "vectors," and malaria is thus designated a "vector-borne disease." The combinations of vectors, *Plasmodium* species, and their astounding adaptability create a bewildering array of manifestations which make malaria "so moulded and altered by local conditions that it becomes a thousand different diseases and epidemiological puzzles" (Hackett 1937, 266).

The details of and voluminous literature on malaria defy summary here. Rather, this review will focus on features of the epidemiology, disease process, its presentation, and ecologies—especially the environmental and spatial aspects that impact the study.

Epidemiology

Four *Plasmodium* species infected humans in antiquity: *P. malariae, P. ovale, P. vivax,* and *P. falciparum*, each with its own peculiarities and severities (*P. falciparum* being the most dangerous in terms of mortality).[1] The lifecycle of the *Plasmodium* protozoan involves transmogrification into at least seven different forms as it takes advantage of the host for its nourishment and the vector for its transport to that victim (Shah 2010, 14-19).

[1] In recent years *P. knowlesi*, formerly only known in chimpanzees, has appeared in humans (Shah 2010: 239-40; Faust and Dobson 2015).

The infected *Anopheles* vector, in obtaining its own blood meal, inoculates the victim with a dozen or two *sporozoites*, slivery forms of Plasmodium, which reach and invade liver cells undetected by the body's defenses, thus creating the infection. Within a week, each sporozoite matures into a *schizont* and can produce 10,000-30,000 "daughter" *merozoites*, which release into the bloodstream when the schizont bursts. The merozoites invade red blood cells where they consume hemoglobin and reproduce asexually, with a six to 30 times increase in merozoites bursting out into the blood stream in a regular cycle. After the parasites reach a critical population density, severe fever occurs as the host's immune system detects and battles the invaders. Surviving merozoites enter new blood cells and burst out again after a non-febrile period of reproduction. The cycle takes 48 hours for *P. falciparum*, *P. vivax*, and *P. ovale*; 72 hours for *P. malariae*. Ancient observers called the recurrent fevers "tertian" (for recurrence on the "third" day) or "quartan" (recurring on the "fourth" day). The cyclic febrile symptoms can persist for months or even years if untreated. Further, in infections by *P. vivax* and *P. ovale*—but not by *P. falciparum* or *P. malariae*—some liver stage forms become *hypnozoites* and remain dormant in the victim for weeks or years (Battle et al. 2014). When wakened by some stimulus, they cause *relapses* (see "Recurrence of Malaria," below); producing blood-stage merozoites and febrile symptoms (White et al. 2014, 723-25).

During the blood-stage, some parasites develop into sexual forms that can transfer to a mosquito with the latter's blood meal. Sexual reproduction, called *sporogony*, occurs only within the mosquito where the produced *ookinetes* lodge in the vector's gut and produce *oocysts*. The life cycle is complete when oocysts burst, releasing the sporozoites

that collect in the salivary glands awaiting inoculation into a new host (White et al. 2014, 724-25).

This complicated cycle would appear to make malaria transmission somewhat random and possibly infrequent. The complexity, however, for centuries masked the cause of the disease and the vectors' role in transmission; and it continues to hamper efforts to combat malaria today.

Malarial Ecologies

Popular simplistic assumptions that malaria risk is the result of swampy conditions and attendant mosquito production (e.g., Wilson 2016, 240-42) are insufficient for understanding the disease. *Infection prevalence* (often termed "parasite rate") is the key calculated statistic used in current cutting-edge efforts to model malaria risk (Weiss et al. 2015, 2-4). The intensity of malaria transmission and resulting infection prevalence is a function of certain environmental variables and other factors related to the three biological components of the disease process: 1) the *Plasmodium* parasite; 2) the *Anopheles* vectors; and 3) human hosts. The environmental variables, especially temperature, rainfall, elevation, slope, and wetness potential, have spatial variation that contribute to the risk formula through the biological components.

Plasmodium parasite. The *Plasmodium* life cycle includes reproduction and metamorphosis of the various parasite forms within both the human (or other mammalian) host and the *Anopheles* mosquito vector. Apart from individual host variation, conditions within the warm-blooded victim are reasonably constant. The cold-blooded mosquito, however, is another matter, as internal temperatures vary with the ambient environment.

Plasmodium sexual reproduction within the mosquito vector is temperature dependent. Sporogony occurs only after a certain number of days above a minimum temperature. Early studies on the vector *Anopheles maculipennis* set the minimum degree-days at 105 for *P. vivax* and 111 for *P. falciparum*; with minimum temperatures of 14.5 °C and 16 °C, respectively (Lysenko and Semashko 1968, 50). But it is more complicated than that. Rather than a simple static threshold, temperature (itself always changing) determines the minimum degree-days. Further, temperature dependence on parasite dynamics is decidedly non-linear. Even above the minimum values, the critical issue is whether the vector will survive the number of degree-days determined by temperature for sporogony to occur in its gut (Gething et al. 2011a, 2-4). Consistently higher temperatures increase the likelihood of infectious sporozoites developing in viable vectors.

Anopheles mosquito vectors. Human-infecting Plasmodium are transmitted only by mosquitos of the genus *Anopheles,* of which over 465 species and species complexes are known worldwide. Of these, some 70 have potential to transmit malarial protozoa to humans and 41 are considered "dominant vector species/species complexes" (DVS); that is, capable of malarial transmission levels of concern to modern public health (Sinka et al. 2012, 1 of 11).

The vector role of *Anopheles* mosquitos was firmly established only in 1898 by Giovanni Battista Grassi of the Italian "Rome School" (Snowden 2006, 35-38). Grassi promoted the expression, "*infected man + anopheles = malaria*," an epidemiological statement known as "Grassi's Law" (Fantini 1994, 84-85). Objections to the theory of mosquito transmission were bolstered by a phenomenon known as *anophelism without*

malaria—the apparent spontaneous disappearance of malaria in several regions of Italy in the late 19th century, despite the continued presence of *Anopheles* mosquitos therein. Careful observation and study in Italy revealed that the established vector, *Anopheles maculipennis*,[2] was not a single species but rather a complex of distinct species (Fantini 1994). For the areas of this study, nine different biological species have been identified by chromosomal banding and DNA analysis within the *Anopheles maculipennis* complex. Of these, seven species are visually distinguishable only by differences in patterns in egg floats or eggs themselves, and two can be distinguished from the others—but not from each other—by minor adult variation. Only three of the nine *maculipennis* complex species have served as important malaria vectors in the past. The presence of identical-appearing mosquitos in non-malarial regions is likely a major factor for why the vector connection was not realized by ancient Greeks and Romans (Sallares 2002, 43-45).

It is important to note that anophelism without malaria developed in certain areas where malaria had been endemic in the past with no apparent change in *Anopheles* density. The transformation implies either some shift in *Anopheles* species dominance or a change in human lifestyle a given region. Both possibilities seem to have contributed to the phenomenon in varying measure for each region. *Anopheles* species, though identical in appearance, differ in selection of breeding sites, sexual behavior, and winter habits. Part of the anophelism without malaria enigma was due to geographical distribution of the different species (Fantini 1994, 103). More importantly, however, those species that are effective malaria vectors also vary in their meal preferences. For example, *A.*

[2] *A. maculipennis* was originally called *Anopheles claviger* by Grassi and others (Fantini 1994, 86).

maculipennis s.s. (also called *A. typicus*) and *A. messeae* are strongly *zoophilic*, that is having a genetic tropism for animal blood (especially pigs) but will bite humans if animals are not available. *A. labranchiae* and *sacharovi*, in contrast, are strongly *anthropophilic*, preferring human victims but will attack animals where humans are not present. *A. atroparvus* falls in an intermediate position with local conditions determining victims. Breeding site preference varies with species' tolerance of saline, shade, plant content, and pollution of larval habitats. Mosquitos also strongly defend their chosen breeding sites against other species (Shah 2010, 63), employing predation and cannibalism at the larval stage (Koenraadt and Takken 2003). A natural and elastic coexistence between species can be upset by minor local changes that significantly shift the *Anopheles* balance (Fantini 1994, 103).

Development of anophelism without malaria in late 19th century Europe north of the Alps provides an example of the dynamics of the sample variables above. Modernization of agriculture reduced breeding sites and increased the availability of animal victims, favoring zoophilic species and reducing *Anopheles*-human contact to below endemic maintenance levels in western and central fresh-water regions. But saline-tolerant *A. atroparvus* continued to compete with *A. messeae* around saltwater so that mildly endemic conditions persisted in some coastal areas until the 1940s. Meanwhile, *A. messeae* remained a consistent malaria threat in the parts of eastern Europe where agricultural modernization lagged and significant *Anopheles*-human contact continued (Fantini 1994, 104).

The situation is more complicated than the example above for the Mediterranean region of concern in this study, in part because twice as many malaria vectors must be

considered. **Table 1** summarizes important genetic preferences for the six human malaria vector *Anopheles* species of Europe and the Mediterranean Near East.

Table 1 – *Characteristics of human malaria vector species in the study area*

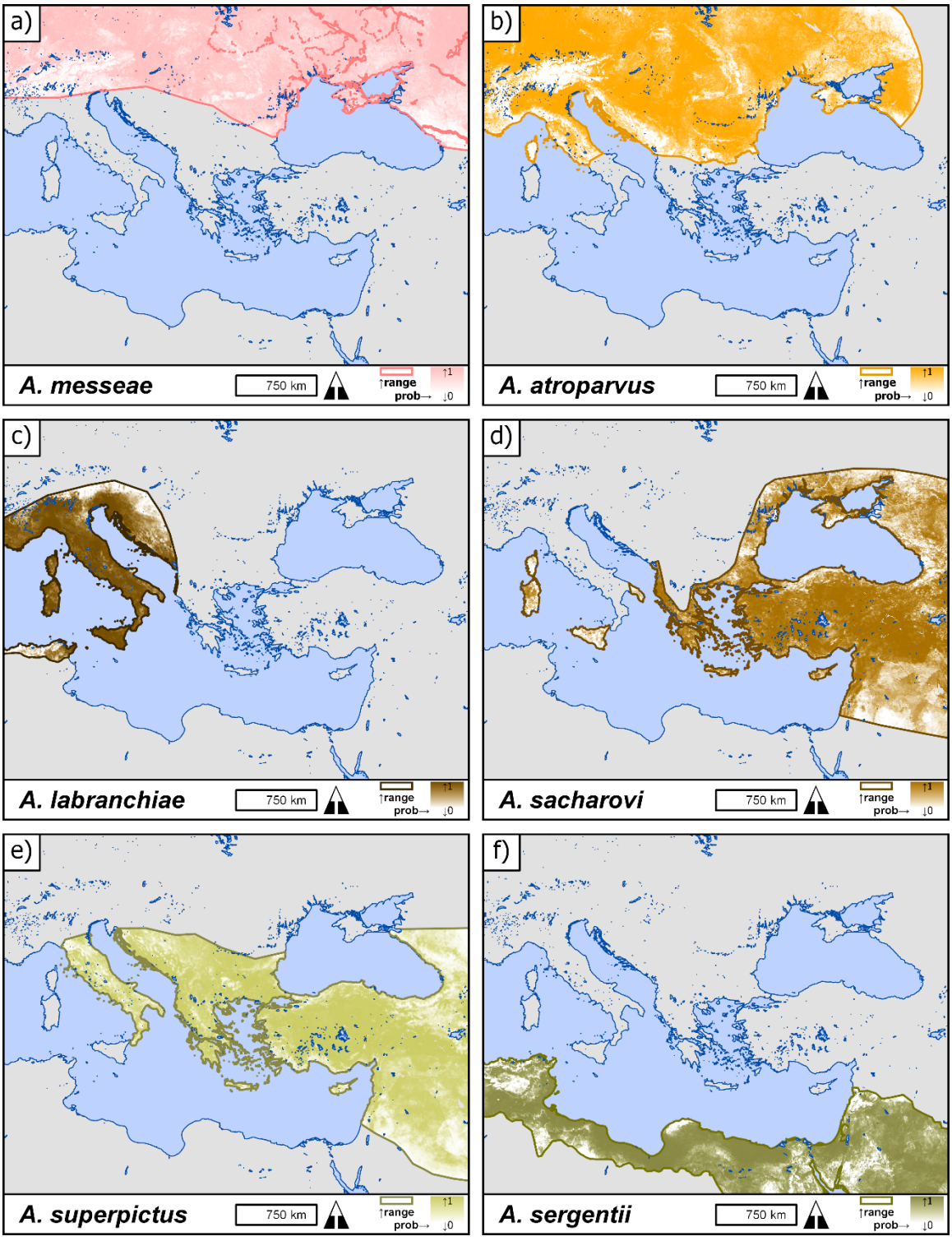
Genetic Preferences → / Vector *Species* ↓ (with sources)	Larval Sites								Blood Preference		Feeding Habitat		Resting Habitat		Hibernate	
	sunny	shaded	brackish	fresh	plants/ algae	no vegetation	clear	polluted	anthropophilic	zoophilic	endophagic	exophagic	endophilc	exophilic	yes	no
A. atroparvus (Manguin et al. 2008, 233-34; Sinka et al. 2010; ECDC 2014a)	●		●	○	●			◦	●	○	●		●		●	
A. labranchiae (Manguin et al. 2008, 232-33; Sinka et al. 2010; ECDC 2014b)	●		○	●	●		●		•	•	•	•	●		◦	
A. messeae (Manguin et al. 2008, 234-35; Sinka et al. 2010)	○	●	○	●	○	●			◦	●		◦		◦	●	
A. sacharovi (Manguin et al. 2008, 232; Sinka et al. 2010; ECDC 2014c)	●		•	•	●		•	•	●	○	•	•	●	○	◦	
A. sergentii (Manguin et al. 2008, 235; Sinka et al. 2010)	●	○	○	●	●		●		○	●	•	•	•	•	•	
A. superpictus (Manguin et al. 2008, 236; Sinka et al. 2010)	◦		○	●		◦			○	●	○	●		◦	◦	

KEY: ● = strong preference; ○ = secondary preference; • = shared preference; ◦ = slight preference

The potential availability of vectors is only limited by the range of each species. Current ranges and spatial probabilities within ranges for the six vector *Anopheles* species appear in **Map 1**. The ranges shown are based on expert opinion for 1985-2009 modified with occurrence data (Hay et al. 2010, Text Supplement 4) and are more limited than in antiquity due to eradication campaigns. For example, *A. sacharovi* (**Map 1d**), now

largely eliminated from the peninsula of Italy (Sallares 2002, 44-45), was common as far north as the river Po in 1926, when it was called *A. elutus* (Fantini 1994, 103). The dataset used for **Map 1**, obtained from The Malaria Map Project, shows only distribution prediction *within* the modern expert opinion ranges; whereas the predicted species distributions in the original study extend beyond the current ranges (Sinka et al. 2010, additional file 3).

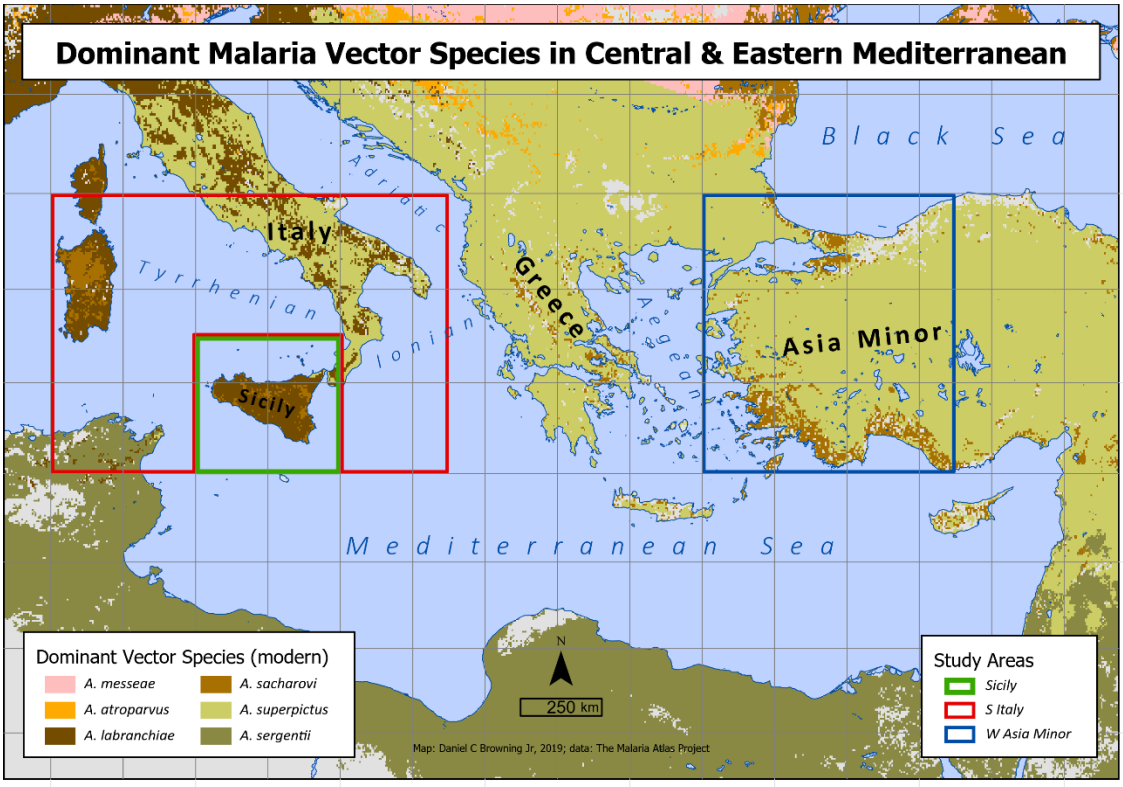
Conditions favoring any of the variations in *Anopheles* species' preferences are profoundly local and difficult to map apart from saline tolerance. Subtle changes in local conditions can easily shift the level of *Anopheles*-human contact and alter the intensity of malarial transmission (Hackett 1937, 222-31). Thus, epidemics are highly localized. To again quote malariologist Hackett, examination of the disease reveals it as "more protean in its character, more diverse in its local manifestations" (Hackett 1937, 22). Therefore, looking ahead to the following chapter, we can expect only to model malaria risk for antiquity by establishing spatial zones for potential disease outbreak if local conditions align for favorable transmission.



