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SPACE, SETTLEMENT, AND ENVIRONMENT: DETECTING UNDOCUMENTED MAYA
ARCHAEOLOGICAL SITES WITH REMOTELY SENSED DATA

By

ANDREW J. VAUGHAN

Under the Direction of Jeffrey Barron Glover, Ph.D.

ABSTRACT

This study utilizes an integrated remote sensing approach to augment settlement pattern research in the Yalahau Region of northern Quintana Roo, Mexico. The region has a long history of human occupation and an environment ranging from coasts, freshwater wetlands, forests, to fields and towns all above a porous karst geology. By utilizing various sensors (LiDAR, GeoEye and Landsat) and collection methods (satellite, aerial) as well as post-processing (band combinations, component analyses and indices) and cross-referencing the data, it is possible to generate a signature, which strongly correlates with evidence of prehistoric occupation. Field verification of a selection of identified signatures was conducted to assess the presence of human cultural material. The results of this investigation are presented together with other regional settlement pattern data in order to assess the status of a number of methodological and archaeological questions and supplement other regional data already available.

INDEX WORDS: Maya, Human Ecology, Remote Sensing, Landsat, LiDAR, Archaeology, Settlement Pattern, Survey, GIS

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ARCHAEOLOGICAL SITES WITH REMOTELY SENSED DATA

By

ANDREW J. VAUGHAN

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Arts in Anthropology

In the College of Arts and Sciences

Georgia State University

2015

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Andrew Joseph Vaughan
2015

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ARCHAEOLOGICAL SITES WITH REMOTELY SENSED DATA

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Dedication

For My Family.

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1 Introduction

Investigations into the prehistory of what is now Quintana Roo date back to the very first decades of the colonization of Mexico (Means et al. 1974; Peck 2005; Restall and Chuchiak 2002). Centuries later, John Lloyd Stephens and Frederick Catherwood (Figure 1) brought the Yucatan Peninsula (presently encompassing the Mexican states of Yucatan, Quintana Roo and Campeche) back to English speaking populations, publishing illustrations of their travels as well as a popular-narrative of years of travel in the area (Roberts 2000; Stephens 1963, 1969). Human occupation in the Yucatan dates to the Paleoindian period (Chatters et al. 2014). Evidence for Maya occupation of the region begins during the Middle Preclassic period (c. 800 B.C.). Maya populations existed throughout the region during the Preclassic, Classic and Postclassic periods; however, population levels fluctuated through time. Modern residents of the area today are descendants of those Maya populations (Brainerd 1956; Castañeda 2004; Gabbert 2001). The modern environment of Quintana Roo consists of both high and low tropical forests and wetlands sitting atop porous limestone bedrock. The tropical environment makes site discovery challenging, with visibility often limited to a few meters in the forest (Chase 2014; Chase, et al. 2014; Garrison 2007).

As archaeological investigations have shifted away from the center/site paradigm, and towards “Landscape Archaeology”, emphasis has expanded on studies of households, hinterlands and other terms for sites which are investigated not for their grandiosity but for the mundane, routine and day-to-day nature of the cultural material available for study (e.g. Ashmore 1984; Hendon 2010; Hutson et al. 2007; Iannone et al. 2014). These types of investigations are multi-scalar, emphasizing center-periphery interactions as well as human-environment interactions (Ashmore 2002; Freter 2004; Hutson et al. 2008; Montmollin 1988; Redman 1999; Turner and Sabloff 2012). Therefore, understanding both the distribution of human occupation on a landscape and the types of activities



Figure 1 - Catherwood Plate XVI: Kab'ah

taking place there have become key components of interpreting the archaeological record (Chase 2014; Crumley 1994; Fedick 2014; Glover 2012; Lucero et al. 2011, Lucero, et al. 2014).

This increased emphasis on past human environmental interaction has coincided with the recent surge in environmental research related to climate change. In fact, archaeologists around the world have been contributing unique knowledge about these interactions to the current global political debate on climate change (Chase and Scarborough 2014; Sandweiss and Kelley 2012). This has led to increased funding for the relevant sects of archaeology. For example, the National Science Foundation (NSF) has made available grants for researchers investigating *Coupled Human Natural Systems* both in the present and past (NSF Solicitation 14-601). NOAA has also funded human-environment interaction research in the Yalahau region in previous field seasons (Glover et al. 2012).

Archaeological. Aiding these investigations are aerial and satellite remote sensing and computer-based tools, which I will now discuss.

Archaeologists have utilized maps and photographs to gain a different perspective on archaeological sites since before the transformation of the discipline from relic hunting into a science (Barber 2009; Deuel 1969). A.V. Kidder and Charles Lindbergh conducted early scientific aerial survey of archaeological sites. More recently, the advent of Geographic Information Systems (GIS) in archaeology has opened up many avenues for research (Ebert 2004; Fitzjohn 2007; Fletcher and Winter 2008; Gillings 2012; Rennell 2012). Remote sensing platforms have become considerably more capable since the days of hot air balloons carrying medium format cameras. Today, multiple platforms are available ranging from personal Unmanned Aerial Systems (Fernández-Hernandez et al. 2015) to airplanes (Chase, Chase, et al. 2014; Prufer et al. 2015; Doneus and Kuhteiber 2013) to satellite-based systems (Parcak 2009; Hixson 2013). The explosion in available data has been accompanied by an equally large number of notions on how to best incorporate these data into archaeological research (Custer et al. 1986; Doyle et al. 2012; Garrison 2010; Garrison et al. 2008, 2011; Giardino 2011).

For the purposes of this thesis, remotely sensed data will be utilized to deduct and test the location of previously undocumented archaeological sites and geographic or geological features of archaeological interest. The region of interest is the Yalahau of northern Quintana Roo, Mexico. Defined by Dunning as one of the unique adaptive zones of the Maya lowlands, the Yalahau region presents a unique set of factors with regards to subsistence practices and therefore past livelihood (Dunning et al. 1998; Fedick et al. 2000). For the purposes of this study, I will continue to utilize the 20 km buffer proposed by Glover (Glover 2012) as a boundary for the region (see Figure 2). Not relying solely on a single sensor or platform, but instead utilizing various platforms (i.e., Landsat, GeoEye-1 and IKONOS multi and hyperspectral imagery as well as SRTM and airborne LiDAR

derived elevation models) strengthens the data upon which interpretations can be made. This also greatly increases the complexity of analysis, and requires understanding nuances of the various platforms used and how best to process data for archaeological purposes.