Map 1. *Ranges and predicted distributions for Mediterranean malaria vectors.*

Ranges: current, based on expert opinion (Sinka et al. 2010, supplementary material); distribution (labeled "prob"): predicted probability based on environmental values within ranges only (MAP).

The six vectors of **Map 1** are combined in **Map 2**, which shows current (2010) local *dominant vector species* (DVS) for malaria in the Mediterranean regions considered by this study. Identification of local DVS is an important aspect in contemporary efforts to combat malaria (Hay et al. 2010, 1-2), but individual species' ranges are not a factor in modern risk modeling. For this reason, and because datasets are only available for current extents, species ranges are not included in this study's risk model for antiquity. The study areas described in the following chapter appear on **Map 2**, demonstrating the ready availability of capable vectors throughout. Local conditions favoring a particular species and its attendant risk depend on subtle changes, usually anthropogenic (Sallares, Bouwman, and Anderung 2004, 311-12).



Map 2. *Dominant malaria vector species of the Mediterranean, with study areas.*

Human hosts. The third biological component to malaria risk is the human host. Population density, deforestation, land use, creation of water features, and other anthropogenic environmental changes (such as road and aqueduct building) are major factors for calculating malaria risk in contemporary studies (Weiss et al. 2015). The spatial certainty required to model these conditions is scarcely possible for antiquity; therefore, they will not serve as factors in the model for risk in antiquity.

One possible exception is the building of roads. Some models of contemporary malaria risk incorporate "distance to road" as a risk layer; as improved roads are seen as corridors of human blood meals and transportation for vectors (Fuller et al. 2014, 4, 6; Mulefu, Mutua, and Boitt 2016). More relevant for this study, the environmental impact of roadbuilding itself creates drainage issues, often giving mosquitos breeding opportunities along with the chance for meal delivery. Such a situation is demonstrable in antiquity for the famous *Via Appia* in the Pontine Marshes (Sallares 2002, 181; O'Sullivan, et al 2008, 758; Harper 2017, 86-87). Nevertheless, it would be difficult to quantify the variable impact of road construction on potential vector breeding sites and no existing dataset attempts to do so. Accordingly, this study focuses on roads as the target of risk assessment rather than a factor in calculating it.

Some aspects of the disease process in human hosts are relevant for the application of model results and potential interpretation of ancient text sources. Malaria overwinters in human hosts in temperate climates (Sallares 2002, 151), and the disease can be introduced into malaria-free environments by the arrival of infected persons. These factors heighten the importance of recurrence and potential immunity to malaria.

Recurrence of Malaria

Recurrence: recrudescence, relapse, and reinfection

One of the hallmarks of malaria is *recurrence*, defined as a newly detectible episode of febrile blood-stage symptoms occurring after a previous infection. Like most things with this disease, the dynamics and terminology are complicated.

Recurrent infections of malaria may be the result of *recrudescence*, *relapse*, or *reinfection* (White et al. 2018, 2). Recrudescence occurs when blood stage parasites from a previous infection persist at low non-symptomatic levels before increasing in density such that symptoms reappear.

Relapse in *P. vivax* or *P. ovale* malaria occurs when dormant hypnozoites are activated. The dynamics of relapse cycles is poorly understood, but strong evidence suggests that other febrile infections can trigger hypnozoite reactivation. This catalyst appears to be true for systemic parasitic and bacterial infections, but not for viral infections (Shanks and White 2013). The most likely parasitic infection in an endemic area is malaria itself, so that inoculation by a different strain can activate hypnozoites from a prior infection creating a relapse on top of the new bout. Cruelly, infection by *P. falciparum* effectively triggers relapse of *P. vivax* (Douglas et al. 2011; White 2011).

P. falciparum and *P. malariae* do not produce hypnozoites so their recurrence is due to recrudescence and, especially, reinfection. In the study areas *falciparum* malaria was a persistent killer of children from antiquity until recent times (Bonelli 1966; Snowden 2008). If a child in an endemic region survived an initial infection, they could expect many reinfections but with a decreasing chance of death (White et al. 2014, 723).

Immunity

Individuals gain immunity to malaria in stages following multiple mosquito-bite inoculations and resulting reinfections. A reduced risk of death from *P. falciparum* malaria may be obtained after possibly one or two infections. Resistance to severe clinical symptoms is achieved only after more and frequent infections, but immunity to the parasite itself requires many more and continuing inoculations. These immunities offer the host resistance against the sporozoites introduced by mosquito bites and the liver stages. Antibodies also develop against the sexual stage gametocytes and gametes that are infectious to mosquitos. These antibodies provide no clinical relief to the individual host but may limit transmission via the vector to the community (Carter and Mendis 2002, 566-67).

Immunity to malaria is specific to the species of *Plasmodium*. Further, each species exhibits great genetic diversity (Walliker et al. 1987) and immunity must be gained for various "strains" by which they may be inoculated within a locality. Even so, such immunity is easily lost when inoculation is not frequent. Anecdotal evidence and consensus suggest that lack of reinfection for six months to a year can leave an individual susceptible to the full range of malarial infection ills (Carter and Mendis 2002, 567). While immunity itself would be difficult to model, it is a critical issue in application of the model to roads and travelers on them.

It is important to note that *Plasmodium*'s genetic diversity presents great geographical variation. Immunity gained against malaria in one locality gives no protection from strains in a different region (Sallares 2002, 36-38**;** Walliker et al. 1987; Battle et al. 2014). Thus, newcomers to endemic regions are at particular risk of infection

or reinfection, despite immunity gained elsewhere. Furthermore, if infected elsewhere, they may introduce strains for which locals have no immunity (Sallares 2002, 224-25). Travelers, then, are particularly at risk and represent risks themselves.

Malaria in the Ancient World

Presence and knowledge of malaria in antiquity

There can be no doubt about the presence of malaria in the ancient Mediterranean world. The earliest certain documentation of the intermittent fevers characteristic of malaria comes from the fifth and fourth century BCE (Sallares, Bouwman, and Anderung 2004, 314). The texts, attributed to Hippocrates, describe the tertian, quartan, and "semitertian" fevers (Hippocrates, *Epidemics* 1, 3) confidently identified with *P. vivax, P. malariae*, and *P. falciparum* malaria, respectively (Grmek 1989, 281; Carter and Mendes 2002, 581; Cunha and Cunha 2008, 195). The Roman physician Celsus, writing in the first half of the first century CE, gave a more exact account (Sallares, Bouwman, and Anderung 2004, 314) and differentiated two types of tertian fever (Celsus, *De Medicina* 3. 3. 1-2). The first (*P. vivax*) came to be called "benign tertian," and the "far more insidious" second type (*P. falciparum*) came to be known as "malignant semitertian" (Cunha and Cunha 2008, 196).

P. falciparum probably was endemic in parts of Sicily by the fifth century BCE and arrived in the Italian peninsula between 400-100 BCE (Sallares, Bouwman, and Anderung 2004). DNA evidence confirmed its presence in Italy from the second and fifth centuries CE (Marciniak et al. 2016; Marciniak et al. 2018). Dated early Christian funerary inscriptions around Rome reveal a pronounced seasonal mortality rate, remarkably consistent with the aestivo-autumnal cycle of *P. falciparum* (Shaw 1996;

Scheidel 2015). These data highlight not only the presence, but also the mortality and morbidity burden of the disease for the Roman period in certain geographical areas (Sallares, Bouwman, and Anderung 2004, 312).

Awareness of spatial malaria threat in antiquity

The case-study application of this study (Chapter IV) does not presume any clinical or ecological knowledge of the malaria disease process but does assume general awareness of the threat. It also assumes a practical wisdom of avoiding locations of high risk or known outbreaks. Certain ancient sources demonstrate that recognition and strategies for avoiding insalubrious areas (Manguin, Carnevale, and Mouchet 2008, 4).

The name eventually assigned to "the fever," *mal'aria* (Italian, "bad air"), reveals its long association with *miasma*, noxious fumes emitted from certain places. Vitruvius, the first century BCE civil engineer and architect wrote that "Those places, however, which have stagnant marshes, and lack flowing outlets, whether rivers or by dykes, like the Pomptine marshes, by standing become foul and send forth heavy and pestilent moisture" (Vitruvius, *On Architecture* 1.4.12).

"Bad air" was not confined to marshes. Frontinus refers to water management efforts of Emperor Nerva in the late first century CE in Rome itself; "unwholesome atmosphere, which gave the air of the City so bad a name with the ancients, are now removed" (Frontinus, *Aqueducts of Rome* 2.87). Nerva's works, in fact, failed and the problem continued for centuries. Rome's medieval inhabitants that were financially able fled for the mountains in summer, especially during the "Dog Days" of August (Sallares 2002, 227-28). The late first and early second century letters of Pliny the Younger suggest that he and other elite Romans, also knew to flee the city at that time for the

comforts of villas in healthier climates. In one letter, Pliny decries a certain irritating Regulus who demanded that people visit him in his villa along the Tiber in Rome "at the most unhealthy time of the year" (Pliny the Younger, *Letters* 4.2.5-6). The seasonal threat of semitertian fever was appreciated as early as Archaic Greece. Homer also lamented the "Dog Days," so named for the Sirius, "the star that men call by name the Dog of Orion. Brightest of all is he, yet he is a sign of evil, and brings much fever [*πυρετὸν*] on wretched mortals" (Homer, Iliad 22.28-31).

Other literary evidence for awareness of malaria's spatial risk appears in the following chapters. Perhaps the most telling ancient observation comes from the late fourth century advice of Palladius Rutilius Taurus Aemilianus: "A fen is by all means to be avoided, especially that which is from the south, or from the west, and which has been used to be dried up, because of pestilential diseases, and of the unfriendly animals which it produces" (Palladius, *On Agriculture* 1.7.4). This is practical advice from a man of the land, who realized the danger of seasonal wet spots—prime breeding zones for mosquitos due to the lack of predatory fish—and almost connected the disease with its vector fourteen centuries before that discovery was made.

CHAPTER III – MODELING MALARIA RISK FOR ANTIQUITY

Malaria Risk Assessment and Modeling

Despite the success of eradication campaigns in Europe and elsewhere in the twentieth century, malaria remains a significant health issue in many parts of the world today. Studies continually conclude that climate change threatens quantitative increase and spatial expansion of malaria threat (Martens et al. 1995; Martens et al. 1999; Lieshout et al. 2004; Caminade et al. 2014; Dasgupta 2018). Modeling malaria risk and production of risk maps thus play an increasingly important role in contemporary efforts to track and combat the disease (Weiss et al. 2015, 2). These efforts provide a starting point for this project's goal of modeling spatial risk of malaria for the past.

Risk factors in contemporary malaria risk models and mapping

Incorporation of environmental spatial datasets as model components for malaria mapping began in the 1980s and is now standard practice. Of special note is the ongoing research of the Malaria Atlas Project (MAP), which maintains an extremely complex malaria risk model (Hay and Snow 2006; Weiss et al. 2019). Most studies identify various risk factors, or covariates, as model inputs. Spatial datasets identified for each covariate are reclassified into a scale (typically 1-5, with 5 representing the highest risk). The resulting risk layers are then combined to arrive at a cumulative risk assessment in map form. This study utilizes the combined risk layer approach as well, but with a 0-3 scale.

Approaches in identifying risk factors and their relative weighting in models vary widely, and rationale for inclusion of particular covariates is lacking in most studies. It appears that certain spatial datasets are simply assumed by near consensus, while others

are selected subjectively or as a matter of convenience and availability (Weiss et al. 2015, 2-4). Often no rationale for weighting of risk factors is provided and the weight assignments for layers are given in a table without comment. Invariably, risk factors in contemporary studies fall into two categories: physical environment and anthropogenic factors. Representative recent studies with their factors so divided appear in **Table 2**.

Table 2 – *Selected contemporary malaria risk studies using a weighted-layer approach.*

Study	Environmental Factors	Anthropogenic Factors
Protopopoff, et al (2009)	• Precipitation • Altitude • Temperature	• Land use • Livestock • Insecticide use • Socio economic status • [various human behavior factors]
Hanafi-Bojd, *et al* (2012)	• Temperature • Relative humidity • Main rivers • Seasonal rivers • Altitude • Slope	• Hazard • Population density • Mean of incidence • Land use/land cover • Development factors • Control activities
Moss, *et al*. (2011)	• index of topographic wetness (slope/flow direction) • topographic position index (slope position/landform type)	• infection incidence
Ahmed (2014)	• Elevation • Slope • Distance to stream • Wetness index	• Breeding sites • Accessibility • Land cover
Fuller, *et al* (2014)	• Elevation • Rivers and streams • Wetlands	• Roads • Urban areas • Population • Vector occurrence points
Mulefu, Mutua, and Boitt (2016)	• Temperature • Distance to rivers • Altitude • Slope • Rainfall	• Breeding sites • Population density • Land cover • Poverty levels • Distance to hospitals • Distance to roads • Control measures

The highest level of covariate justification and scrutiny to that time is provided with MAP's 2010 global maps of malaria endemicity (Gething et al. 2011b; Gething et al. 2012). As part of an effort to include dynamic layers (accounting for changes with time)

and refine its mapping efforts, a subsequent MAP project performed a meta-analysis of covariates used by 113 previous studies (Weiss et al. 2015, 2-4). Nine categories of covariates were outlined, some yielding multiple dynamic datasets. The results have improved MAPs subsequent products (Weiss et al. 2019, 324) and are presented as guide for "researchers seeking to maximize the utility of a rich set of environmental covariates while also limiting subjective decisions within the variable selection process" (Weiss et al. 2015, 17).

The nature of this project precludes the use of certain covariates, since some data is not consistently available for antiquity. Other covariates must be limited to synoptic datasets (of annual averages), as dynamic data would be too speculative for the ancient world. Nevertheless, the MAP study described above provides a useful framework for discussion and selection of risk layers for this research. The nine MAP covariate categories (Weiss et al., 2015, 4-7) are enumerated below with discussion and rationale for inclusion or rejection of individual risk layers for this study's malaria risk model:

1. **Temperature**. Well-established as important for vector and parasite survival, temperature is one of the "assumed" covariates and the most-used risk factor in previous studies. With its goal of incorporating dynamic data, the MAP study used metrics derived from MODIS land surface temperature datasets (Weiss et al., 2015, 4-7). Such dynamic observations are obviously impossible for the ancient world. Furthermore, even synoptic averages are speculative. Still, no option exists apart from using near-contemporary data to estimate ancient temperatures. In earlier mapping efforts a binary layer representing limits of temperature suitability for both parasite sporogony development and vector survival functioned as a

mask (Hay et al. 2009, 287). For the 2010 global malaria endemicity maps (Gething et al. 2011b), MAP developed additional hybrid covariates of temperature support and suitability. The first is a 1 x 1 km pixel size raster representing the number of days per year temperatures can support infectious vectors. Because tropical areas tended to have large swaths of saturation for support, an additional index layer was created to provide a metric of the "degree of suitability" and thus greater contrast in those areas (Gething et al. 2011a). This study's model incorporates MAP's temperature support layer, provided with the metric of infectious days per year. These datasets are open-source and available for both *Plasmodium falciparum* and *P. vivax*. Their hybrid incorporation of temporal data over a large span (1950-2000) and 0-365 range of values (Gething et al. 2011a) provides some mitigation for the necessary use of modern climatological data and the potential effect of recent climate change.

2. **Precipitation**. Like temperature, precipitation is near-universally incorporated in malaria risk models. Its importance in providing temporary standing water for mosquito larvae is obvious, but it also indirectly contributes by determining habitat types. As no suitable remotely sensed dynamic data is available for precipitation, MAP uses datasets from the WorldClim project (Hijmans et al. 2005) to produce seasonal metrics (Weiss et al. 2015, 5). This research follows suit in using the WorldClim product. So that the temporal range falls within the span of the chosen temperature layer (and also mitigate against effects of recent climate change), WorldClim Version 1.4 was chosen. It is interpolated from observed data representative of years 1960-1990, with 30 arc-second resolution

(Hijmans et al. 2005). WorldClim's monthly average precipitation surfaces are aggregated to a synoptic annual average layer for inclusion in the risk model.

3. **Land Cover**. Contemporary malaria risk models (including MAP) often include land cover covariates, as mosquito species have certain ecological preferences. This requires remote sensing imagery of higher spatial resolution than that of the analysis itself. Clearly such data cannot be obtained for the ancient world. Any attempt to project or estimate land cover for the ancient world would be too general and introduce confusion. For example, *Anopheles* species prefer dense forest cover (Weiss et al. 2015, 5-6), but widespread deforestation by ancient Rome was likely contributary to the increase of standing water and overall malaria risk in parts of Italy (O'Sullivan et al. 2008). For these reasons, land cover is not used as a risk layer in this study's model.
4. **Surface Moisture and Breeding Site Information**. Datasets that characterize the availability of standing water for vector breeding require either high resolution dynamic remote sensing or labor-intensive ground survey sources. Neither are possible for the ancient world. One proxy for this type of data is a probable wetness index. As probable wetness is a digital elevation model (DEM) derivative (Weiss et al. 2015, 6), it will be discussed in that section below. Another proxy for surface moisture and direct breeding site information is a metric for distance to stream or other waterbody. European Union (EU) Hydrography data, a high-resolution (25 m) dataset covering all study areas for this project, is available through the Copernicus Land Monitoring Service. Although some artificial features such as culverts appear in the dataset (San José 2015), it is incorporated

in the risk model as a layer under the premise that such features usually replace potential flowing or standing water locations.

5. **Vegetation Indices**. Although used in many contemporary studies, vegetation indices also require temporally-variable remotely sensed data, such as MODIS imagery (Weiss et al. 2015, 6), and are not applied to this study.
6. **Elevation**. Elevation's association with temperature and precipitation creates doubt in authors of the MAP study about its expected direct contribution. They nevertheless include it "in the interest of thoroughness" (Weiss et al. 2015, 6-7). This study grants elevation greater initial expectation for direct contribution to ancient malaria risk for several reasons. Areas of known pre-eradication endemicity appear to have a high spatial correlation with lower elevations. Also, *Anopheles* mosquitos are poor fliers and cannot easily ascend to higher elevations, making local high spots theoretically safer—as anecdotal data seems to confirm (Sallares 2002, 57). Finally, ancient textual sources suggest an awareness of this factor (Vitruvius, *On Architecture* 1.4.1; Varro, *On Agriculture* 1.12; Antyllus, quoted by Stovaios, *Florilegium* 1010.18, trans. Sallares 2002, 57). A DEM created from the Shuttle Radar Topography Mission (SRTM) dataset serves as a risk layer in the model, as well as the basis for slope as a DEM derivative below.
7. **Humidity**. Humidity-related covariates were incorporated in nearly a quarter of surveyed prior studies. Nevertheless, no products with suitable resolution were available for the MAP study, which relied on remote sensing derivatives as proxies (Weiss et al. 2015, 3, 7). Humidity is not used in this project.

8. **DEM Derivatives**. Slope, which determines water runoff, is the most frequently incorporated DEM derivative in surveyed studies. Topographical wetness index incorporates slope and flow accumulation in a single metric and provides a useful dataset (Weiss et al. 2015, 3, 7) as a proxy for surface moisture and breeding sites. This model utilizes a slope risk layer created from the elevation DEM. For topographical wetness, the European Environment Agency provides a convenient Water and Wetness Probability Index, covering all study areas. The index, available via the Copernicus Land Monitoring Service, indicates the "degree of wetness in a physical sense, assessed independently of the actual vegetation" (Langanke, 2016).
9. **Socio-economic Variables**. Socio-economic data is inherently anthropogenic and cannot be known for antiquity at a spatial resolution sufficient for this study.

Modeling for antiquity: risk factors and the problem of validation

Some geophysical factors in contemporary risk models are functionally similar at the spatial resolution of this study's model, such as slope, elevation, and distance to stream. The foregoing discussion, however, illustrates that anthropogenic influences are difficult to define spatially with confidence. While population centers can be reconstructed for certain periods and places, estimates of population density remain speculative. Land cover, another major factor in providing habitat for mosquitos, is also impossible to discern with any reasonable resolution for antiquity. Therefore, this (or any) assessment of ancient malaria risk for a given area must be limited to factors dependent on the physical environment. The risk layers chosen for this study's model are outlined in **Table 3**, including dataset sources, documentation, and relevant metadata.

Table 3 – *Risk layers used in the malaria risk model with dataset details.*

Risk Layer	Dataset (reference)	Source	Spatial Resolution	Data Type
Elevation	SRTM 1 Arc-Second Global (Farr et al. 2007)	USGS EarthExplorer: https://earthexplorer.usgs.gov/	30m	raster; DEM tiles
Temperature	a) *P. falciparum* Support b) *P. vivax* Support (Gething et al. 2011a)	MAP: https://map.ox.ac.uk/explorer/	1000m	raster; interval-like range, 0-365 (days)
Precipitation	WorldClim Ver. 1.4; precipitation, 30 arc-sec (Hijmans et al. 2005)	WorldClim: https://www.worldclim.org/current	1000m	raster; avg mo. totals (mm)
Slope	Derived from Elevation DEM	Elevation layer, above	30m	raster; DEM
Distance to Stream/Water Body	EU-Hydro River Network; river segments (San José, 2015)	EU Copernicus Land Monitoring Service: https://land.copernicus.eu/	(25m)	vector; line feature class
Probable Wetness	EU Water and Wetness Probability Index (Langanke, 2016)	EU Copernicus Land Monitoring Service: https://land.copernicus.eu/	20m	raster; interval-like range, 0-100%

The complex nature of malaria's epidemiology and ecology may conceal hidden or surprising variable issues (as shown by Paaijmans et al 2012). Validation of contemporary models remains problematic (MacLeod and Morse 2014; Tomkins and Thomson 2018) and usually consists of running the model using past data ("hindcasts") and comparing predicted results with observed spatiotemporal disease burden indicators

(MacLeod et al 2015). Complications arise from inaccuracies in—or outright lack of—field data (Tjaden et al 2018, 235).

Validation of a model for antiquity looms as a major difficulty in light of the above limitations. The lack of hindcasts and spatiotemporal outcome data make usual evaluation methods unfeasible. An alternate method would involve comparing model risk predictions against an existing map of pre-modern endemic malaria within a region of the target study areas. A candidate map must necessarily depict controlled observations from a pre-eradication date. Happily, such a map exists.

The Torelli Map

Malaria was still endemic in many parts of Mediterranean Europe in the nineteenth century, especially in Italy (Snowden 2006, 12-26; Majori 2012). Attempts to unify the new Kingdom of Italy after 1861 by railway construction were met with great delay. Senator Luigi Torelli, commissioned by Parliament to investigate in 1878, discovered that railway workers were suffering and dying from malaria at an alarming rate. Realizing the threat of malaria to unification efforts, Torelli gathered regional data on the disease (Snowden 2006, 13). All 259 provincial health councils were directed to report malarial zones using a standardized graphic system on 590 sheets of a complete map of Italy produced by the new Military Geographic Institute. Returned maps were collated into a single 1:1,000,000 scale chart, presented to the Italian Parliament in 1882 (Bagnato 2017) and published by Torelli with an educational book (Torelli 1882).

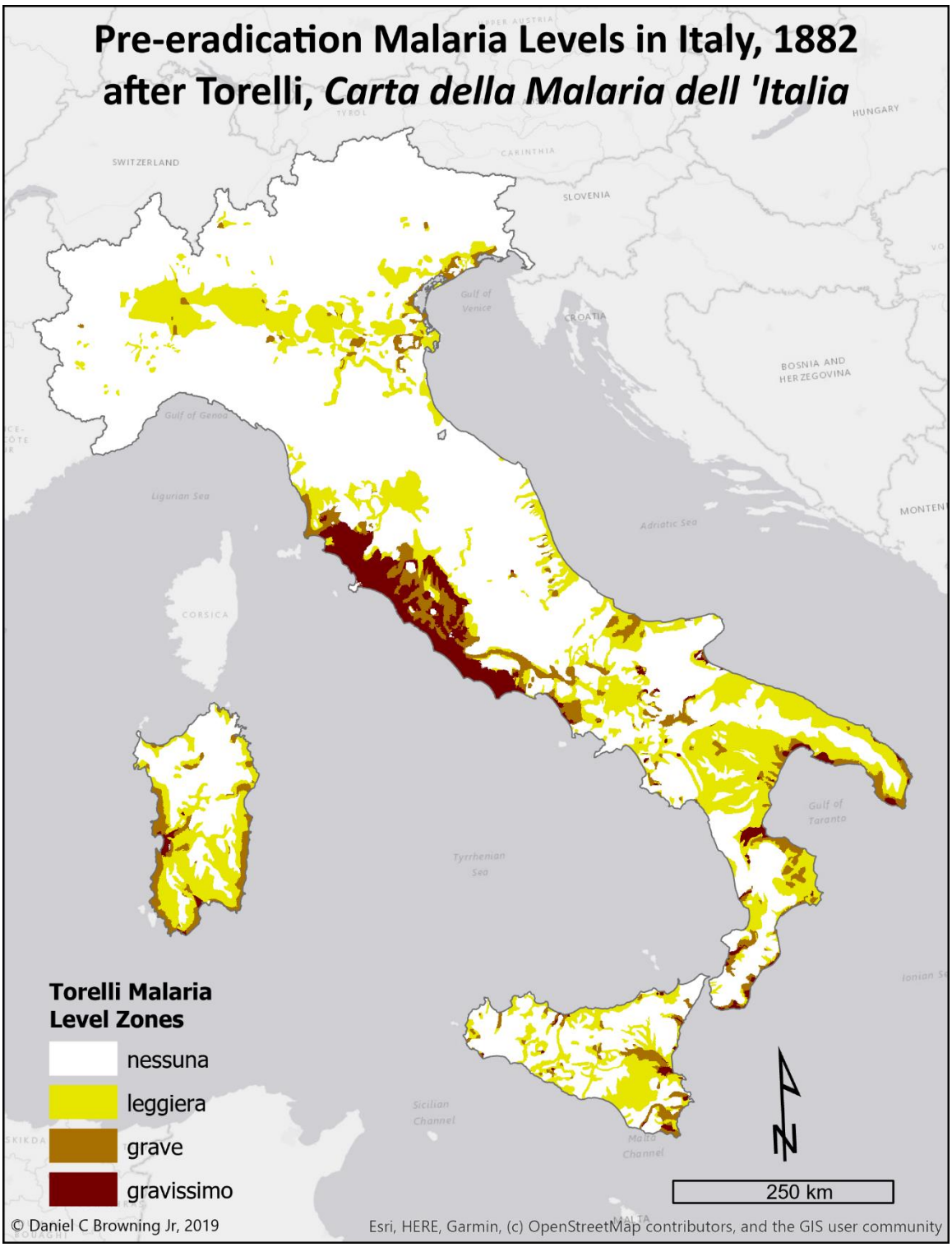
Figure 1. *JPEG image of the Torelli (1882) map.*

From Bagnato (2017).

While *Carta della Malaria dell'Italia* (hereafter, "Torelli map") is relatively modern, it was produced just before the discovery that malaria is caused by protozoan parasites and 17 years before the role of mosquitos in transmission was known (Bagnato

2017). The modern nature of the map gives it the advantage of accuracy and the possibility of overlay using GIS software. For these reasons, it provides a best-case baseline for comparison, adjustment, and validation of this study's model. The Torelli map categorizes malaria endemicity (for 1882) in three categories: 1) ***leggiera***, or "slight;" 2) ***grave***, or "serious;" and 3) ***gravissimo***, or "most serious."

Use of the Torelli map is not without difficulty. Neither an original copy, nor a high-resolution scan of the map could be located. A large fine jpeg image of an unfolded original (**Figure 1**) was obtained from an online article (Bagnato 2017). Preparation of a raster layer for validation use in ArcGIS Pro involved several steps. Using the image cataloging and editing program ACDSee Pro 9, the jpeg was converted to a TIF image, unneeded detail manually removed, and color/bit depth reduced. The resulting TIF image was registered in ArcGIS Pro using the Monte Maria (Rome) Italy coordinate system. The registered image was then subjected to an iterative process of alternately comparing with other layers (such as a coastline dataset from the EU) in ArcGIS Pro, and manual removal of noise and clarification as needed in ACDSee. Finally, the clarified TIF was reclassified using ArcGIS Pro's Reclassify Wizard, producing a layer suitable for model verification. The resulting layer projected as a map approximating *Carta della Malaria dell'Italia* is shown in **Map 3**.



Map 3. *Pre-eradication malaria levels in 1882 Italy.*

After Torelli (1882).

Malaria Risk Model for this Study

Model concept and construction

A malaria risk model for the ancient Roman world was constructed from seven risk layers created from source datasets outlined in **Table 3**. The model allows combination of these layers at varying weights to arrive at the formula that best predicts malaria risk in pre-eradication conditions. All geoprocessing was conducted in ArcGIS Pro 2.3.

Model calibration, verification, and validation used the Torelli map as "field observation data," with the three 1882 endemicity levels assumed as indicative of risk levels. Areas of no endemicity were assumed to have minimal, or zero, risk. This resulted in four discrete values for the registered and classified Torelli raster layer: 0 = none (*nessuna*), no malaria risk; 1 = slight (*leggiera*) risk; 2 = serious (*grave*) risk; and 3 = most serious (*gravissimo*) risk.

Dataset sources or derivatives for four risk layers are continuous data and three (both vector temperature support layers and probable wetness potential) sources have large interval-like ranges. For consistency with the Torelli layer, each risk layer raster was rescaled to a continuous value range of 0-3 using the ArcGIS Pro 2.3 Rescale By Function geoprocessing tool with the most appropriate "transformation function" applied for each dataset as outlined in **Table 4**.

Limitations

Certain limitations inherent in model construction should be noted. First, the relatively large scale of the Torelli map coupled with the relatively low resolution of the map image available for registration contrasts with the resolutions of the various risk

layer source datasets. This issue is most likely to introduce inaccuracies along edges of zones classified from the registered Torelli map and used for calibration of risk layers and model validation. Also, the Torelli map presents nominal data which is classified for model use in discrete form. The model is therefore limited to using data reclassified on a discrete scale (0, 1, 2, or 3) for calibration and validation of metrics on a continuous scale (0-3). While this reduces expectations for error reduction metrics during calibration and verification, it also should supply a mitigating effect for the issues of scale noted above.

As with all archival data use, uncertainties exist for the standards of control in nationwide data collection which resulted in the Torelli map. The reported endemicity level areas (reclassified here as zones) were no doubt subject to human interpretation and potentially uneven in assessment. Even so, reporting of the data emphasizes the process and attempts at standardization (Torelli 1882). The very nature of the Torelli study's field observations imply human presence, as malaria endemicity in humans is not possible without people. Meanwhile, human population and anthropogenic conditions are necessarily excluded from this study's model because they cannot be known with spatial certainty for antiquity. It seems more likely that the Torelli study missed areas of potential risk for lack of population than that it overreported risk, since any endemicity levels imply risk.

Despite these limitations, the Torelli map provides a reasonable baseline for calibration and validation of the model. It is at once the only known potential source but also remarkably convenient for the intended application area.

Study areas for risk model verification and application

The target application study area for this project is western Asia Minor (modern Turkey), which contains the ancient Roman provinces and geographic regions named in the Acts accounts of Paul's relevant journeys. To include all of mainland western Asia Minor, the bounding coordinates of the application area are 26-32.5 °E and 36-42 °N.

Southern Italy, including Sardinia and Sicily, provides an unparalleled study area for model construction, calibration, and verification. Several considerations contribute to this choice: 1) the Torelli map provides a convenient pre-eradication malaria baseline for the area; 2) Southern Italy has the same approximate latitude limits of the target study area; 3) it shares identical and comparable mosquito vectors; 4) considerable textual data with apparent spatial reference to malaria is extant for Italy; and 5) Italy was the focus of early malaria eradication campaigns and therefore much ancillary data is available.

The bounding coordinates for model verification and validation are 8-19 degrees E and 36-42 degrees N. Within that zone, only land in the Italian peninsula, Sardinia, and Sicily are included in study area (see **Map 2** and **Map 5**).

Model calibration and verification: Sicily study area

Sicily served as the initial study area for calibration of model risk layers and model verification. This choice resulted in an isolated study area with coastal and elevation features akin to those of the remainder of southern Italy and allowed the latter's use for model validation. For convenience of data preparation, the Sicily study area includes the adjacent extreme tip of mainland Italy. The bounds of the calibration and verification study area are 12-16 degrees E and 36-39 degrees N (**Map 2** and **Map 5**).

Calibration occurred at the point of rescaling each risk layer to a continuous value range of 0-3 using the ArcGIS Pro 2.3 “Rescale By Function” tool. The transformation function selected in the Rescale By Function tool varied according to the nature of the raw raster data. For example, the “Small” transformation function is used when lower values are “preferred” or, in this case, carry greater risk; as for elevation and slope. The “Large” transformation function is appropriate for layers in which higher values presumably create more risk as for precipitation. Input variables for the Rescale By Function tool differ for each transformation function and provide the opportunity for calibration of certain risk layers.