1.1 Overview of Thesis

The questions addressed by this thesis are diverse and derived from previous research in the region. Primarily, this thesis seeks to determine whether or not remotely sensed data can be used to detect undocumented prehistoric human settlement in the Yalahau region. Tied with this are a number of secondary questions about the relationship between settlement and environment that have been raised by previous studies to which remotely sensed data may provide some insight. In addition, a methodological comparison between conventional survey and remote sensing based survey is addressed.

I examine the results of this program of remote sensing and verification in the context of the previous field survey (Glover's Yalahau Region Settlement Pattern Survey; Glover 2006, 2012) upon which my own research is based. Glover raises three issues in his dissertation for which remotely sensed data may provide some insight. The first of these is the primary question of this thesis – what sites were missed using informant-based survey? The other two issues raised by Glover are the lack of settlement in what appears to be a low-lying zone to the east of the wetlands and whether or not the apparent lack of settlement in the area around Kantunilkin was a sampling error. Data from Daniel Leonard's dissertation research (2013) also greatly enhanced this project. During investigations in the regional wetlands, Leonard came across a number of previously undocumented sites. I present Leonard's findings in the context of my own research as a form of de-facto field verification, as some of the previously unknown archaeological sites Leonard reports finding are locations shown to have various remote sensing signatures correlated with human habitation.



Figure 2 - Location of the Region of Study, ESRI National Geographic Basemap

Context is essential in order to frame my research project that I call the Space Settlement and Environment Project (SSEP). To that end, Chapter 2 provides an overview of the theoretical positioning upon which this research is based. Background information is provided on the

geography, biology, environment and history of the Yalahau region in Chapter 3, including information about previous archaeological research in the region. Chapter 4 explains the various methods utilized in remote sensing data acquisition, processing, interpretation and validation. Chapter 5 presents the results of the survey, including maps, diagrams and descriptions for anomalies identified as well as those verified in the field (either by myself or by colleagues). In Chapter 6, I discuss the results of the research questions in the context of the theoretical positioning found in Chapter 2. I compare the different methods used in this project and the YRSPS upon which my own research is based. I conclude with an examination of future research directions with regards to the continued use of remote sensing.

2 Theoretical Orientation of Research

Though not an archaeologist, Heinrich Schliemann produced many maps and plans through the course of his excavations in what he deemed ancient Troy (Schliemann 1884). Spatial interpretation, at all scales, has long been an integral part of the archaeological discourse (Ashmore 2002; Ebert 2004). Ashmore (2002:1173) states “[m]yriad scholars, in the United States and elsewhere, have long sought to reconstruct social (or societal) organization from the archaeological record, as viewed through artifacts and features mapped across space (e.g., Chang 1958; Childe 1951; Fox 1932).” Aerial photography in archaeology goes back to some of the earliest aviators (Barber 2009; Deuel 1969), and remote sensing techniques have continued to develop (Comer and Harrower 2013; Ebert 1984; Giardino 2011; Giardino and Haley 2006; Lasaponara and Masini 2011; Parcak 2009). Trends in archaeological cartography have followed those broader themes in archaeological theory as well as in cartographic, geographic and social theory.

I treat the use of remotely sensed data in archaeology as a part of a process, conducted in parallel and integrating with research questions at many levels - as opposed to a standalone method

with definitive inputs and outputs. Regardless of the source, resolution, or analytical method used, mapped data is still a *representation* of the real world, and not the real world itself. As long as this is acknowledged, it is possible to effectively incorporate GIS into a program of archaeological research. Acknowledging that this exchange must work both ways, I situate this research within the broader framework of historical ecology, which I discuss below.

The completion of a map of Teotihuacan in 1970 (Millon 1970) after 8 years of work in recording every possible feature in painstaking detail (Millon 1964) is an example of the state of spatial archaeology prior to the advent of GIS technology. This project can be seen as an archaeological implementation of what Crampton and Krygier term “Scientific Cartography” (Crampton and Krygier 2005:20), which is the use of techniques, method and theory for creating ever more precise and accurate maps. According to Crampton and Krygier the development of this theoretical paradigm during and after World War II was for the purpose first of waging war and then rebuilding Europe (Crampton and Krygier 2005).

Critics of this stance, among them Crampton and Krygier, contend that map accuracy is a subjective quality, which is constrained by the social and political contexts within which a given map is created. Post-processual archaeology and critical cartography both recognize the situated-ness of knowledge (Crampton and Krygier 2005; Trigger 2006). Both stem from broader philosophical trends, notably postmodernist philosophy on the creation of knowledge, as Trigger explains: “Postmodernists agreed that there could never be a single objective version of human affairs; instead there were multiple versions or truths seen from different standpoints, such as those of poor and rich, winners and losers, females and males, different professions and various ethnic groups” (Trigger 2006:446). Mark Monmonier and Blij (1996:2) bring this point back around to mapped data succinctly: “A single map is but one of an infinitely large number of maps that might be produced for the same situation or from the same data.” The sustained critique of forced objectivity in

scientific inquiry; whether stemming from post-processual archaeologists, critical cartographers, or their like-minded peers in other disciplines; has undoubtedly had an impact on the uses of GIS and other forms of computation in archaeology.

Geographic Information Systems, like other informational paradigms should be viewed as one of many possible tools to investigate archaeological (and ultimately anthropological) research questions. Those research questions, and the specific integration of GIS into research questions depends on the social, political and theoretical contexts within which the research questions are formed. Gillespie illustrates the issues archaeologists face as consumers of cartographic theory in her examination of the cartographic history of Complex A at the site of La Venta (Gillespie 2011). Gillespie notes that the variety and diversity of styles and representations present in many decades of mapping archaeological work at the site has led to more confusion than clarity in regards to the appearance and structure of the complex – and because it has since been destroyed, the variety of maps are all that remains. There is a simultaneous duality with regards to mapping in archaeology – maps must balance convention with effectiveness, and must often convey spatially and temporally complex information. Gillespie’s assessment of the maps of Complex A illustrates the importance of documenting the process involved in the creation of maps, if only for the later assessment of the methods used.