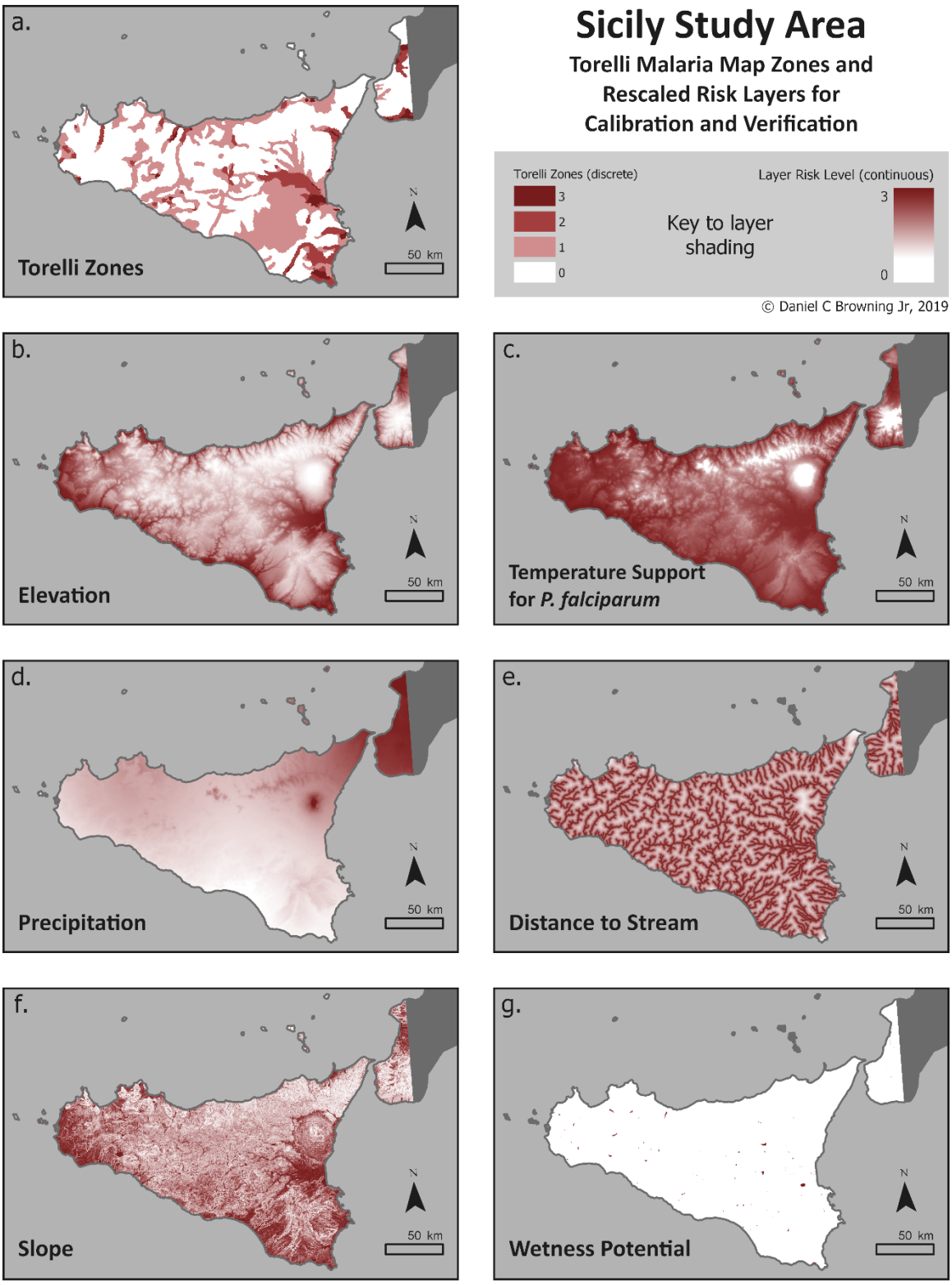
Optimal values for each layers’ transformation function were determined by iterative nested loop processes executed via Python scripts tailored for each risk layer. For each iteration, root mean square error (RMSE) values were calculated for the resulting raster (now with continuous data of risk in range 0-3) against each Torelli map “zone” (0, 1, 2, and 3) for the Sicily study area. The average RMSE for the four zones (the mean of the means) served as the evaluation datum for the input values of each iteration. The overall minimum average RMSE determined the values used for transformation functions of corresponding layers for subsequent study areas. Other potentially usable transformation functions, including linear rescale, were also tested on each risk layer as appropriate to ensure optimal results were obtained by the chosen function. In the case of precipitation, the linear function provided a slightly lower average RMSE than did the “Large” function and was therefore used. For risk layers with interval-type index data a linear rescale function was assumed and utilized for the final product. These were the two temperature support layers and probable wetness potential,

presumably already optimized in creation of their index datasets. Details on preparation and calibration of each risk layer are outlined in **Table 4**. All ArcGIS geoprocessing operations used environments for snap raster, cell size, and mask set to equal the elevation DEM layer.

Table 4 – *Risk layer preparation and optimal calibration data for Sicily study area.*

Risk layer	Raster Layer Data Preparation (`Operations` using ArcGIS Pro 2.3)	`Rescale By Function` Transformation function & parameters, optimal values	Avg RMSE of optimal calibrated layer
Elevation	1) create mosaic for study extent 2) fill sinks and voids 3) set water bodies to `NODATA` 4) `Extract By Mask` for land	Small (no thresholds) midpoint = 275 spread = 1	0.94572
Temperature: *P. falciparum* Support	Layers ready-to-use as provided, after rescale	Linear (no thresholds)	-
Temperature: *P. vivax* Support			-
Precipitation	calculate annual average raster = Sum((each monthly avg raster) x (days in month)) / 365	Linear (no thresholds)	1.03401
Slope	create raster using `Slope` tool with elevation DEM input	Small (no thresholds) midpoint = 8 spread = 1	1.19052
Distance to Stream/ Water Body	create raster using `Euclidean Distance` to riversegments shapefile	Small (no thresholds) midpoint = 1500 spread = 1	1.16109
Probable Wetness	1) create mosaic from source tiles 2) `Extract By Mask` for study extent 3) `SetNull` for value = 255	Linear (no thresholds)	-

The six calibrated and rescaled risk layers with continuous 0-3 range values, along with the Torelli map zones as discrete values 0-3 for the Sicily study area in consistent symbology appear in **Map 4**. The temperature support layer for *P. vivax* is omitted because it is visually akin the temperature support layer shown for *P. falciparum*. All seven layers were applied in the full model for verification.



Map 4. *Sicily study area.*

Torelli Map endemicity zones (a) with individual rescaled and calibrated risk layers (b-g) for Sicily study area.

The full model utilized a Python-scripted iterative nested loop process to combine the seven rescaled layers by incremental powers. In each iteration, the calculated product raster was divided by the total of the powers used for each calibrated risk surface in order to maintain the 0-3 range in the final product. The resulting risk prediction raster was compared against the Torelli zones for Sicily using the ArcGIS "Zonal Statistics As Table" tool. For each Torelli map zone, RMSE values were calculated, and the average of those RMSE values provided the assessment criterion. Standard deviation of the RMSE values by zone was calculated as an additional statistic for reference and included in tables below.

The iterative nested loop process was executed multiple times with increasingly focused power ranges for each risk surface as trends emerged. At the most focused ranges, average RMSE values became random within reasonably narrow ranges for the lowest values. This phenomenon is likely due to the coarser resolution of the original Torelli zone map and the variance in spatial resolution of the risk layer sources (see **Table 3**), all of which were rescaled and "snapped" to the resolution of the DEM-elevation source layer (30 m). Thus, at the most focused ranges, slight variations in the weighting of the originally lower resolution layers create the seemingly random results. **Table 5** demonstrates the trend with 20 lowest average RMSE combinations of risk layers for the Sicily study area.

The lowest average RMSEs obtained by the best performing combinations consistently have elevation contributing 52-57 percent, precipitation 27-29 percent, temperature for *P. falciparum* support 14-15 percent, temperature for *P. vivax* 0-3

percent, slope and wetness potential 0-2.5 percent, and distance to stream 0 percent. Since distance to stream contributed nothing in combinations yielding the lowest average RMSE values for Sicily as well as those for the rest of southern Italy in validation, the layer was excluded in the final model.

Table 5 – *Sicily study area verification data*

Iterations with 20 best combinations, showing: percent contribution of each risk layer, RMSE values for each Torelli zone, standard deviation, and average RMSE; mean percent values for each risk layer are given at the bottom.

Iteration reference	% contribution of risk layers							RMSE for Torelli Zone 0	RMSE for Torelli Zone 1	RMSE for Torelli Zone 2	RMSE for Torelli Zone 3	Stand. Dev. of zonal RMSEs	Average RMSE
	Elevation	Temp: *P falciparum*	Temp: *P vivax*	Precipitation	Slope	Distance to Stream	Wetness Potential						
535	55.4	14.9	0.0	28.4	0.0	0.0	1.4	1.30241	0.55664	0.56109	1.08441	0.37701	**0.87613**
539	54.7	14.7	1.3	28.0	0.0	0.0	1.3	1.31249	0.56241	0.55233	1.07755	0.38046	**0.87620**
543	53.9	14.5	2.6	27.6	0.0	0.0	1.3	1.32233	0.56820	0.54384	1.07087	0.38395	**0.87631**
534	56.2	15.1	0.0	28.8	0.0	0.0	0.0	1.32016	0.57359	0.55044	1.06122	0.37816	**0.87635**
517	57.1	14.3	0.0	28.6	0.0	0.0	0.0	1.31396	0.57326	0.55594	1.06242	0.37446	**0.87640**
538	55.4	14.9	1.4	28.4	0.0	0.0	0.0	1.33014	0.57938	0.54188	1.05457	0.38199	**0.87649**
196	54.7	14.2	0.9	27.4	0.9	0.0	1.9	1.30027	0.55593	0.56138	1.08889	0.37716	**0.87662**
116	54.0	15.0	1.0	27.0	1.0	0.0	2.0	1.30717	0.55956	0.55485	1.08490	0.37983	**0.87662**
120	53.5	14.9	1.0	27.7	1.0	0.0	2.0	1.30477	0.55321	0.55716	1.09134	0.38126	**0.87662**
80	54.5	14.1	1.0	27.3	1.0	0.0	2.0	1.29930	0.55471	0.56180	1.09078	0.37739	**0.87665**
208	54.2	14.0	1.9	27.1	0.9	0.0	1.9	1.30736	0.55999	0.55522	1.08404	0.37953	**0.87665**
192	55.2	14.3	1.0	26.7	1.0	0.0	1.9	1.30253	0.56201	0.55929	1.08279	0.37576	**0.87666**
84	54.0	14.0	1.0	28.0	1.0	0.0	2.0	1.29696	0.54837	0.56411	1.09722	0.37893	**0.87667**
124	52.9	14.7	1.0	28.4	1.0	0.0	2.0	1.30244	0.54700	0.55953	1.09771	0.38271	**0.87667**
132	52.9	14.7	2.0	27.5	1.0	0.0	2.0	1.31218	0.55757	0.55072	1.08624	0.38369	**0.87668**
160	55.2	13.3	1.0	27.6	1.0	0.0	1.9	1.29280	0.55143	0.56801	1.09447	0.37490	**0.87668**
172	54.7	13.2	1.9	27.4	0.9	0.0	1.9	1.30002	0.55547	0.56171	1.08953	0.37723	**0.87668**
542	54.7	14.7	2.7	28.0	0.0	0.0	0.0	1.33987	0.58518	0.53358	1.04810	0.38584	**0.87668**
92	54.0	14.0	2.0	27.0	1.0	0.0	2.0	1.30691	0.55906	0.55520	1.08558	0.37990	**0.87669**
96	53.5	13.9	2.0	27.7	1.0	0.0	2.0	1.30451	0.55272	0.55751	1.09201	0.38133	**0.87669**
	54.5	**14.4**	**1.3**	**27.7**	**0.6**	**0.0**	**1.5**	← mean of 20 above percentages for each risk layer					

Model validation by withheld data: southern Italy study area

For validation the model was applied to the S Italy study area; that is, the remainder of southern Italy, including the mainland peninsula south of 42° N and the island of Sardinia. As in the verification phase for Sicily, each of the seven risk layers were weighted by incremental powers in an iterative nested loop executed by Python script. At the most focused ranges, as expected in light of the Sicily verification data above, slight variance in weighting again produced random average RMSE results within narrow ranges. Results of the 20 lowest average RMSE iterations appear in **Table 6**.

Overall, percentage contributions for the lowest RMSE combinations of risk layers were similar to those obtained for Sicily. Averages for each layer of the best combinations varied within five percent between the Sicily and S Italy study areas. Southern Italy optimized with slightly lower elevation and precipitation percentages combined with slightly higher overall temperature, slope, and wetness potential contributions. The precipitation and temperature variances are not surprising, given the overall higher temperatures and lower precipitation averages for Sicily compared to the mainland.

As with Sicily, the lowest combinations had no stream distance factor. Therefore, stream distance was eliminated mathematically from model application parameters.

Table 6 – *Southern Italy validation data*

Iterations with 20 lowest average RMSE, showing: percent contribution of each risk layer, RMSE values for each Torelli zone, standard deviation, and average RMSE; mean percent values for each risk layer are given at the bottom.

Iteration reference	% contribution of risk layers							RMSE for Torelli Zone 0	RMSE for Torelli Zone 1	RMSE for Torelli Zone 2	RMSE for Torelli Zone 3	Stand. Dev. of zonal RMSEs	Average RMSE
	Elevation	Temp: *P falciparum*	Temp: *P vivax*	Precipitation	Slope	Distance to Stream	Wetness Potential						
204	50.0	10.5	5.3	23.7	5.3	0.0	5.3	1.41883	0.69114	0.46738	0.87688	0.40628	**0.86356**
34	48.6	10.8	5.4	24.3	5.4	0.0	5.4	1.42331	0.68707	0.46260	0.88189	0.41052	**0.86372**
18	50.0	11.1	5.6	22.2	5.6	0.0	5.6	1.41183	0.69251	0.46951	0.88153	0.40227	**0.86384**
198	51.4	10.8	5.4	21.6	5.4	0.0	5.4	1.40769	0.69676	0.47458	0.87653	0.39806	**0.86389**
2	51.4	11.4	5.7	20.0	5.7	0.0	5.7	1.40010	0.69884	0.47772	0.88150	0.39336	**0.86454**
216	48.7	12.8	5.1	23.1	5.1	0.0	5.1	1.42731	0.69858	0.45820	0.87435	0.41209	**0.86461**
142	47.4	13.2	5.3	23.7	5.3	0.0	5.3	1.43189	0.69487	0.45319	0.87919	0.41637	**0.86479**
149	53.8	12.9	3.2	24.7	2.2	0.0	3.2	1.44423	0.72394	0.46130	0.83014	0.41617	**0.86490**
66	48.6	10.8	8.1	21.6	5.4	0.0	5.4	1.42158	0.69886	0.45952	0.88002	0.40907	**0.86499**
134	48.6	13.5	5.4	21.6	5.4	0.0	5.4	1.42101	0.70034	0.45988	0.87879	0.40848	**0.86500**
153	55.2	12.5	3.1	24.0	2.1	0.0	3.1	1.43837	0.72768	0.46781	0.82616	0.41105	**0.86500**
210	50.0	13.2	5.3	21.1	5.3	0.0	5.3	1.41673	0.70421	0.46517	0.87396	0.40423	**0.86502**
157	56.6	12.1	3.0	23.2	2.0	0.0	3.0	1.43296	0.73133	0.47411	0.82254	0.40622	**0.86523**
151	53.2	12.8	3.2	24.5	3.2	0.0	3.2	1.44465	0.72450	0.46256	0.83105	0.41587	**0.86569**
50	50.0	11.1	8.3	19.4	5.6	0.0	5.6	1.41043	0.70507	0.46741	0.87994	0.40057	**0.86571**
228	47.5	15.0	5.0	22.5	5.0	0.0	5.0	1.43544	0.70581	0.44962	0.87201	0.41766	**0.86572**
155	54.6	12.4	3.1	23.7	3.1	0.0	3.1	1.43885	0.72820	0.46897	0.82711	0.41081	**0.86578**
174	46.2	15.4	5.1	23.1	5.1	0.0	5.1	1.44011	0.70244	0.44441	0.87670	0.42198	**0.86591**
158	46.2	12.8	7.7	23.1	5.1	0.0	5.1	1.44067	0.70107	0.44407	0.87788	0.42254	**0.86592**
159	56.0	12.0	3.0	23.0	3.0	0.0	3.0	1.43348	0.73180	0.47517	0.82351	0.40604	**0.86599**
	50.7	**12.4**	**5.1**	**22.7**	**4.5**	**0.0**	**4.7**	← mean of 20 above percentages for each risk layer					

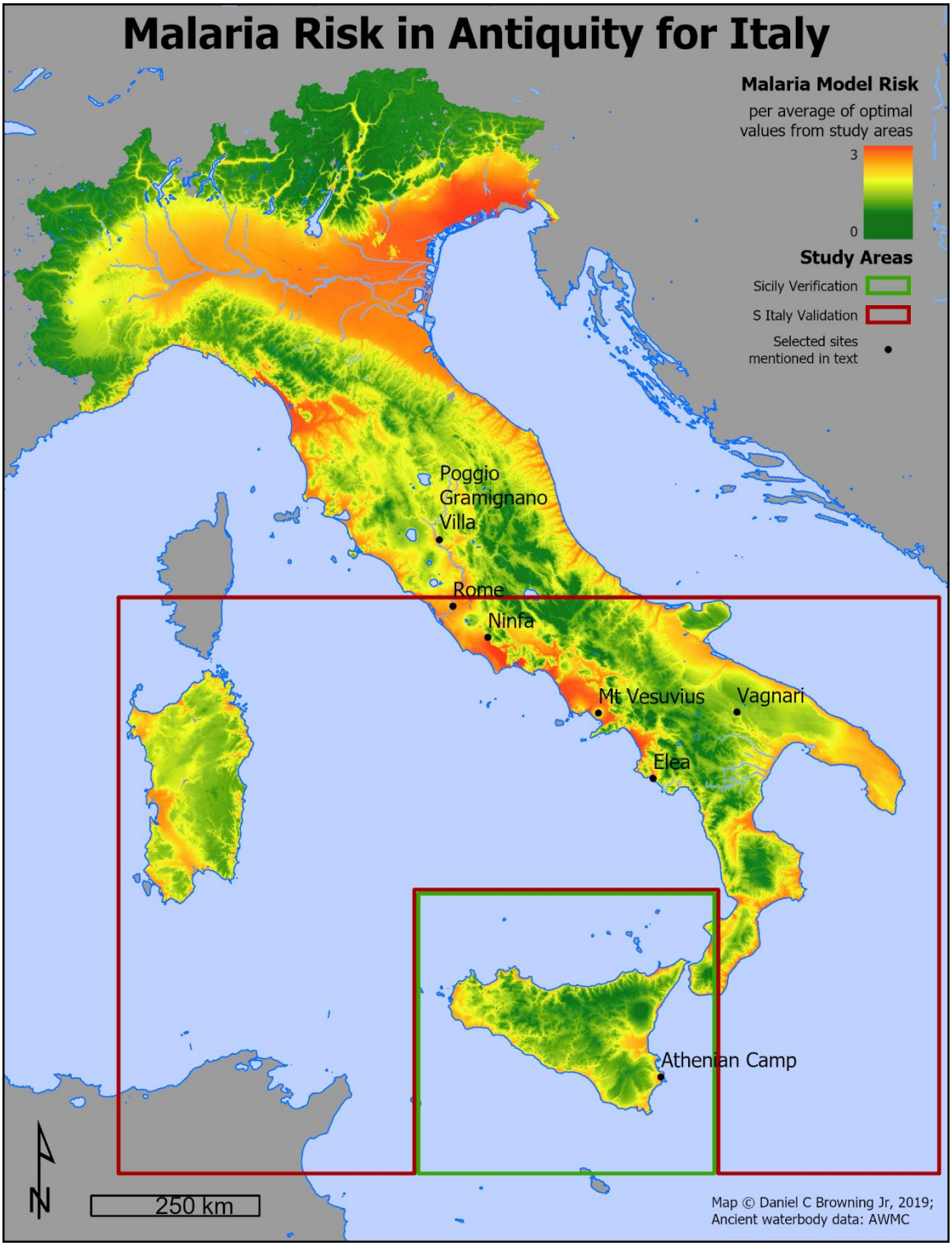
For model application, the mean percent values for each risk layer in the lowest combinations from the Sicily and S Italy study areas (Tables **5-6**, bottom) were averaged, resulting in the following weights: Elevation, 52.6 percent; Temperature suitability (*P.*

falciparum), 13.4 percent; Temperature suitability (*P. vivax*), 3.2 percent; Precipitation, 25.2 percent; Slope, 2.6 percent; and Wetness Potential, 3.1 percent. Model output using these parameters for all of Italy appears in **Map 5**.