2.1 History of GIS in Archaeology

David Ebert (2004:319) identifies GIS as the set of software tools “for the collection, storage, retrieval, [and] manipulation of spatial data from the real world.” The introduction of GIS has simply made the previously established workflows within spatial analysis far easier to accomplish, and broadened the possibilities for innovation. Ebert conceptualizes GIS in archaeology as three hierarchical categories of visualization, management and analysis (Ebert 2004:320). Cartographic uses fall under the category of visualization. This is simply the translation of mapping

techniques for archaeological sites from ink and paper drafting to computerized mapping (GIS). Management is the collation and recordation of site location data, artifact data, soil stratigraphy, architectural contexts and project metadata for the purposes of resource management. Analysis comprises the highest level in Ebert's hierarchy of uses. In this level, GIS is used to derive and test social theory. This hierarchical approach, while not complete, provides a general overview of the roles GIS technology can play in archaeological investigations. Technological advances, both in software capabilities and in the quality and availability of data will continue to aid archaeologists in answering diverse research questions.

Many diverse archaeological projects have implemented GIS programs (e.g. Ashmore 2002; Bevan and Conolly 2002; Doyle et al. 2012; Eckardt et al. 2009; Fitzjohn 2007; Fletcher and Winter 2008; Garrison 2010; Garrison et al. 2008, 2011; Glover 2012; Kosiba and Bauer 2013; Sharon et al. 2004; Sayer and Wienhold 2013) especially for locational context information integral to any archaeological reporting. Data used in this thesis from previous projects was collected, stored, analyzed and incorporated in the form of GIS data – including ceramic data as well as structures, platforms and pyramids.

Mapping of archaeological remains for the purposes of complex spatial analysis is common, even predating GIS. For example, Folan et al. (1983) examined the correlation of paleo-climatological data to sociopolitical circumstances, and Drennan (1984) examined long distance trade, both in the Maya region without the use of modern GIS. Today these types of analysis would generally be conducted in GIS as a matter of course.

More involved than data storage is the use of modeling to predict the location of undocumented sites. Specifically, modeling assigns probability to space, with regards to the likelihood of the presence of human cultural material. Verhagen and Whitley (2012) provide an account of the history of predictive modeling in archaeology. According to Verhagen and Whitley

(2012:3) such models can take on two forms: inductive and deductive. Inductive models utilize known site locations and statistical regression of environmental data to extrapolate site probability to unknown areas. Deductive models utilize hypothetical explanations for site location and are not based on known site locations. The theoretical and practical implications of such models are widely debated. Processual and post-processual thought have played a major role in developing and critiquing the use of predictive models respectively. Perhaps the most compelling criticism of predictive modeling is that archaeologists relying on models will never be *certain* of locating all archaeological resources and materials in a given area (Verhagen and Whitley 2012:5). This problem is most apparent when such models are used to drive the implementation of a survey project in the absence of a mechanism for feedback of field experience into the survey design.

The inductive methodology most commonly utilized in archaeological site modeling may suffer a severe bias towards reinforcing what is already known about site distribution. As a brief example, consider Loebel (2012), who examined the patterns of Midwestern fluted point distribution. In Loebel's analysis, these points, often used in research to purportedly reconstruct patterns of Paleo-Indian period land use, were subject to a significant form of confirmation bias from factors such as modern population, geological processes, and intensity of prior archaeological research. Loebel's analysis has significant implications for the validity of inductive models for site location. As Verhagen and Whitley (2012:54) point out "it is illusory to think that we will be able to detect all archaeological remains in an area without stripping it completely." Though I would point out that it may absolutely be *possible* to detect all the remains, as a scientist working with current technology it would be impossible to be *certain* of detecting everything without excavating and screening 100% of the soil in the zone in question ("stripping it completely"). Even then, questions would remain as to what evidence present in the ground at the conception of the excavation was lost

in the very process of excavation – for example botanical remains in soil. Further, did human beings even take part in activities that would leave any record at all hundreds or thousands of years later?

Knowing that we cannot ever recover a full record of the past, and knowing that what we do recover can be biased significantly in ways we do not always notice, the validity of inductive models must be examined very closely and they must not be implemented uncritically. Specifically, such models inherently limit and possibly exclude the possibility of finding novel sites that do not fit, or cannot be predicted by the model. Further, because a particular location exhibits a remote sensing signature indicative of habitation does not secure status as a site of habitation.

Predictive modeling does have more practical applications, despite acknowledged theoretical deficiencies. Leslie Reeder et al. (2012) utilize GIS to record site locations and assess site vulnerability on and off the California coast. Their study integrates modern climatological and environmental models with known site locations not to assess social theories but to determine site vulnerability to environmental changes such as erosion. Reeder et al. encourage archaeologists to quantify threats to the archaeological record with modern environmental models, and the synergy between their objectives and methods is compelling. However, it is important to acknowledge that by integrating the models of other fields into archaeological research, researchers become consumers of the theoretical paradigms of that field and model. It is, therefore, critical to evaluate how well those theories integrate with aims of the research project. Regardless of academic discussion, Cultural Resource Management firms and many State Historic Preservation Offices in the United States as well as some equivalent agencies internationally have bought into predictive models uncritically which has led to a gap in the application of these models and current theoretical trends. Quantitative methodologies are not unique to GIS within archaeology.

David Hurst Thomas (1978) provides a compelling account of the use and misuse of quantitative statistical methodologies in archaeology dating back to the very beginnings of the New

Archaeology. These critiques and criticisms are as applicable to GIS (and any other quantitative methods) today as they were in 1978. In science more generally, Jacob Cohen's (1994) scathing assessment of the null-hypothesis method of significance testing in the context of psychology rings true for archaeology as well. Close reading of the Thomas (1978) and Cohen (1994) articles reveal the same basic criticism: scientists applying statistics to research questions do not know enough about statistics.

I must emphasize here that I am not rejecting out of hand the utility of quantitative statistics in archaeology. In my view what is most critical to take away from Cohen and Thomas is to not rely on a single set or type of data when interpreting answers to research questions, and in particular to not rely solely on statistical tests when making interpretations. Statistical significance and correlation can provide compelling evidence, which will lend credence to a given interpretation of a given set of data. However, correlation must not be mistaken for causation. Simply because a given model works does not mean that the underlying social interpretations are true. A keen, critical eye and careful thought must be applied to any analytical method, including statistics. Approaches which employ a variety of quantitative, qualitative or interpretive data are preferred. Statistics can help build or reject an argument – but only with critical thought, and preferably with the help of many supporting lines of evidence.