It is important to note that the model and maps of its results do not predict where malaria will occur. They rather attempt to show potential risk geographically in terms of favorable conditions for malaria endemicity or outbreaks. The quantitative analysis above demonstrates the model's validity against a systematic record of data-collection from pre-eradication Italy in 1882. While earlier controlled and systematic geographically referenced data for malaria occurrence does not exist, anecdotal evidence can demonstrate the viability of the malaria risk model for earlier periods, including ancient times.

Anecdotal complements to verification for Italy

Considerable data of various kinds exist that detail pre-eradication malarial conditions in Italy. These range in date from the late nineteenth century back well into antiquity. A few examples have spatial components of sufficient resolution to justify comparison with the model's risk prediction. Those based on textual sources also anticipate and preview application of the ancient malaria risk model to such a case in the following chapter.



Map 5. *Modeled malaria risk map for Italy in antiquity.*

Risk levels modeled using mean of optimal values from Sicily verification and S Italy validation study areas.

Northern approaches and the city of Rome. Excavations since 1987 at Poggio Gramignano, near the River Tiber north of Rome (**Map 5**), uncovered an infant cemetery of the mid-fifth century CE with over 40 burials made in a short span within the remains of an abandoned Roman villa. The excavators concluded from skeletal deformations that the numerous infant, child, and premature fetus graves were the result of a *P. falciparum* malaria epidemic (Soren and Soren 1999). Subsequently, at least one skeleton yielded *P. falciparum* ribosomal DNA, confirming its presence there (Sallares and Gomzi 2002). Some graves include items suggestive of witchcraft or magic including ritually sacrificed puppies. A three-year-old girl's legs were secured by heavy stones, a practice used in some cultures to keep the dead in their graves; in this case perhaps to prevent the spreading of the disease (Soren and Soren 1999; Lane 1999). The three-year-old was the first DNA-confirmed malaria victim and the oldest child uncovered in the cemetery until 2018. That year a 10-year-old was uncovered, significantly with a rock placed in its mouth—perhaps another desperate ritual measure to contain the outbreak (Blue 2018). The location of the villa cemetery itself has a moderate model risk value of 1.7 (on the scale of 0-3) but is surrounded by higher risk areas with values over 2.0 within 1000m.

The approaches and outskirts to Rome from the north were especially pestilential and appear to have provided a malarial defense against attacking armies; all the more as newcomers would not have the immunity native Romans would have acquired (Sallares 2002, 201-34). Attila the Hun invaded Italy in 452, about the same time as the malarial outbreak that apparently filled the Poggio Gramignano infant cemetery. Attila's otherwise inexplicable retreat following the sack of Milan was attributed to "heaven-sent disasters: famine and some kind of disease" (Hydatius, *Chronicle* 29). It is tempting to

attribute the affliction of the Huns to malaria as other researchers have done (Sallares 2002, Harper 2017, 196-97, 338, n. 74).

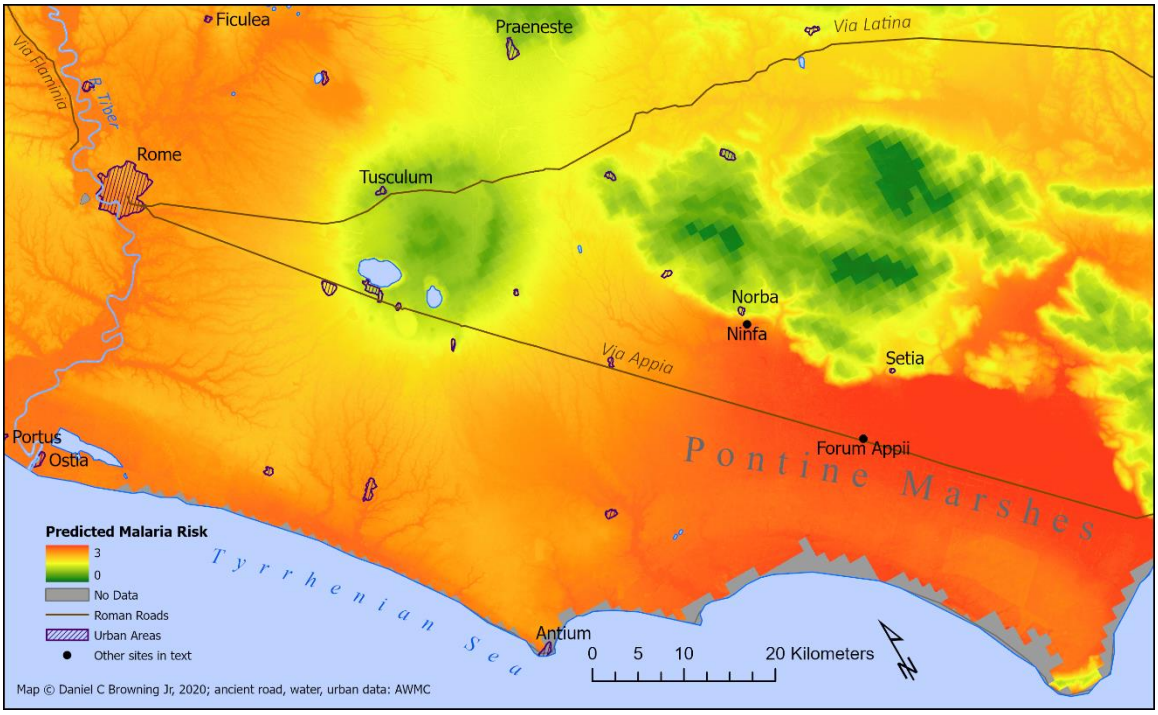
Rome itself and its immediate environs were notoriously malarial from antiquity to the modern period (Sallares 2002, 201-18) and the model predicts as much. Still, there was ancient awareness of variation of risk within the city. Cicero notes that Romulus, in founding his city, chose a healthful site with hills, "though in the midst of a pestilential region" (Cicero, *The Republic* 2.6.11). The traditional spot of Rome's first settlement, confirmed by excavation, was the Palatine Hill. Model results show the Palatine and the other of the famous "seven hills" of Rome as islands of medium risk in a dangerous sea.

History abounds with examples of the malarial dangers of Rome's lower districts. While not describing the symptoms, the historian Livy described an epidemic that struck the Gauls during their siege of Rome about 386 BCE, attributing it to the unhealthy location of their camp "between hills on low ground" (Livy, *History of Rome* 5.48.1-3). This sort of situation recurred with some frequency; ancient accounts giving scant clinical details, but with medieval and early modern reports describing typical malarial fevers (Sallares 2002, 224-30). By inference, it is possible to attribute malaria as a probable malady in the ancient cases. Two episodes in the dangerous summer months from different eras illustrate the point. Following the death of the Pope on 8 July 1623, cardinals from other regions—and likely without local *P. falciparum* immunity—assembled to elect a replacement in the low-lying Vatican. Within a month the conclave was "decimated" by malaria. Eight cardinals and 30 other officials died, and many others sickened. The newly elected pope Urban VIII fled from the Vatican to the higher Quirinal hill for safety (Sallares 2002, 202). In 69 CE, the short-lived Emperor Vitellius occupied

Rome and, according to Tacitus, much of his army "camped in the unhealthy Vatican district, as a result of which there were a great many deaths . . . the Germans and the Gauls, whose bodies were already liable to disease, were weakened by their lack of tolerance for the heat and their desire for the river's water" (Tacitus, *Histories* 2.93). The Vatican district was apparently as perilous for visitors in the summer months of the first century CE as it was in 1623 (Sallares 2002, 226).

The Pontine Marshes. Any discussion of malarial conditions in Italy prior to modern eradication efforts inevitably focuses on the Pontine Marshes, a quadrangular stretch of Lazio between the coast and the Volscian Mountains south of Rome. Finally drained by bonification efforts of Mussolini, the now former marshland was one of the major chronically endemic malarial regions of Italy from antiquity until the 20th century (Sallares 2002, 4, 168-91). The model identifies the region, shown in **Map 6**, as especially problematic. Some specific examples make the point clearer.

The late nineteenth century malariologist Celli noted regarding the hill town Sezze (ancient Setia; see **Map 6**), above the marsh, that inhabitants of houses on the slope facing the marsh contracted malaria, while those on the opposite slope were generally spared (Celli 1901, 84). Other researchers noted that women who stayed in their houses were less infected than men who went down to work the fields below the town, and it was not unusual for them to have married and lost three husbands to malaria before the age of thirty (Sallares 2002, 55-57)!



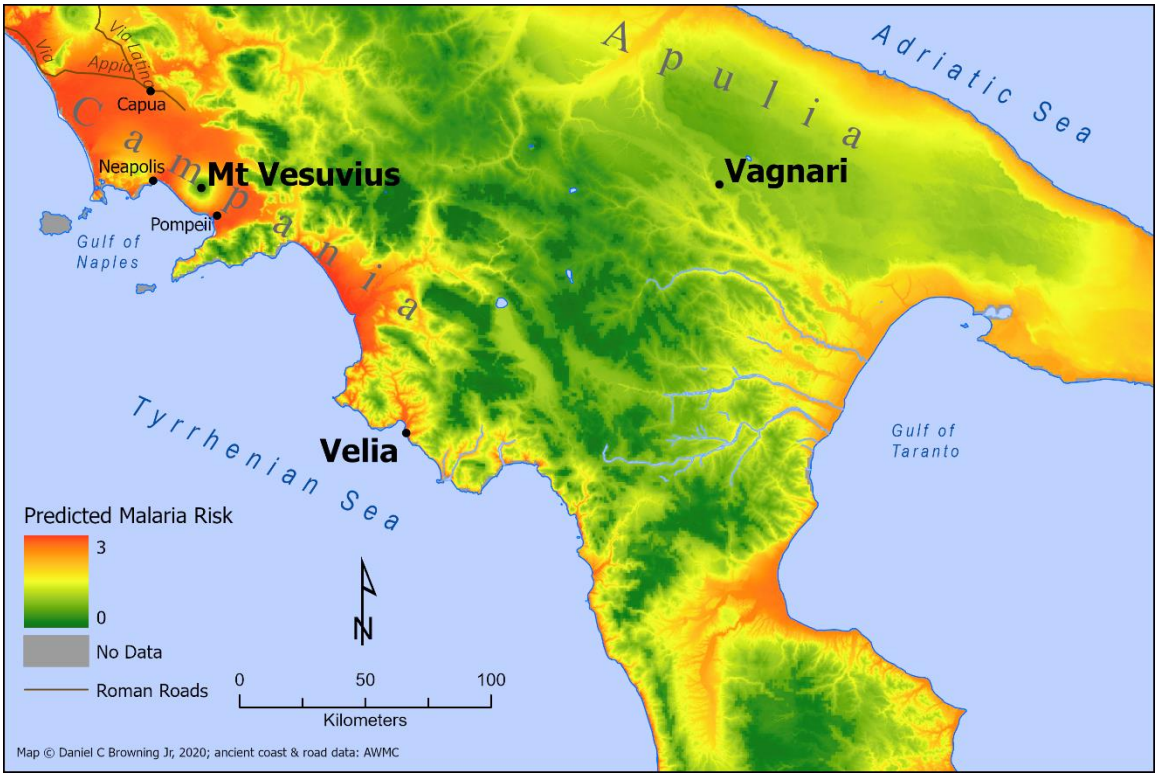
Map 6. *The Tyrrhenian seaboard of Italy from Rome to the Pontine Marshes.*

Map shows malaria risk predictions according to the study's model with locations in the text.

A more dramatic demonstration can be seen in two towns about one kilometer apart. Norma (ancient Norba) sits on a hill at 450 m elevation, precipitously overlooking the Pontine Marshes, and was malaria free in the nineteenth century. Nearby Ninfa at the base of the cliff was intensely malarious, leading to its eventual abandonment in the late seventeenth century (Celli 1901, 85; Hackett 1937, xi-xii; Sallares 2002, 57-60). The model's risk map (**Map 6**) highlights the different environments of the neighboring towns. Ancient text references to road conditions in the Pontine Marshes are covered with the extension of the model to Roman roads in the following chapter.

Southern Italy and Sicily. The Poggio Gramignano infant cemetery remained the only definitive proof of malaria in ancient Italy until the detection of *P. falciparum* mitochondrial DNA in two burials of the 1st-2nd century CE in southern Italy (Marciniak

et al. 2016). One is from a cemetery within an inland rural estate farm at Vagnari in Puglia and the other from Velia, a small port city on the Tyrrhenian Sea (see **Map 7**). The cemetery at Vagnari, like the Poggio Gramignano infant cemetery, is on a low hill with a moderate modeled malaria risk but surrounded by small valleys with higher risk levels. Deforestation and agricultural activities may well have heightened the risk there (Marciniak et al. 2018, 218-20). At Velia the cemetery, the lower part of the city, and much surrounding territory are in higher risk zones as evident in **Map 7**.



Map 7. *Ancient malaria risk in Campania and Apulia.*

Risk according to the study model; locations shown as mentioned in text.

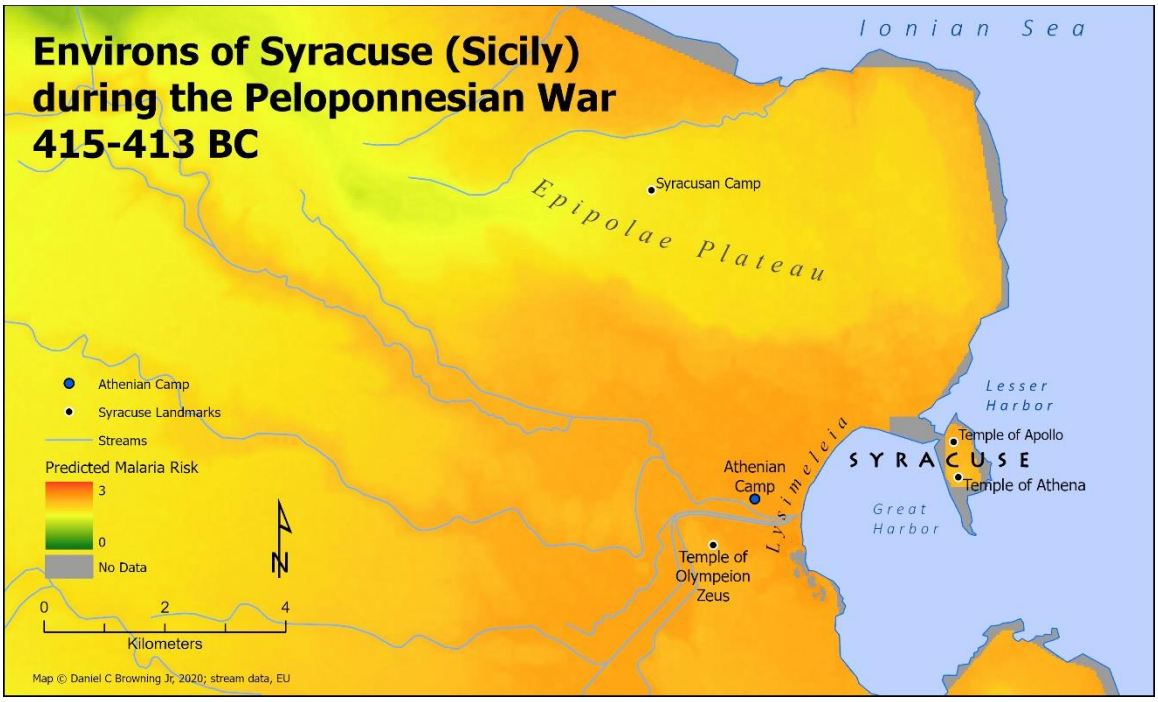
A final example demonstrates the potential usefulness of the malaria risk model for evaluation of text sources in historical problems of antiquity. During the extended Peloponnesian War (431-404 BCE) between Athens and Sparta, a pivotal role was played

by the disastrous Athenian siege of Sparta's ally Syracuse in Sicily from 415-413 BCE, as reported by Thucydides in his objective *History of the Peloponnesian War.*

The Athenian expeditionary force, based on the recommendation of Syracusan defectors, established their main camp south of the city, near the Temple of Olympian Zeus. The site was protected from cavalry attack in part by the large Lysimeleia marsh (Thucydides, *History of the Peloponnesian War* 6.64-66), but that defense held disadvantages as well. Through the summer of 414 BCE the battle was for the high plateau called Epipolae, just northwest of Syracuse. When the tables turned against the Athenians, they were forced to retire to the marsh-protected camp where disease began to take its toll. The generals observed that their forces "were distressed by sickness for a double cause, the season of the year being that in which men are most liable to illness, while at the same time the place in which they were encamped was marshy and unhealthy; and the situation in general appeared to them to be utterly hopeless" (Thucydides *History of the Peloponnesian War* 7.47.2). The expedition ended in catastrophic failure; the entire Athenian force died from disease, were massacred, or captured and enslaved by the end of 413 BCE.

P. falciparum malaria is the most obvious culprit for the Athenians' epidemic. Thucydides' note reveals that the generals and his readers were aware of both the risks of marshy land and the seasonal cycle of illness. Thucydides does not make the connection, but M. Grmek suggests such knowledge guided Syracusan strategy in so aggressively defending the Epipolae, avoiding open battle in certain seasons, and confining the Athenians to their camp by land and sea (Grmek 1979, 154-58). The model corroborates with this hypothesis (see **Map 8**), given that the location of the Athenian camp has a high

risk of 2.25 and the Epipolae plateau averages below 1.80. Grmek further suggests that the Athenian expedition was responsible for introducing *P. falciparum* to Attica (Grmek 1979, 150-60; Grmek 1989, 282), but the Athenian troops' susceptibility is more easily explained by their lack of gained immunity to local Sicilian strains of the pathogen (Sallares 2002, 36-37; Retief and Cilliers 2004, 131).



Map 8. *Malaria risk in the environs of Syracuse during the Peloponnesian War.*

Modeling and Mapping Malaria Risk for Antiquity: Conclusions

Despite the lack of data for anthropogenic risk layers such as land use, the model appears to predict malaria risk for pre-eradication conditions as indicated by consistent and favorable results in validation against the Torelli map. Consistency of modeled risk layers with spatially referenced indications found in relevant text sources of various periods coupled with definitive archaeological evidence for malaria in high-risk areas push confidence in the model back into antiquity. Furthermore, the final anecdotal

example above illustrates the model's usefulness in providing considerations for historical inquiry. For this study, it remains to extend the model to include ancient Roman road risks.

CHAPTER IV – EXTENSION TO ROMAN ROADS AND APPLICATION TO PAUL'S TRAVEL DECISIONS IN ASIA MINOR

Extension of Risk Model to Roman Roads

Concept and Discussion

The main intended application of this study's model is to malaria risk on Roman roads. As noted above, some contemporary malaria risk studies use roads as a covariate, although the sophisticated MAP models do not. In the modern studies, roads represent a risk factor because of the mobility they provide for potentially malaria-infected hosts. In this study, they are the focus of the threat assessment. Therefore, roads are not used as a factor in the risk model's calculations to avoid the possibility of circular reasoning. Rather, the model results are spatially applied to ancient road datasets in order to arrive at relative risk levels for specific road segments.

Road construction, undoubtedly, can make subtle changes to the landscape and create roadside opportunities for vector breeding (Sallares 2002, 181; O'Sullivan et al., 2008; Marciniak et al. 2018, 220). Thus, roads do represent a spatial malaria risk themselves, but this is difficult to quantify and would vary with specific combinations of landscape and construction. In addition to whatever risk the roadside landscape contributed, malaria peril for travelers was enhanced by the immunity issues discussed in Chapter III, coupled with exposure to multiple risk areas.

Several ancient texts refer to illness during travel. Two examples suffice here. The late fourth century Galatian ascetic Palladius traveled to Egypt in order to personally visit the Desert Fathers, prototypical Christian monks. He relates a journey of 18 days, partly by road, partly by boat, to see John of Lycopolis in Upper Egypt, noting "it was the time

of the flood, when many are ill; which was also my experience" (Palladius, *Lausaic History* 35. 4). The referenced flood is the annual Nile inundation which left standing water all along the narrow Nile Valley. While outside the study areas, Palladius highlights awareness of seasonal travel risks.

Renowned second-century orator Aelius Aristides also wrote a fascinating and detailed medical diary full of clinical descriptions of his physical woes. Therein he traces the origin of his troubles to a journey in 144 CE from Mysia in Asia Minor to Rome by the *Via Egnatia*. Along the road he describes much rain, "fields swampy as far as the eye could see," and his "strong fevers and other indescribable ailments" (Aelius Aristides, *Sacred Tales* 2. 60-62). Aristides begins in Mysia, which is of interest in the application to Paul's journeys below, but most of his journey and malady description lies in Macedonia, outside this project's study areas.

Accounts of travel with more applicable geographical relationship to this study are surveyed as anecdotal support for the model's extension to Roman roads below.

Roman Road Data and Processing

Ancient roads are known from physical remains of roadbeds themselves, surviving bridges at stream crossings, extant milestones, and numerous literary references. A few Roman road datasets suitable for GIS application are available. Those offering empire-wide coverage, and the only ones available for Asia Minor, have a common origin in the last comprehensive classical period print atlas, the *Barrington Atlas of the Greek and Roman World* (Talbert and Bagnall 2000). The Ancient World Mapping Center (AWMC) produced a road shapefile by digitizing the *Barrington Atlas* (Ancient World Mapping Center 2019). This dataset, in virtually identical form, is used by the

Digital Atlas of the Roman Empire (DARE) and made available in GeoJSON format (Åhlfeldt 2019). A modified and expanded version of the same dataset is incorporated into *The Digital Atlas of Roman and Medieval Civilizations* (DARMC) and available as a shapefile (*The Digital Atlas of Roman and Medieval Civilizations* 2018).

All the above datasets share the same deficiencies for GIS use, apparently the result of the digitization process. Many road sections and intersections are not spatially joined; that is, nodes and vertices do not connect, resulting in discontiguous polylines. The spatial accuracy of the represented roads is subject to question, given the datasets' origin from a print source without GIS-level precision (AWMC 2019). The DARMC shapefile, furthermore, differs somewhat from the other two.

For this application, I chose the AWMC shapefile over that from DARMC because the latter project's additions may result from medieval data. The AWMC data was clipped to the study area and modified by eliminating disconnects. In some cases, especially in areas of interest to the case study, I moved nodes or vertices to more accurate positions using satellite imagery and based on my field observations in Turkey. All editing and geoprocessing operations were conducted using ArcGIS Pro 2.3.

Because polyline features are one-dimensional, the resulting road feature set was buffered prior to analysis by overlay with the model-produced risk surface. A buffer distance of 542 meters was used; one summary study's identified average flight range for genus *Anopheles* mosquitos (Verdonschot and Besse-Lototskaya 2014, 72). Flight ranges vary greatly between species and with local climate and terrain difference—and far higher distances have been measured with wind assistance (Le Prince and Griffitts 1917; Verdonschot and Besse-Lototskaya 2014). Nevertheless, this figure represents a

reasonable one which provides a local area average risk, avoids potential overreach, and somewhat mitigates uncertainty about precise road location.

For analysis, the buffered road feature set was overlaid with the model's output risk surface for the study area. Zonal statistics operations in ArcGIS Pro 2.3, with mean malaria risk calculated for each buffered road segment (or entire routes as needed) provide comparative metrics.

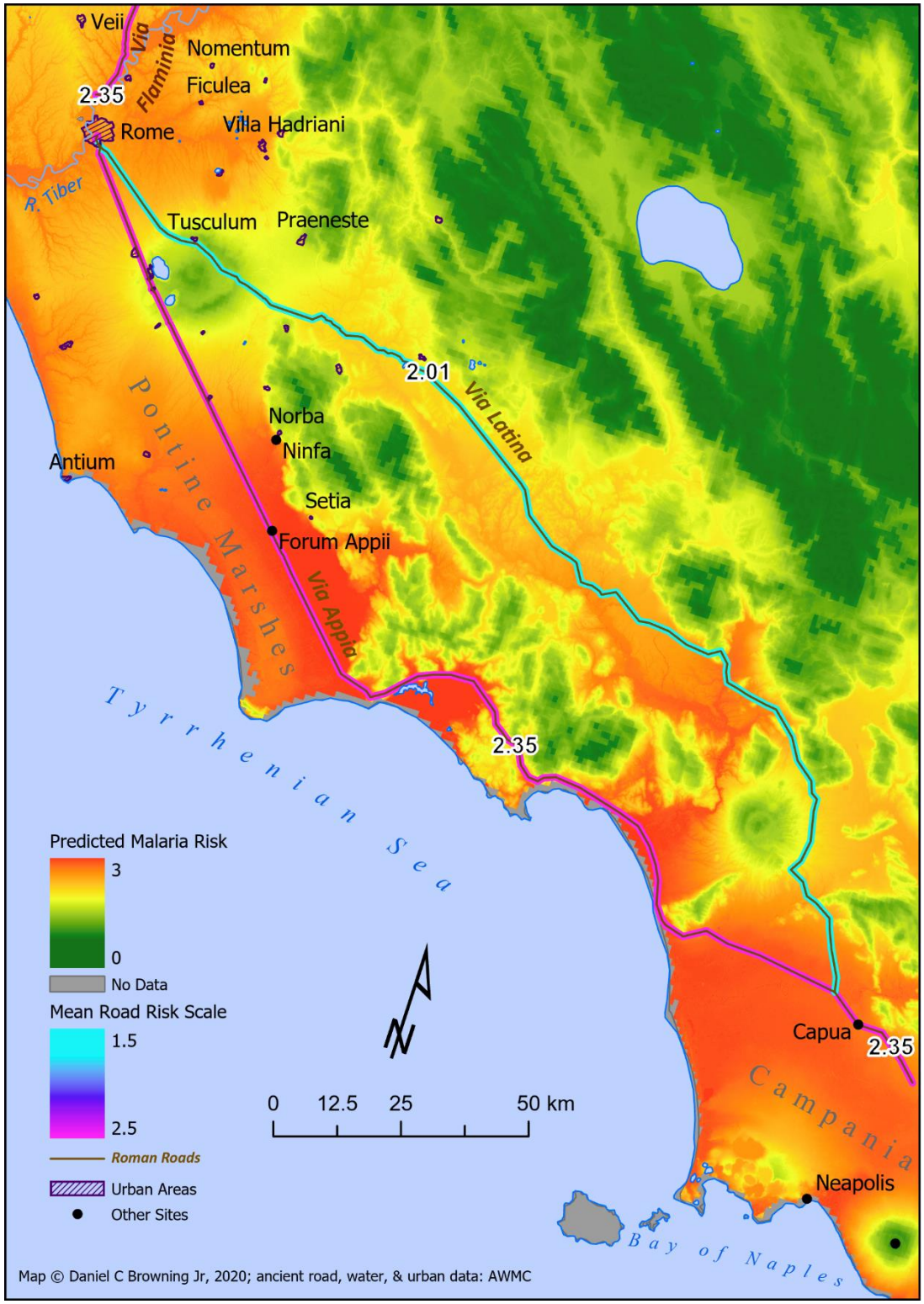
Application to Ancient Texts

Via Flaminia. A few ancient sources provide applicable details relating to specific Roman roads in the areas of this study. The Gallo-Roman aristocrat Sidonius Apollinaris describes a 467 CE trip to Rome in a letter to a friend. The portion of the journey from Ravenna to Rome specifically details travel along the *Via Flaminia*. Along this stretch, he apparently contracted malaria, blaming it on "poisonous blasts of air that brought on sweats and chills alternately; and infected my whole body with its atmosphere" (Sidonius Apollonaris, *Letters* 1.5.8). Using the zonal statistics method outlined above, the model calculates an average malaria risk of 1.83 (on the 0-3 scale) for the entire *Via Flaminia*. Doni, an important seventeenth century investigator of malaria noted the portion of the *Via Flaminia* immediately north of Rome as especially unhealthy (Sallares 2002, 64). The model agrees with his assessment, with a mean risk value of 2.35 in that section.

The Via Appia in the Pontine Marshes. Some references detail Roman road conditions in the Pontine Marshes (see **Map 9**). The poet and satirist Horace describes the frustrations of travel along the *Via Appia* in recounting a trip to Brundisium in 36 BCE. On the second night, at the road station called Forum Appii below Setia, he curses

the "damned mosquitos" of the region (Horace, *Satires* 5.14). While he makes no reference to fever, Horace nevertheless highlights the favorable vector capacity of the area, which was made all the greater by construction of the road itself (Sallares 2002, 181). His description of activities at Forum Appii also imply the presence of a canal on which transport plied as an alternative to the highway. This is confirmed in the late first century BCE by Strabo who mentions the canal as flowing beside the *Via Appia* from near Terracina towards Rome, supplied by water from the marshes, and used for transport (Strabo 5.3.6.233). Procopius, in the sixth century, says the locals call it "*Decennovium* in the Latin tongue, because it flows past nineteen milestones" (Procopius, *History of the Wars* 5.11.2). The unusual presence of a parallel canal suggests the area had become permanently marshy by the first century BCE; the once fertile region transformed by deforestation and construction of the road (O'Sullivan et al 2008, 758).

Procopius nevertheless describes the Via Appia in glowing terms, praising its utility, width, construction, and durability as "one of the noteworthy sights of the world" (Procopius, *History of the Wars* 5.14.7-11). This is interesting, as the description comes immediately after Procopius makes note that the Roman general Belisarius avoided the *Via Appia* during the Gothic Wars, electing instead to move his army from Neapolis (modern Naples) toward Rome on the *Via Latina* (Procopius, *History of the Wars* 5.14.6-11). The reason for Belisarius' alternate—and less efficient—route is not given, which makes this episode an interesting analogue to the travel decisions of Paul in Acts 16:6-10 and 19:1, which will be treated in detail below.



Map 9. *Malaria risk in antiquity from Rome to Campania.*

Malaria risk and mean road risk according to study model; ancient road, water, and urban data: AWMC.

Application of the malaria risk model to the two Roman roads between Rome and Campania (Naples) provides data for consideration, as shown in **Map 9**. The *Via Latina* receives a relatively high mean risk of 2.01 (on the 0-3 scale), but the *Via Appia* averaged 2.35, with a maximum risk of 2.78! Given Procopius' praise for the *Via Appia* juxtaposed with silence on the reason for its rejection, any consideration of Belisarius' seemingly inefficient choice to use the *Via Latina* should consider the possibility of a malarial outbreak along the former.

It is interesting to note, given the application below, that the Apostle Paul later traveled along *Via Appia* through the Pontine Marshes—though as a prisoner with no choice in the matter—and met well-wishers at Forum Appii (Acts 28:15).

Application to the Travel Decisions of Paul in Asia Minor

Review of the Problem

Acts 16:6-10. As noted in Chapter I, the impetus for this study was my interest in the seemingly indecisive movements of Paul during his second journey:

> 6 And they went through the region of Phrygia and Galatia, having been forbidden by the Holy Spirit to speak the word in Asia. 7 And when they had come opposite Mysia, they attempted to go into Bithynia, but the Spirit of Jesus did not allow them; 8 so, passing by Mysia, they went down to Troas. 9 And a vision appeared to Paul in the night: a man of Macedonia was standing beseeching him and saying, "Come over to Macedonia and help us." 10 And when he had seen the vision, immediately we sought to go on into Macedonia, concluding that God had called us to preach the gospel to them (Acts 16:6-10).

Other passages are relevant to the intended application (see below) but Acts 16:6-10 is interesting on many levels and an appropriate starting place. The account contains a significant level of geographical reference in terms of cultural regions and Roman provinces, but without the usual naming of cities in which Paul conducted his evangelization efforts. Furthermore, it is unique in expressing uncertainty regarding Paul's direction while simultaneously attributing causation to vaguely worded divine

direction. The outcome of the actions described precipitated a significant shift in the work of Paul—assuming Acts can be taken as a factual account. This study is not intended to make a judgement on that point, but rather to provide data for consideration in the ongoing debate. In that spirit, a review of the issues impacted by the question is in order. An important note: the volume of literature on the following issues is difficult to overstate and a full review is impossible here. Therefore, references are cited as examples and no comprehensive bibliography is implied or attempted.

In my view, assessment of Acts 16:6-10 is "held hostage" by individual interpreter's overall theological and literary assumptions (or motivations) about the Pauline corpus and its relation to Acts. "Conservative" (for lack of a better term) commentators tend to assume the historical and chronological veracity of Acts and integrate it with an understanding of Paul's letters. In this approach, Acts serves as a chronological guide for certain letters and is treated as a factual account. Paul's movements and direction in Acts 16 are generally attributed to unequivocal divine intervention (Bruce 1990, 354-55), as implied by a simple reading of the text. Consideration of other causation or practical circumstances is thus often thwarted, despite clear indications that divine direction was initially lacking or incomplete, resulting in diversion and misdirection.

In contrast, many if not most "critical" interpreters attempt to reduce the role of Acts in integrated study of Paul and his letters. Pauline studies, in this context, focuses on his theology and "thought" based solely on literary analysis of the letters attributed to him (Johnson 2012, 66). Perceived development of Pauline theology is tied to an ordering of his letters (Metzger 1983, 217-18) that precludes the use of Acts as a major chronological

source. An assumption of Acts' chronological unreliability consequently results in its dismissal as a factual guide to events. However, studies of Paul's life—claims to the contrary notwithstanding—invariably turn to Acts for support (Murphy-O'Connor 1996, vi; Johnson 2012, 66-67).

Relation to Other Issues. The Pauline document most affected by this dichotomy of views is his letter to the Galatians. Galatians contains an advanced statement of Paul's theology quite like Romans, so it is generally placed chronologically with Romans; that is, later in the overall sequence of his letters. The problem is that Galatians contains some significant relative chronological statements by Paul about visits to Jerusalem (Galatians 1:17-2:2) which can be correlated with Acts' record of his visits there (Acts 9:26; 11:29-30; 15:1-30). Accepting the full veracity of those references in both books logically positions Galatians early in Paul's Acts sequence, between the so-called "First" and "Second" Journeys of Paul. The address of Galatians, uniquely to a group instead of a church in a single city, provides an option. If the addressed "Galatians" are residents of the Roman province Galatia, then the letter is most naturally to the churches founded in the southern part of that province during the First Journey (Acts 13:13-14:26). If the addressees, however, are viewed as *ethnic* Galatians, who lived in the northern part of the Roman province of Galatia, the letter can be divorced from the churches of the First Journey. Because of the chronological problem of Paul's visits to Jerusalem, Acts must be downgraded or completely disregarded as a source to posit a "north Galatian" theory for the letter. Acts does not record any visit of Paul to north Galatia. Ironically, many critical scholars resort to using the Acts 16:6-10 misdirection to justify assuming an otherwise unmentioned visit by Paul to the region (Metzger 1983, 222; Murphy-

O'Connor 1996, 161-62). In so doing, they both explain away (one of the Jerusalem visits) and read into (a north Galatian visit) the text of Acts to support their position.