2.2 Recent Trends in Archaeological GIS

Recent developments in archaeological GIS include attempts to integrate concepts from post-processual archaeological thought with GIS. Landscape archaeology, phenomenology and other more interpretive realms of inquiry within archaeology have all made use of GIS technology. Wendy Ashmore (2002) has called upon archaeologists to socialize spatial lines of inquiry. Many researchers engaged in the sorts of socially driven spatial investigations Ashmore encouraged have utilized and benefited from advances in GIS technology and data.

Viewshed analysis is a common GIS function utilized by landscape archaeologists (Doyle et al. 2012; Ebert 2004; Eckardt et al. 2009). Viewshed analysis is “a map of locations that are visible/not visible from a given location, derived from a digital elevation model” (Ebert 2004:329). The result of this operation is a map of only two values - one value representing visible locations, and another those not visible. Viewshed can be interpreted in many different ways in an archaeological setting. Doyle et al. (Doyle 2012; Doyle et al. 2012) utilize viewshed along with cost surface analysis to model movement and visibility and possibly territoriality near Tikal. Eckardt et al. (2009) utilized viewshed to ascertain the relationship between Roman barrows and the surrounding landscape. Fairén-Jiménez (2007) examined Neolithic rock art in Britain through the lens of visibility. Fletcher and Winter (2008) applied GIS to visibility at sites in the Middle East. In India, Mack (2004) examined viewsheds with relation to different temples. In the US, Jones (2006) examined Onandaga site location with respect to viewshed in New York State. In these cases the use of viewshed is an attempt to ascertain how landscape was perceived in the past through modeling sight lines.

Viewshed analysis, despite ostensibly direct acknowledgment of the biomechanics of human sight, is not without critics (Fitzjohn 2007; Gillings 2012; Llobera 2007, 2012; McEwan and Millican 2012; McEwan 2012; Rennell 2012). Mark Gillings (2012) criticizes viewshed as an example of the “toolbox” problem in GIS. That is: the tendency of archaeologists to compromise nuance in order to fit the research question to preexisting GIS methods (Gillings 2012). Many critics also attempt to reconcile the toolbox nature of the viewshed analysis capabilities present in GIS software with the experiential and phenomenological theories that are often prevalent in landscape archaeology. In particular, viewshed is known to assume a level of deforestation, which can be difficult to support empirically *throughout* time in the Maya area, though many population estimates for major centers may imply it (Doyle 2012). McEwan (2012), McEwan and Millican (2012) and Gillings (2012) all

recommend the construction of middle range theories bridging critical and practical aspects of incorporating GIS within *archaeological* research, as well as further innovation in GIS tools developed specifically to suit archaeological investigations.

Middle Range Theory, according to L. Mark Raab and Albert C. Goodyear (1984), is the concept of abstracting social theories from ostensibly empirically obtained inputs used to test them. For Raab and Goodyear, effective implementations of middle range theory serve as a form of “proof” in the mathematical sense, a chain of logic or series of propositions which abstract and bridge data with theory. Simultaneously this serves as a check both on untestable pontification and uncritical empiricism. This idea can be used to incorporate GIS based analytical methods into social theories reliant on other sources of data. McEwan (2012), McEwan and Millican (2012) and Gillings (2012) encourage the further development of theories for utilizing GIS based inputs to test higher order theory.

Many critics of GIS cite the work of Marcos Llobera in innovating with GIS software tools to investigate interpretive archaeological problems. Llobera (2007) utilized a concept of banded viewsheds to better understand inter-visibility in Roman barrows, a problem discussed earlier (Eckardt et al. 2009). By breaking the viewshed from its binary visible/not visible computer friendly method, Llobera (2007) attempted to incorporate the nuance of human visual perception into the software analysis by creating range limited viewsheds at near, mid and far break points established by other researchers. Rennell (2012) also utilized banded viewsheds, incorporating field survey distance classes into their viewsheds. This allows a researcher to present a derived viewshed in a more nuanced way, representing the differential perception of human vision over increasing distances.

2.3 Geospatial Revolution: Critical Theory and Remote Sensing

Recent calls for and developments in Middle Range Theory within Archaeology have coincided with a vast increase in availability and quality of data about the earth’s surface (Chase,

Chase, et al. 2014; Chase et al. 2012, 2011; Prufer et al. 2015; Parcak 2009; Hixson 2013; Doneus and Kuhteiber 2013). The data becoming available in the projects and volumes cited has improved or eased the implementation of traditional archaeological methods like pedestrian survey and manual excavation. In the case of Caracol (Chase et al. 2011; Chase, Chase, et al. 2014; Chase et al. 2012) LiDAR based survey methodology has expedited mapping of the landscape surrounding the site immensely. For the Caracol project, LiDAR based survey is one form of survey input, along with traditionally conducted pedestrian architectural surveys and many other sources of data. All are used to interpret the site.

For Chase and colleagues (2012:12916) improvements in spatial technology can be seen akin to the advent of C14 dating: “[a]rchaeological research revolves around temporal and spatial data; thus advances in either parameter can be transformative.” However, given the toolbox problem identified by Gillings (2012) with GIS methods. This toolbox problem can also be applied more broadly to other archaeological and anthropological methods – say with relation to available isotopic assays both permitting and constraining certain types of bioarchaeological investigation. Archaeologists must acknowledge and include these constraints in the theoretical positioning of their work.

The issues of how to integrate remotely sensed data into a program of archaeological research are not relegated simply to elevation derived viewshed. Satellite imagery is increasingly available at ever-higher resolutions to archaeological researchers. The edited volumes by Douglas Comer and Michael Harrower (2013) and Sarah Parcak (2009) explore recent possibilities in satellite remote sensing in archaeology. The *chaîne opératoire* concept presented by Doneus and Kuhteiber (2013) for integrating national LiDAR data sets into archaeological research in Europe provides a useful mechanism for explicitly situating remotely sensed data in general within an extant framework

of archaeological research. This concept requires the researcher make explicit the links between the decisions made at all stages of remote sensing research.

Mentioned above, Wendy Ashmore has issued a call for archaeologists conducting spatial analysis to engage more fully with the social aspects of archaeology. Ashmore posits the concept of “life history of place” (2002:1178) as one way to accomplish this socialization. She defines this concept as “examining evidence for human recognition, use, and modification of a particular position, locality, or area over the full time span of its existence” (2002:1178). By so doing, Ashmore is in essence calling for the construction of a middle range theory explicitly establishing links between GIS and other forms of spatial analysis and broader theorization within archaeology. In response to Ashmore’s challenge, this study establishes links, but also acknowledges the possible gaps, between observed material culture, remote sensing data and the “decisions and dispositions” of human beings in the past. I aim to further answer this challenge by being explicit in how the theoretical framework of Historical Ecology has informed this study in design, implementation and interpretation.