To summarize: both conservative and critical approaches tend toward inconsistency in the use of Acts 16:6-10 vis-à-vis their overall assumptions about the text. I suggest that application of this study's model to three relevant passages relating to Paul's travels in Asia Minor can add meaningfully to discussion by providing assessment of a potential circumstantial issue in his decision-making. Those texts are: 1) Acts 13:13-14; 2) Acts 16:6-10; and 3) Acts 19:1.

The Genre of Acts Travel Accounts. A brief review of discussions about the genre of the travel accounts in Acts is in order here. If the full book is viewed as historical writing (e.g., Palmer 1993), then it follows that Acts' travel accounts are intended as factual records. It becomes more complicated if the book is judged to belong to a different genre. In the latter case—and even if the genre is "history"—various combinations of "fact" and "fiction" are possible depending on views of the author's sources. For this study it is only necessary to establish a reasonable possibility that the travel accounts are actual itineraries, or that significant scholarship treats them as such, in order to apply the model results for consideration in debate and historical reconstruction. A few relevant examples of the widely divergent views Acts' genre and intent treated here to establish the potential usefulness of model results in discussion.

Researchers that consider Acts wholly fictional would have no interest in the present application. This includes those who view Acts as an intellectual biography such as those produced by Diogenes (Talbert 1974), in which fiction may be incorporated to enhance the biography's appeal (Fairweather 1974). Loveday Alexander, a classicist with

interest in the genre of Acts, concludes that the book's travel narratives provide a purposeful connective narrative itinerary quite in contrast with the formulated anecdotes in intellectual biographies (Alexander 1993a, 45). Another view sees Acts as a historical novel with the travel narratives added as an entertaining adventure component (Dockx 1989; Pervo 1990; Zeitlin 2017). Again, Alexander shows Acts' itineraries are less akin to the fantasy trips of the novels and rather closer to the factual *periplus* documents (practical handbooks for sailors) known from antiquity. She also posits they are a fulfillment of the *αὐτόπται* (usually translated "eyewitnesses"), promised by the author in the preface of Luke (Alexander 1995, 41). Elsewhere Alexander demonstrates that *αὐτόπται* is used overwhelmingly in Greek sources for medical and geographical information (Alexander 1993b, 34-41, 120-23). She concludes Paul's "adventures" occur "in a realistic, contemporary landscape, a world of trading ships not of triremes" (Alexander 1995, 44-45). These studies suggest that, apart from opinions on the overall genre of Acts, the nature of the travel accounts themselves justify seeing their origin as actual itineraries.

Critical scholars that disallow Acts as a relevant source in reconstructing Pauline thought and theology represent another category. As previously noted, this group of researchers often utilize Acts as a supplement while failing to realize the problem of doing so vis-à-vis their own presuppositions (Murphy-O'Connor 1996, vi, 162-65). Others have justified this use by supposing "the author of Acts had an independent 'itinerary source'" (Smith 2015, 153). Perhaps the most extensive apology for this approach is that of Jewett, who recognizes theological tendencies of the author, but asserts "travel and historical details incidentally mentioned in the text have a higher claim

to accuracy than the overall framework in which they appear" (Jewett 1979, 9-10). Justified or not, the use of Acts itineraries in reconstructing a life of Paul makes application of the model's data appropriate for consideration.

Finally, considerable scholarship is devoted to reconstructing Paul's movements and chronology by scholars that accept Acts as a factual source. This fact alone makes application of the malaria model to the itineraries of the book relevant for discussion and potential historical reconstruction. It remains, then, to survey views regarding the pragmatic aspects of Paul's travel decisions in the relevant passages.

Acts 13:13-14 and Ramsay's malaria theory. The first episode relates a major transition in the First Journey. The group, with Paul now in apparent leadership, left the island of Cyprus and arrived at Perga in the coastal region of Pamphylia. The only activity described at Perga is the departure of John Mark to Jerusalem, while Paul and Barnabas move on to the distant and upland Pisidian Antioch (Acts 13:13-14). The reasons for the move to Asia Minor, John Mark's departure, and the choice of Pisidian Antioch are debated but beyond the scope of this study. In any event it is notable that Paul does not preach in the significant city of Perga, according to the narrative, until the return journey (Acts 14:24-26).

Based on his personal experience, William R. Ramsay first argued in 1892 that Paul contracted malaria upon his arrival in the Pamphylian plain, which necessitated a hurried departure for higher ground. He incorporates Paul's remark to the Galatians that "you know it was because of a bodily ailment that I preached the gospel to you at first" (Galatians 4:13) to use his supposition as an argument against the "North-Galatian theory" (Ramsay 1903, 61-65). When challenged by supporters of the north Galatian

theory (Chase 1893, 416-17), Ramsay repeated and expanded his theory to suggest malaria was also the "thorn in the flesh" (2 Corinthians 12:7) about which Paul famously complains (Ramsay 1920, 91-97).

Ramsay's malaria theory received some continuing interest by evangelicals (Stott 1990, 31; Witherington 1998, 310, n. 39), but is ignored by most recent commentators. The late dean of conservative interpreters, F. F. Bruce, called it "an interesting speculation, but nothing more" (Bruce 1990, 300; Larkin 1995, 197). This is echoed as "speculative" in Keener's 2015 *magnum opus* on Acts, but with a kinder assessment in the footnote (Keener 2015, 2032).

Mark Wilson argues against Ramsay's experienced assertion that Pamphylia was pestilential by claiming it "does not square with ancient testimony about Pamphylia" (Wilson 2016, 240-41). He cites a single episode in Livy's account of the Roman-Seleucid War in which sailors, sickened at Phaselis, by "the insalubrious locality and the time of year (it was midsummer)," departed there and put in at the mouth of the river Eurymedon east of Perga (Livy, *Roman History* 37.23.2-4). Wilson claims that "according to Livy's account, the Pamphylian coast was the place of escape known by the ancients fleeing from malaria-like symptoms" (Wilson 2016, 241). Livy implies no such thing; he does not mention the illness after departure from Phaselis and does not imply any sojourn in Pamphylia, only a brief gathering of intelligence on the enemy fleet (Livy, *Roman History* 37.23.4). Such overstatements of evidence are unfortunately rife in biblical studies.

Practical considerations in Acts 16:6-10. Considerations of Acts 16:6-10 are surveyed broadly above, so only a few specifics require review here. As noted, most

conservative and evangelical commentators attribute Paul's changes in direction to direct divine revelation of some kind (Wilson 2005). Ramsay hints at an illness motivation in suggesting that Paul sought out "Luke the beloved physician" (Colossians 4:14) upon his unintended arrival at Troas (Ramsay 1920, 200-205). Despite not being named in the book, Luke's presence is inferred by the sudden shift of the narrative to the first-person plural ("we") in Acts 16:10 and the traditional view that he is the author of Acts. Ramsay further argues that Luke is also the "Macedonian man" in the vision (Ramsay 1908, 34-38; 1920, 200-203).

Ramsay is still widely utilized by commentators for his first-hand knowledge of Asia Minor, publication of relevant inscriptions, and the like (e.g., Keener 2015), but his arguments for Paul's malarial condition as a motivation and Luke's role have largely faded to obscurity. This is likely the result of four factors: 1) Ramsay's attachment of his theory to arguments against the north Galatian theory, a debate that has faded in recent years; 2) conservatives' unease over replacing divine direction in Acts 16:6-10 with practical considerations—to include the idea that the Macedonian vision was precipitated by a human agent; 3) critical scholars' disinterest in the matter; and 4) lack of supporting data, as evidenced by characterization as mere speculation (Bruce 1990, 300; Larkin 1995, 197; Keener 2015, 2032). This study, I submit, provides evidence to mitigate the above factors, especially the latter.

Acts 16:6-10 in particular goes begging for satisfactory explanation. To illustrate this and the foregoing, one proponent of the north Galatian theory writes of the passage:

> But why would Paul make a turn diametrically opposed to his planned journey to the west? It is impossible to find motivation for a change of plan. Something must have happened to force Paul to abandon temporarily his project to work his way around Asia. The illness he mentions (Gal. 4:13) is such an explanation, but to speculate on what it was and how it changed his plans is fruitless (Murphy-O'Connor 1996, 162).

The quote also assumes a view on another issue in the passage, Paul's intended destination. On this, there is not much debate; the overwhelming majority of commentators understand that Paul intended to go to Ephesus, the economic and cultural capital of Asia—regardless of whether Asia is understood as a Roman provincial name or geographic regional designation. Ephesus was a major center and the obvious choice for dissemination of Paul's message (Murphy-O'Connor 1996, 166; Wilson 2005, 82) and the logical next move (Robertson 1949, 143-44; Kelso 1970, 57). The text itself evidences Paul's intention by: 1) his direction at the point of diversion; 2) the need for a "vision" to convince him to go to Macedonia from Troas, from whence he could easily have taken a ship to Ephesus; and 3) Paul's direct voyage to Ephesus after the Macedonian-Achaean "detour" at the end of the journey (Acts 18:18-21).

Consensus also holds true on Paul's intended route. The clear choice was the major highway through the Lycus and Meander valleys (Ogg 1968, 116; Wilson 2005, 82-83), referred to by Strabo as a "kind of common road" (Greek κοινή ὁδὸς) "used by all who travel from Ephesus towards the east" (Strabo, *Geography* 14.2.29).

The "upper country" of Acts 19:1. The third unexplained travel decision of Paul occurs in narration of his Third Journey. Beginning again in Antioch of Syria, Paul "went from place to place through the region of Galatia and Phrygia, strengthening all the

disciples" (Acts 18:23). After this, "Paul passed through the upper country and came to Ephesus" (Acts 19:1). The Greek phrase ἀνωτερικὰ μέρη, "upper country" or "upper parts," is a *hapax legomenon* (i.e., used only once) in the New Testament, and therefore the subject to speculation. One proponent of the northern Galatian theory, for example, desperately interprets "upper" in the sense of "northern" in order to posit a visit to the ethnic Galatian regions (French 1994, 55).

Though the Greek ἀνωτερικός ("upper") does not appear elsewhere in the New Testament, a close cognate form used in the Septuagint (a Greek translation of the Hebrew Bible; designated LXX) has the sense of "higher elevation" (Wilson 2018b, 3-4). A route taken for the purpose of maximizing elevation from the east to Ephesus would indeed be further north than the main highway through the Lycus and Meander valleys, but certainly not through northern Galatia. A path through the Cayster Valley appears most likely (Ramsay 1920, 265; Wilson 2018b, 7-12). Some north Galatian proponents contend that such a route would be natural if Paul were coming from north Galatia. While true, there is still no mention in the text of any location in north Galatia. A higher (and slightly more northern) route would also be logical if Paul had avoided Strabo's "common road" due to a malaria threat in the valleys (or other reason) on the Second Journey and wished to do so again while still reaching Ephesus on the Third.

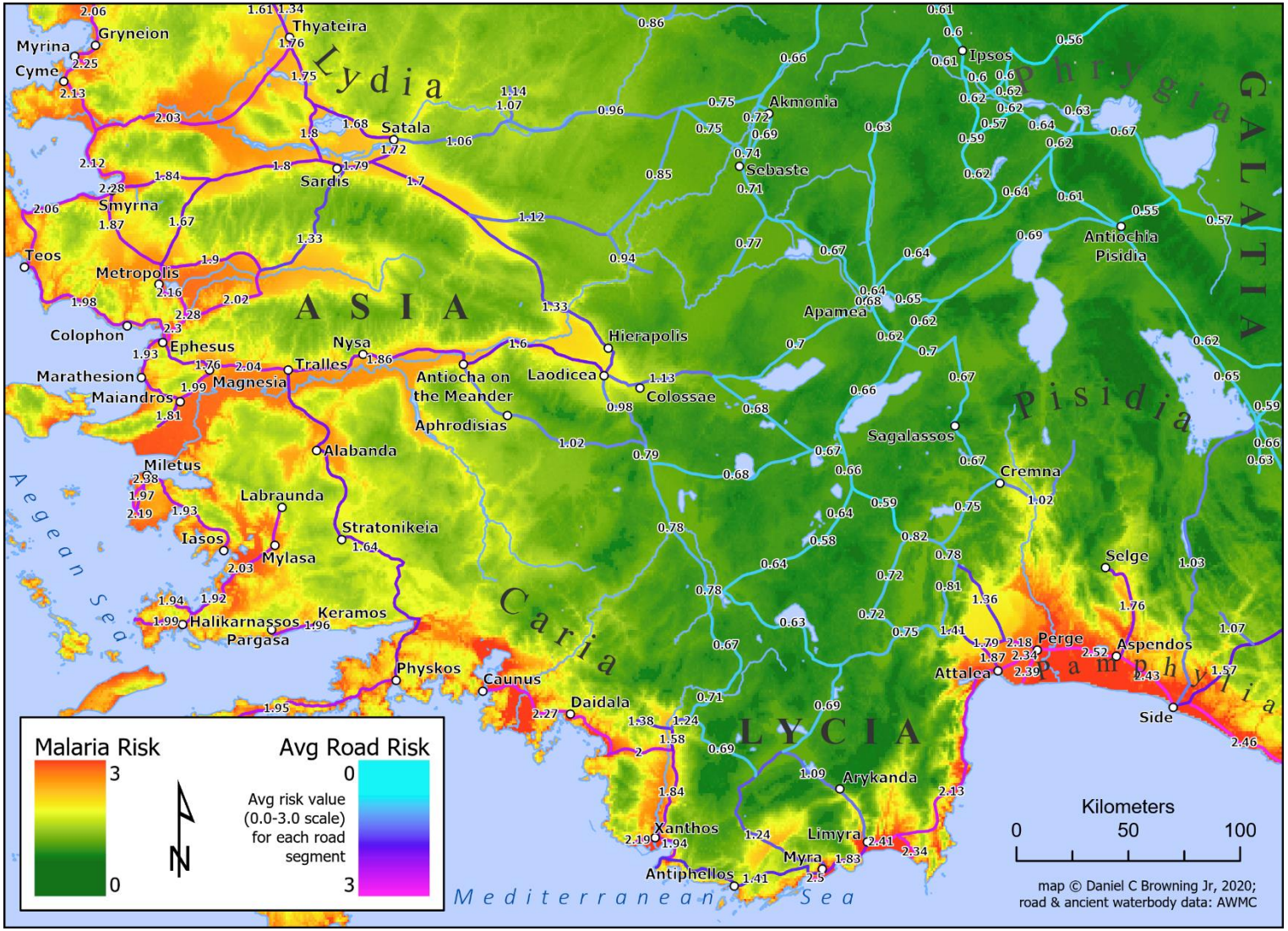
Unfortunately, apart from a circuitous route extending north to Sardis, there are no known improved roads that give passage to Ephesus. It is quite possible that an elevation preference included tracks and trails across the mountains north of the main highway that were not paved and not known as Roman roads today. One possibility, suggested by Wilson (2018), will be examined in the discussion section below.