2.4 Historical Ecology

“The composite place-the local landscape and its constituent natural and accumulated cultural elements-remained a critical arena and set of referents for mapping social and political change.”

- Wendy Ashmore (2002:1179)

The “life history of place” called for by Ashmore requires assessing human impacts on past environments. In this study I examine how human beings manipulated and continue to manipulate the landscape to their own ends and how in turn the landscape has guided and constrained human

activity. I view these factors at a regional scale, through the lens of available remotely sensed data. Life history of place envisions the landscape as a sort artifact – the sum total activities of any number of generations of human beings imprint themselves upon the landscape. But in this model, the life history of *place*, we must acknowledge that a place has history, and a life, both at the hands of humans and beyond.

Human beings around the world have adapted to a great diversity of environments and at the same time have changed them (Crumley 1994). Historical Ecology, or Landscape History, – the theoretical framework laid out by Carole Crumley recognizes the explicitly interrelated nature of human relationships with the environment. This framework brings together physical and natural sciences with historical and archaeological frameworks. The aim of this is to resolve perceived deficiencies in integrating the growing body of environmental data with historical, archaeological and other explicitly human focused avenues research. As Crumley identifies, the advent of computer assisted GIS data manipulation has allowed for the mapping of environmental change over time, which when integrated with data on human activities can help to illuminate the possible dialectical relationships between humans and the environment (2006:1173).

By incorporating a number of remotely sensed data sets, discussed in Chapter 4, along with the previous archaeological research as discussed in Chapter 3, my aim is to determine what utility remote sensing has in the aid of settlement pattern research in the region. By combining multiple data sets from interrelated projects that are oriented at various aspects of the archaeological record, it is possible to assess the utility of remotely sensed data with regards to the interpretation and analysis of the diversity of archaeological features found in the Yalahau region, to be discussed in chapter three.

2.5 Conclusions

This research is one component in a series of projects that are “filling in” the picture of settlement use and human modification of the Yalahau region. This aids in understanding the specific dialectical interactions between humans and the environment that influenced sociopolitical development within the Yalahau region and that have impacted the landscape in such a way that they are still observable today. By building on these attempts at using post-structural theory in overcoming possible pitfalls of GIS based analysis, and by integrating multiple sources of data – archaeological, geological, hydrological, satellite and airborne remote sensing – this project aims to assess the utility of remote sensing for detecting long term human impacts on the environment. By first starting from a position that acknowledges the theoretical limitations of the methods used, I seek to understand the pitfalls in order to avoid them. I posit that by understanding the limitations and wielding the strengths of these various remotely sensed data I can more effectively conduct archaeological research, primarily the settlement pattern research to which I seek to contribute.

3 Natural, Cultural and Archaeological Background

The Yalahau region of northern Quintana Roo represents a unique opportunity to examine the interactions between human beings and their environment (e.g., Fedick et al. 1995; Glover 2012). The abundant wetlands of the Yalahau region are resource rich (Leonard 2013). Underlying the region is a layer of porous limestone, which creates a karstic landscape. Along the eastern part of the peninsula is the eastern block fault zone, a zone of horst and graben geology forming a series of long, low lying areas running north to south, known as the Holbox Fracture zone (Ward et al 1985:1-12). Chemical dissolution of the karstic limestone in this already low-lying area had an impact in the development of the Yalahau Region wetlands (Perry 2002). This landscape is home to an extensive network of caves, many submerged along the eastern coast of the peninsula (Beddows

2003, Fedick 2014, Lesser and Weidie 1988, Ward et al. 1985). In this region, rapid infiltration of surface water below the surface results in a lens of freshwater above a layer of salt water, with the fresh water lens thicker further from the coast (Beddows 2003:29). There are a number of other related karst features in the region including *Corchales* (deep, soil filled depressions), *Lagunas* (shallow ponds) and *Rejolladas* (shallow soil filled depressions) but the most famous feature of this landscape is the *cenote*. *Cenotes* punctuate the porous landscape and ideally contain water at the bottom. The cenote at Bolonchen (Figure 3) is an example of how important these geologic features were within Maya culture. Here Stephens and Catherwood observed a community collecting water and making offerings within the *cenote*. The edited volume from Pruffer and Brady (2005) provides an overview for the context of ritual use of caves, *cenotes*, rock shelters and other features common of the limestone landscape of Quintana Roo.

In order to discuss Maya beliefs about caves, it is important to establish the concept of *ch'en*. In this paper, and many other modern investigations of caves the English word “cave” is used in the sense of the Maya word *ch'en*. The word *ch'en* has been translated variously as “cave” or “well” but perhaps the most important translation is that of “hole in the Earth” (Brady 1997; Laughlin 1975). This concept is important, because in order to understand caves and the rituals taking place there in emic terms we must attempt to understand how the ancient Maya themselves conceptualized caves (Brady 1997). The translation of “hole in the Earth” allows for a very broad definition of cave, which encompasses many features present in a karst landscape which have different names in English, and therefore might be ignored in cave studies. These include traditional horizontal caves, sinkholes, depressions, fissures, rock shelters, cenotes (defined above), and various manmade holes (e.g. *chultuns* or storage pits) (Brady 1997). Epigraphic evidence from Vogt and Stuart (2005) provides a reading of *ch'en* for a previously un-deciphered Maya glyph, leading to many new discussions about caves in the field of epigraphy.



Figure 3 -Catherwood Plate XX: Well at Bolonchen

Physical evidence of ritualism and caves as special places dates back to the very beginnings of cave archaeology (Butler 1934; Gordon 1897; Stephens 1841 and 1843) and continues through today (Brady and Prufer 2005; Brady and Rissolo 2006; Halperin et al. 2003; Ishihara-Brito et al. 2011; Moyes et al. 2009; Prufer and Brady 2005; Prufer and Dunham 2009; Prufer and Hurst 2007; Weishampel et al. 2012). Vogt and Stuart (2005) provide, in addition to their epigraphic interpretations, ethnographic evidence for the sacred, ritual nature of caves for the Maya, along with

Brady and Kindon (2005), Adams and Brady (2005) and Petryshyn (2005[1968]). Caves, both natural and completely artificial abound both within Maya sites throughout the region, and dispersed across the countryside within the Yalahau region.

The recent nature of this analysis of architecture and karst topography means that not many sites have been systematically surveyed for cave associations. Even when such surveys are undertaken the rugged nature of the terrain can present challenges in locating cave sites. Weishampel et al. (2012) examined airborne LIDAR for the site of Caracol in an attempt to locate cave sites. The survey was partially successful but they note that the methodology used precludes the identification of horizontal cave features, which are very common in the karst topography of the region. Even if survey is undertaken for the express purpose of locating cave features, the Maya often took steps to bury entrances, as Brady (1997) observed at Dos Pilas.

3.1 Natural History of the Yalahau Region

The Yalahau region wetlands are geologic features, with fractures in the limestone bedrock resulting in flat areas of lower elevation within the already flat and low Yucatan Peninsula (Fedick et al. 2000; Fedick 2014; Leonard 2013; Wollwage et al. 2012). Lowlands grade slowly and shallowly into upland areas with relatively higher elevation, areas of forest in various states of growth from primary regrowth to proper high forest, with high canopies and open spaces between large trees. Dunning et al. (1998) defines the Yalahau region as a distinct physiographic zone that presents unique opportunities and constraints for subsistence practices. The region is defined geographically and geologically, and subsequently environmentally, by the lowland wetlands, known locally as *sabanas*, and the seasonal wetland resources they provide access to. For the purposes of this study, the Yalahau region refers to the area encompassed by a 20 km buffer extending from the dry season limits of the wetland *sabanas* (Figure 4), following Glover's (2012) definition as mentioned above.

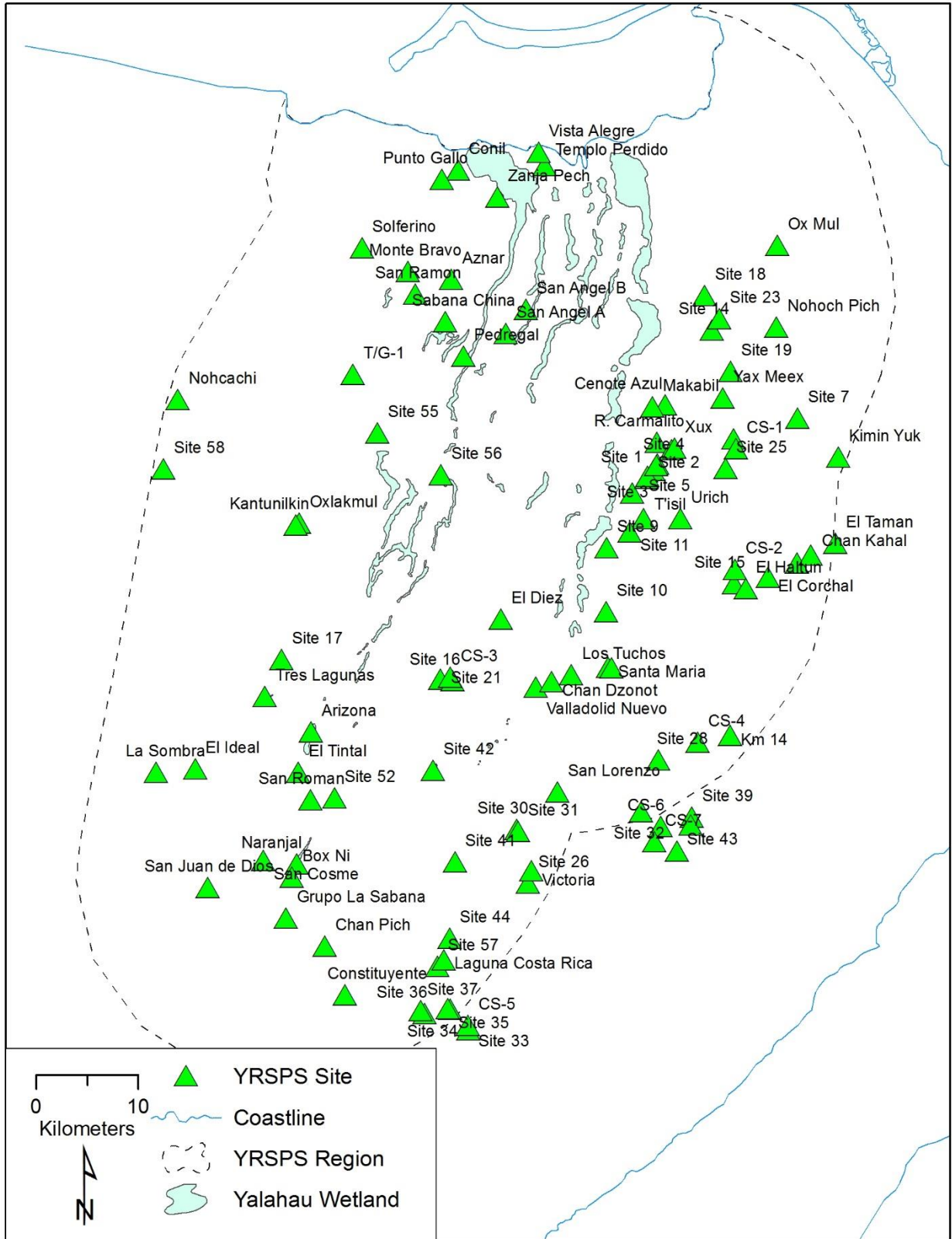


Figure 4 - YRSPS Known Sites

The general low lying nature of the northern Yucatan Peninsula, means that slight relief in terms of elevation can have dramatic impacts on the flow of water. The wetland sabanas are fed by rain and the underlying water table – which is itself dependent on a number of factors, including sea-level (Fedick et al. 2000; Fedick 2014; Glover 2012; Leonard 2013). The sabanas are pulse based, filling with water in the rainy season, and discharging it into Laguna Holbox (Leonard 2013). Sea level – thus the water table, and consequentially, the sabanas – were up to one meter lower in the rainy season during the Terminal Preclassic (75 BC – AD 400)(Fedick 2014; Leonard 2013). This lower maximum for the water level means that the wetlands would have been considerably narrower during their high water level during this time period.

Further research by Daniel Leonard (2013) in the regional wetlands, the focus of his dissertation project, has broadened the evidence of human modification of the wetlands, previously reported by Fedick and colleagues (Fedick et al. 2000). Investigations into wetlands elsewhere in the Maya region (Beach et al. 2009; Dunning et al. 2002; Pope and Dahlin 1989) confirm the importance of these resources, especially during the Preclassic. Intensive modification of the wetlands is correlated with the increase in human activity and populations in the region as reported by Leonard (2013).