Map 10. *Modeled malaria risk for western Asia Minor in antiquity.*

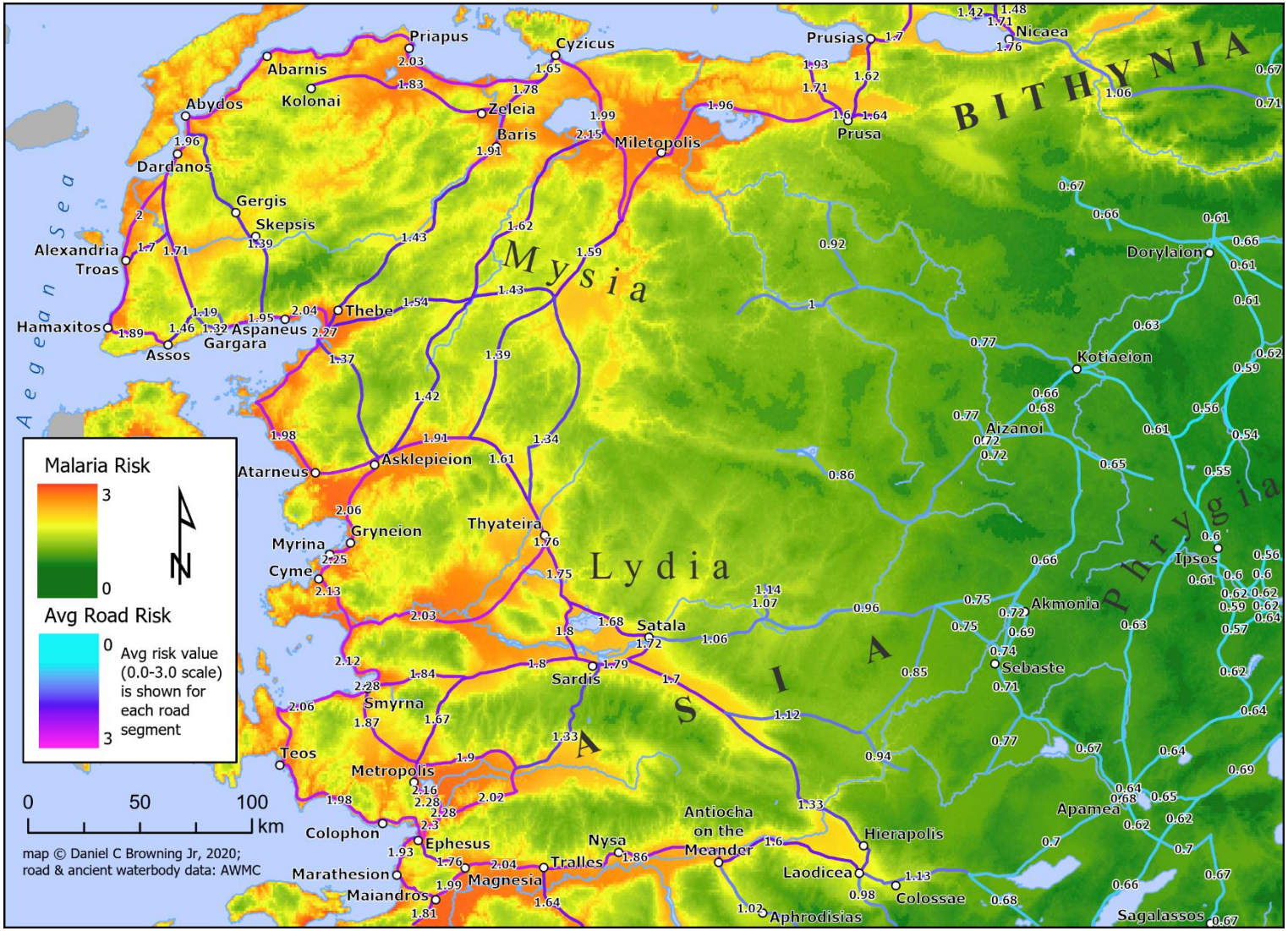
Model results for Asia Minor

Dataset equivalents for those used in model calibration and validation (**Table 3**) provided sources for risk layers in the western Asia Minor application study area. Risk layer preparation was identical to that determined in calibration for the Sicily study area (**Table 4**). As for all of Italy, the average of mean percent values for the lowest RMSE layer combinations from the Sicily and S Italy study areas (**Tables 5-6**, bottom) determined risk layer weights: Elevation, 52.6 percent; Temperature suitability (*P. falciparum*), 13.4 percent; Temperature suitability (*P. vivax*), 3.2 percent; Precipitation, 25.2 percent; Slope, 2.6 percent; and Wetness Potential, 3.1 percent. Model output for western Asia Minor using these parameters appears in **Map 10**. As expected, the higher elevation and slope areas show lower model risk values with higher risks concentrated along coastal and alluvial valleys.

For extension of risk to Roman roads, the road dataset from AWMC was prepared, modified, and buffered as outlined above, under "Roman Road Data and Processing." For basic presentation, modeled malaria risk values are calculated for each road segment. Results for SW Asia Minor appear in **Map 11**; those for NW Asia Minor in **Map 12**.



Map 11. *Average malaria risk for Roman road segments in SW Asia Minor.*



Map 12. *Average malaria risk for Roman road segments in NW Asia Minor.*

Discussion

Application of model results to the issue of Paul's travel decisions in Asia Minor follows by relevant passage in biblical chronological order.

Acts 13:13-14: Departure from Perga in Pamphylia to Antiocha Pisidia. Model results show a "hotspot" of malaria risk in the Pamphylian plain, as immediately evident in **Maps 10** and **11**. A five-kilometer radius from central Perga results in a mean risk of 2.41, with values in excess of 2.65 along the 8 km distant Cestrus River, by which Paul and his companions probably arrived (Wilson 2016, 234-35).

In contrast, Antiocha Pisidia has a modeled risk under 0.65. The *Via Sebaste*, which connects Perga with Antiocha Pisidia, has a similarly low risk after rising out of the Pamphylian Plain. By demonstrating the exceedingly high-risk potential in Pamphylia and low risk for both the journey and destination, this study's model provides support for Ramsay's contention that malaria is a reasonable cause for Paul's departure to higher ground (Ramsay 1920, 91-97). Wilson's attempt to dismiss Ramsay's theory "once and for all" (Wilson 2016, 240-42) thus appears ill founded as well as poorly argued.

Acts 16:6-10: False starts and redirection on Paul's Second Journey. The Acts 16:6-10 passage contains many unknowns. As mentioned above, however, interpreters overwhelmingly conclude that Paul's intended destination was Ephesus, capital of Asia (Robertson 1949, 143-44; Kelso 1970, 57; Murphy-O'Connor 1997, 166; Wilson 2005, 82; Thompson and Wilson 2016, 225).

Less clear is the point of diversion from this plan, whatever the reason for it. Since Paul's purpose at the outset of the Second Journey was to "visit the brethren in every city where we proclaimed the word of the Lord, and see how they are" (Acts

15:36), arrival at Antiocha Pisidia at the western extent of "Phrygia and Galatia" (Acts 16:6) is the logical conclusion of that effort (Thompson and Wilson 2016, 221-24). A change of direction at Antiocha Pisidia is possible, but a major junction of highways further west at Apamea makes more sense (Thompson and Wilson 2016, 226-28), given current knowledge of the Roman road network. Routes from the highlands around Antiocha Pisidia towards Mysia with access to Bithynia (Acts 16:7) are simply not known (French 1994, 54). Some suggest Paul's diversion occurred at Laodicea (Thompson and Wilson 2016, 228, n. 52), where a major route leads northwest towards Lydia and Mysia.

In any case, interest focuses on the continuing path to Ephesus from the point of diversion. The obvious and well-traveled route to Ephesus from central Anatolia was the "common road" (Strabo, *Geography* 14.2.29), the major highway through the Lycus and Meander valleys (Ogg 1968, 116; Wilson 2005, 82-83). **Maps 10**, **11**, and **12** demonstrate the higher risks for that section of the itinerary. The model assigns a mean risk of 1.44 to the entire road from Apamea to Ephesus. The section from Laodicea to Ephesus averages 1.79 with a maximum of 2.18; obviously the more risk-laden part of the intended journey.

News of a "fever" outbreak at some point along the highway would certainly be carried by travelers in all directions, and it is reasonable to assume Paul may have received such information. While no proof is implied, the model clearly supports the possibility of malaria as a catalyst in Paul's decision to change direction.

From either Apamea or Laodicea, a diversion to the north with Ephesus still in play as a destination would present other options to travel west and arrive there, most obviously via Sardis. But all known roads to the west traverse high malaria risk valleys

and an epidemic may have spread along with news of it. Failure to move west would inevitably bring Paul "opposite Mysia;" that is, south of that fuzzily defined region. Bithynia, a reasonable substitute for unreachable Ephesus, appears as the new goal, but is also somehow thwarted (Acts 16:7). The road risk model output demonstrates that the only routes to Bithynia feature the same high malaria risk levels as the westward valleys (**Map 12**).

In couching the prohibitions against activity in (the provinces of?) Asia and Bithynia in vague terms of divine directives, Acts does not indicate whether the same practical considerations can be assumed in both instances (Acts 16:6b, 7b), although this seems likely. Aside from unequivocal divine instruction, only government prohibition of Paul's work receives serious consideration as the cause. Arguments that provincial authorities may have denied Paul the right to preach his message in light of disturbances elsewhere (Acts 13:50; 14:5) may be reasonable for the province of Asia. But no such disturbances are recorded to this point on the Second Journey, and it is difficult to imagine a prohibition coming from provincial authorities in Bithynia given Paul's seeming on-the-fly decision to journey there. Meanwhile, the risk model clearly demonstrates risk of malarial outbreak as a potential causation for diversions away from both Asia and Bithynia in Acts 16:6-10.

Acts 19:1: the "upper country" route to Ephesus. The lower malaria risk predicted by the model on Mount Messogis north of the "common road" to Ephesus through the Lycus and Meander valleys is immediately noticeable in **Maps 11-12** and therefore of interest as a potential location for the "upper country" path taken by Paul in Acts 19:1 on his Third Journey. As noted above, there are no known Roman roads

approaching Ephesus in that area, between the Meander valley and the road from Sardis, to which the risk model can be immediately applied. Suggestion or creation of a route in this context would amount to circular reasoning. However, application of the model to routes proposed by others is certainly possible and represents the study's utility.

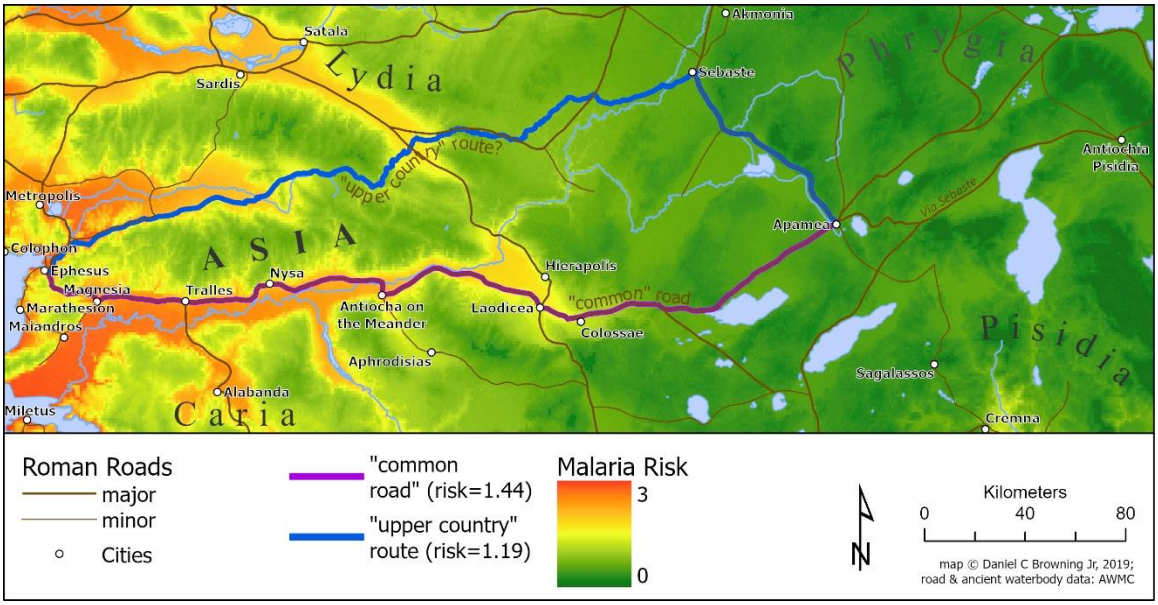
A recent suggestion provides an ideal case for application. Mark Wilson thoughtfully examines the problem of the "upper country" of Acts 19:1. After exploring other options, he suggests a path from Apamea via Sebaste and along the north slope of Mt. Messogis to Ephesus. Wilson laid out his proposed path with Google Maps, "using modern village names that lie along the approximate ancient route," and performed a rudimentary least cost distance (LCD) analysis using an online route profiler (Geocontext 2010; Wilson 2018a; 2018b, 16-19). Considering only time and distance as potential cost factors he rejects this "upper route" in favor of the Meander and Lycus valleys highway. Despite having rightly established the significance of the phrase "by the upper country" as referring to elevation, Wilson ignores the import of this only descriptor of Paul's route to Ephesus. He concludes, "unless a significant reason existed to deviate, none of which is known, the Southern Highway would be the natural route for Paul's third journey" (Wilson 2018b, 21).

Wilson's conclusion is valid for the LCD approach, but his claim not to know any "significant reason" for Paul to deviate from the more efficient route is surprising since, as noted above, he himself argued against Ramsay's malaria theory for the Acts 13:13-14 passage in an earlier article (Wilson 2016, 240-42). Following a 2016 presentation of his "upper country" research, I asked Wilson in person if he considered Ramsay's theory and whether malaria threat might be an issue on the main Meander Valley route. Wilson's

simple response, “where are the swamps?” highlights his limited understanding of malarial ecology and its potential impact.

Quantification of this response requires a comparison of relative malaria risk between the “common road” and an “upper country” route using this study’s model. In this comparison, modeled malaria risk replaces time and distance as preference for evaluating the alternate routes. It is appropriate here to address the difference between LCD analysis and the malaria risk model output—in other words, why not use malaria risk as a “friction surface” in an LCD approach? Malaria risk is not a certainty that is accumulated like time or distance or fuel consumption, but rather a figure of relative risk for an outbreak in a particular location. Mean risk of a route section is thus more meaningful metric than the accumulated risk. Maximum risk for a road section might be suggested as a datum but, again, the risk is not a certainty and maximum values are only mentioned for comparison.

With no known Roman roads, the “upper route” requires preparation for consideration. Google Earth’s “directions” function, when used for foot routing from Apamea (modern Dinar) to Sebaste (modern Sivaslı) and Sebaste to Ephesus produced what appears to be a nearly identical path to Wilson’s, apart from eliminating his unnecessary double crossing of the Cayster Valley to include the city of Hypaepa (near modern Ödemiş). This “upper country” route was transferred to ArcGIS Pro in kmz format for buffering and overlay with the model malaria risk layer to obtain mean risk values for comparison as illustrated in **Map 13**.



Map 13. *Malaria risks for two routes from Apamea to Ephesus.*

For the entire route from Apamea to Ephesus, the calculated mean risk for the Lycus and Meander valleys "common road" is 1.44, while the "upper country" route has a lower mean risk value of 1.19. Greater divergent values would result if the alternate paths were assumed to diverge at Laodicea, for example, or if the "upper road" were moved upslope on Mt. Messogis instead of along its north foot in the Cayster Valley. Nevertheless, it is not this study's goal to propose new routes to fit the data but rather to contribute data to discussion and debate. Therefore, I suggest the difference in malaria risk for the routes above and greater variances with other paths may represent Wilson's unknown "significant reason" for Paul to deviate from the "common road" to Ephesus and seek to travel "by the upper country.

CHAPTER V – CONCLUSIONS

General Conclusions

Despite the limitations outlined in Chapter III, the malaria risk model developed in this study performed well in prediction of malaria risk for pre-eradication conditions in the study areas as indicated by favorable and consistent results during validation. Comparisons of malaria risk prediction against anecdotal evidence in the form of textual data with spatially indicated conditions extend confidence in the model's viability back into antiquity.

Extension of the model to Roman roads produces mean risk values for specific routes or sections thereof that conform to conditions reflected in textual references to those roads within the study areas. In the specific case study of Paul's travel decisions in Asia Minor, model results highlight the varying risk levels of regions departed from or journeyed to and the potential risks of roads not taken versus ones possibly taken. While proof that malaria was a causative factor in the apostle's travel decisions is not possible, model results strongly suggest that such cannot be ruled out as some would argue. Meaningful contributions to current debate thus result from model application.

Potential Expanded Application

To other historical issues

Application of the model to other historical issues is certainly possible and should provide the same kind of contribution, either to ongoing debate or by initializing new interpretive possibilities. Two examples in the model's study areas have already been encountered above.

In the case of the Athenian expedition against Syracuse, Grmek has already proposed that malaria risk was incorporated into the latter's military strategy for defense (Grmek 1979). His argument has been cited but has not received wide discussion, perhaps due to a lack of tangible supportive data. This case represents an opportunity for the present model to contribute to and continue discussion.

Procopius' brief notation that Belisarius avoided the lauded Via Appia during the sixth century Gothic Wars (Procopius, History of the Wars 5.14.6-11), cited in Chapter IV, may present an opportunity for proposal of a new interpretation. Without a full search, I am unaware of any proposal that malaria could have contributed to the decision. The model results suggest such a theory is tenable.

In other regions

The above examples lie spatially within the study areas of the current project. Interest in ancient disease as a factor in ancient history has increased worldwide to judge from recent publications. The approach used here may add significantly to studies in other areas. Outright application of this study's model to other regions must be done with caution. The model's calibration, validation, and application study areas were all within the same latitude limits and results have not been tested outside that range. The model could be validated for higher latitudes within Italy using the same Torelli map-based data, but that has not been attempted in this study.

Enhancement Possibilities

Improved model calibration

Model calibration could be substantially improved with a better exemplar of the Torelli map. The map was published in fold-out form in the back of an explanatory book

(Torelli 1882). WorldCat (www.worldcat.org) does not list any libraries in the United States as holding the volume and shows the nearest at the Bibliothèque nationale de France in Paris. Because the original publication date is beyond copyright laws, some reproduction services offer reprints but without the original multicolor large size map. A large jpg image of an original unfolded map was the best version available for this study.

Given the promising results obtained with the small-scale image of the map, an effort to obtain a large-scale image for registration and classification may be warranted. Torelli's original maps, on which responding regional centers recorded endemicity, apparently would cover a town square when assembled (Sallares 2002, 236). The original cartography was done by the then newly formed Italian Geographic Military Institute (IGMI). IGMI maintains an online map portal (IGMI 2020), but the Torelli map is not listed as available in print or electronic form. Direct inquiries to IGMI might reveal whether archival copies of the Torelli map or its source maps exist and if they are available for scanning in person or by some other arrangement.

Seasonal variation

The varying seasonal risk of malaria, especially for *P. falciparum*, has been noted in the course of this study. A seasonal component to the model would represent a desirable enhancement. The level of sophistication required, however, may well exceed the limitations of available data. This limitation might even represent an opportunity for criticism of the current model's application.

On the other hand, the model results in their present form might be useful in chronological reconstruction. As an example, studies in Pauline chronology often debate seasonal details, including those related to Paul's travel. If this model's output is assumed

to represent maximum risk at the most likely times of the year (August-October), such data could be applied to these studies.

An Implication for Further Study

While this study demonstrates the potential of GIS applications to certain aspects of historical study, it also highlights some of the limitations of current data. As noted in Chapter IV, the available Roman road datasets all share an origin in the digitization of a print atlas. The accuracy and resolution of resulting products are truly inadequate for high resolution GIS studies. In the present case, the dataset was modified to repair disconnects in road segment polylines and correct some spatial errors through personal knowledge of extant remains so that confidence can be maintained in the results. Other applications of the model to road-based studies as suggested above, however, would require systematic updating of the dataset.

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