Despite the intensive utilization of the wetlands, sites are generally located in upland contexts. However, recent research by Leonard (2013) shows structures do exist within 10 meters of the margins of some wetlands, however the aforementioned rise in sea level since the Terminal Preclassic may be causing the encroachment of the wetlands at some sites. The largest sites within the region are all located at the margins of the region, near the edge of the study area. Sites close to the wetland were located in upland contexts, with access to both the wetland and upland resources. Understanding of settlement pattern data within the region is aided by further refining our

interpretation of the relationship between sites and the wetlands used to delineate the region, a task which remote sensing can assist with.

3.2 Culture History of the Yalahau Region

In an attempt to relate the conception and results of this thesis back to the broader anthropological questions currently under debate in the Yalahau, I recap the current, general understanding of the chronology of the region, first addressing the general culture-history of the Maya Lowlands from the Preclassic through the Colonial period (Table 1). Ceramic data (Amador 2010) support two primary periods of occupation in Yalahau region, the Terminal Preclassic (75 B.C. – A.D. 400) and the Postclassic (A.D. 1100/1200 – 1521). The first documented human presence in the region, however, begins in the Middle Preclassic period (approx. 700 B.C.) (Glover et al. 2011; Rissolo et al. 2005). Research (Glover 2012, Glover and Stanton 2010) has shown that the vast majority of settlement occupation in the Yalahau region dates to the Terminal Preclassic (75 B.C./ A.D. 100 - A.D. 400). By the Early Classic period, many sites in the region were abandoned, with a notable exception at Vista Alegre (Glover et al. 2011). This widespread depopulation at most sites throughout the region continues until around A.D. 1100 or 1200, at which time there is a reoccupation of many sites throughout the region (Amador 2010; Glover 2012; Leonard 2013).

Table 1 - Chronology of the Region (after Glover 2006:350)

Time Period	Beginning	End
Middle Preclassic	700 B.C.	200 B.C.
Late Preclassic/Early Classic	200 B.C.	A.D. 600
Late/Terminal Classic	A.D. 600	A.D. 1200
Postclassic	A.D. 1200	A.D. 1521
Post-Contact	A.D. 1521	Present Day

By Late Preclassic (200 B.C. - A.D. 250), the entire lowlands experience a population surge, including the Yalahau region (e.g., Bey et al.1998; Glover 2012; Stanton 2000). This increase in population also corresponds, according to Glover (2012) with an increase in monumental

architecture in the region. Ceramic series from this time period are widespread and represent some of the most common ceramic material recovered regionally in Glover's YRSPS (2012). This phase represents the peak occupation of the Yalahau region. Supporting the ceramic data is the presence of the Megalithic architectural tradition at a number of sites in the region. This is a distinct architectural tradition dating to the Late Preclassic and Early Classic periods and is present elsewhere in the northern Maya lowlands (Glover 2012; Mathews 2001; Taube 1993).

Following the Terminal Preclassic apogee in a population is a regional abandonment during the Classic Period. The lack of Classic period diagnostic architecture and more importantly the lack of polychrome pottery and slate wares in the region support this interpretation (Glover 2012). The primary exception during this time period seems to be at the island port site of Vista Alegre, where the occupation extends into the Classic period and seemingly peaks in the Terminal Classic. The population boom during the Late/Terminal Preclassic period is not seen by Glover or others (Amador 2010; Glover 2012) as indicative of large-scale migration into the area. Rather, the ceramic data point to a build-up of a local Chicanel ceramic sphere from an earlier Nabanche tradition (Rissolo et al. 2005).

Following widespread depopulation of the region between A.D. 100 and 400, reoccupation begins around A.D. 1100/1200 (Amador 2010) and continues until the Contact period (Andrews 2002, Andrews and Jones 2001). Postclassic ceramic material was present at 24 of 35 sites where ceramic materials were collected as part of Glover's YRSPS (Glover 2012), indicating a broad reoccupation. Significantly, the primary architectural influence at this time period seems to stem from the East Coast as evidenced by sites like San Ángel (Gallareta Negron and Taube 2005), which has Postclassic period painted murals in a style identified to be affiliated with the East Coast and speaks to connections with the broader Mesoamerican world.

3.3 Relevant Archaeological Research

Archaeological research in northern Quintana Roo has a sporadic but long history. Investigations by Ramos (1946) and Sanders (1955) revealed the presence of archaeological remains at sites throughout Quintana Roo, including the Yalahau region. Analysis of the historical political geography of Yucatan by Ralph L. Roys has also contributed to our understanding of the region (Andrews 1984; Roys 1957). More recently the research of Karl Taube and Scott Fedick took place under the umbrella of the Yalahau Region Human Ecology Project (YRHEP).

The YRHEP was initially led by Scott L. Fedick and Karl Taube (Fedick and Taube 1995). Subsequently, Fedick and Jennifer Mathews directed the project (Fedick and Mathews 2005). Taube (1993) examined the megalithic architectural tradition within the Yalahau region, a topic revisited by Mathews (2001) and Glover (2006, 2012). The YRHEP worked at the site of Naranjal and subsequently at the El Eden wetlands and the site of T'isil, where the project documented the most densely occupied site known within the region.

Other research from the Yalahau region includes Mathews' work Radiocarbon dating architectural mortar from the site of El Naranjal (Mathews 2001), Sorensen's examination of Late Preclassic site planning principles at T'isil (Sorensen 2010), Wollwage and colleagues who examined the depositional chronology of the cenote at the center of the site of T'isil (Wollwage et al. 2012), Shaw and Mathews' edited volume *Quintana Roo Archaeology* (Shaw and Mathews 2005) includes contributions from a number of scholars working in the Yalahau region. Recent research by the Proyecto Costa Escondida, directed by Glover and Rissolo, has focused on coastal sites like Vista Alegre (Glover, Rissolo, and Mathews 2011; Glover and Rissolo 2010; Glover et al. 2012).

The dissertation research of Dominique Rissolo (2003) further confirmed the importance of cave resource utilization for the people of the Yalahau region. In this project, Rissolo surveyed anthropogenic impacts in caves within the Yalahau region, and found evidence of similar activities as

found elsewhere within the Maya region. As established above, caves play an important role in Maya culture across the Maya region, the confirmation of the importance of these features within the Yalahau region was crucial in determining methods to be used.

The dissertation research of Jeffrey Glover, the Yalahau Region Settlement Pattern Survey, provides one of the two bases for this research (Glover 2006). In that project, Glover identified 104 sites within the Yalahau region. This total number includes sites previously known (n=52) and the 52 sites that he identified during his dissertation research. This database of locations served as the basis upon which this thesis was built. Glover broke the regional sites down into a simple 4 rank hierarchy, Yalahau rank 1 being the largest regional sites, and Yalahau rank 4 being the smallest. In that study, Glover identified sites primarily through the use of informant-based survey. This method has advantages and disadvantages, but the primary qualification for this form of survey is that effectiveness is directly proportional to the amount of time spent in a given area of the landscape. What this means is that the effective limits of the survey are the areas where the informants you have contacted regularly frequent. There are, however, still portions of the Yalahau region that remain unexplored to archaeologists due to the lack of local guides. This is a critical issue that remote sensing can help remedy, and I return to it below.

The Yalahau Region Wetland Survey, the dissertation project of Daniel Leonard (2013) provides a valuable set of additional site locational information. This survey focused on the modifications to the region's wetlands by the ancient Maya, as well as the relationship between sites and the wetlands. In addition to many rock alignments within the regional wetlands that Leonard surveyed, he registered five new sites.

3.4 Conclusions

The site location information provided in these dissertations as well as the rich contextual information available from other research in the area made this thesis research possible. The

research questions addressed by this thesis stem from what is now more than 30 years of ongoing research into the Yalahau region, as discussed above. Building upon the work of Glover (2006) and Leonard (2013), I seek to add to the growing settlement pattern data within the Yalahau Region. The fractured limestone geography (Tulaczyk et al. 1993) has produced regional wetlands that have a demonstrated significance for prehistoric peoples (Beach et al. 2009; Dunning et al. 1998; Fedick et al. 2000; Leonard 2013). Understanding the pattern of human use and habitation of the landscape of the Yalahau is critical for interpreting answers to questions that have arisen with regards to the sociopolitical organization of the region. The primary question this thesis seeks to address is: What undocumented sites still exist within the Yalahau Region? There are a number of angles from which this question could be answered, as demonstrated by the location of five new sites during the course of Leonard's separate, wetland focused work without the benefit of remote sensing anomaly detection (Leonard 2013). Other valid methods would include survey by transects (Ford and Fedick 1992) or through randomized sampling (Garrison 2007). However, given this question and, bearing in mind my interest in and discussion of GIS analysis for the purposes of archaeological research, I decided to approach these questions from a Remote Sensing angle, incorporating the GIS data from the YRSPS (Glover 2006) and the YRWS (Leonard 2013). The specific remote sensing methods utilized to answer this question are described in the next chapter.

4 Methods

As discussed in more detail above (see Chapter 2), this chapter outlines the specific remote sensing *chaîne opératoire* (Doneus and Kuhtreiber 2013) utilized in this research – the middle range theory, as it were, allowing the construction of interpretations from heterogeneous sources of information. In the following sections I address data collection and data processing for each of the remote sensing systems utilized for this thesis. Within Section 4.1 I examine Geocye-1, followed by

Landsat. Within the elevation section I evaluate Airborne LiDAR and Shuttle Radar Topography Mission (SRTM) derived DEM's. For each of these systems, I address what is detected as well as how the system acquires its data. I discuss data availability and access restrictions as well as post-processing methods utilized to analyze the data from each system. Also critical to understanding the limitations of this thesis is an understanding of the limits of coverage for remotely sensed data. To that end each data set used is presented with relevant specific scene information. In section 4.3 I bring these aspects together and discuss the limitations of the selected methods.

In the case of Yalahau region, research is only beginning to integrate remotely sensed data with research questions. For the purposes of this study, the primary use of remote sensing is in supplementing and validating regional survey data. To this end, as discussed in Chapter 2, situating human activity in the Yalahau region requires acknowledgement of the importance environmental factors play in decisions related to human habitation - as well as the acknowledgment of the significance of the impacts that human activity can have on the environment. With this in mind, for multispectral imagery both GeoEye-1 and Landsat were selected. For elevation SRTM and Airborne LiDAR were the chosen platforms. The reasoning behind these selections is given in their respective sections below.

4.1 GeoEye-1

The geospatial imagery company Digital Globe has a great deal of multispectral coverage available – though the frequency of repeat coverage can be irregular. For this thesis I applied for and received an imagery grant from the Digital Globe Foundation. In applying for this grant I had to make certain decisions. The economic (and physical data storage) realities did not allow for the request of all imagery for the Yalahau region from every satellite operated by Digital Globe. I did request this initially and it was, as expected, rejected – however the narrative associated with my application prompted them to suggest that I restrict the area requested and that I pick which satellite

passes I was interested in – with the promise of acceptance. I based the area selection on a cross section of the various microenvironments and the presence of known sites – as well as imagery availability and percentage of cloud cover (Figure 5). In the end I selected scenes from the GeoEye-1 satellite, which has Near Infrared, Red, Green and Blue and Panchromatic bands and has approximately 45 cm pixel resolution. Because the spatial coverage of this data set is limited, and the repeat coverage sporadic, the ability to detect undocumented archaeological remains with this sensor is also limited; a point I make more clearly below. The high spatial resolution means smaller, more detailed scenes. Lesser spatial coverage and less frequent repeat coverage make it difficult to obtain the single scene broad area coverage free of clouds. Lower spectral resolution but higher spatial detail makes it more difficult seek out spectral signatures. These limitations mean that this sensor was not used for the primary purpose of this thesis – detecting undocumented sites – and will not be addressed with the results in Chapter 5 as a result.

Table 2 - GeoEye-1 Scenes used for this thesis

Satellite	Date	Scene Identifier
GeoEye-1	February 14, 2011	162658
GeoEye-1	June 25, 2013	163002
GeoEye-1	April 23, 2012	163827

4.2 Landsat

While waiting on the results of the application to the Digital Globe Foundation, I began working through historic Landsat imagery trying to find scenes free of cloud cover to use as a baseline. The 16 day per satellite repeat coverage of the Landsat system offered by LANDSAT 7 during the early years of that satellite provided a welcome contrast to the often cloud filled one-off scenes available from commercial providers. The more complete picture afforded by LANDSAT comes at the cost of spatial resolution. Landsat 7 and 8 have 30 m pixel resolution for the bands of interest. The higher spatial resolution but “only” 4 bands of the GeoEye-1 satellite can be

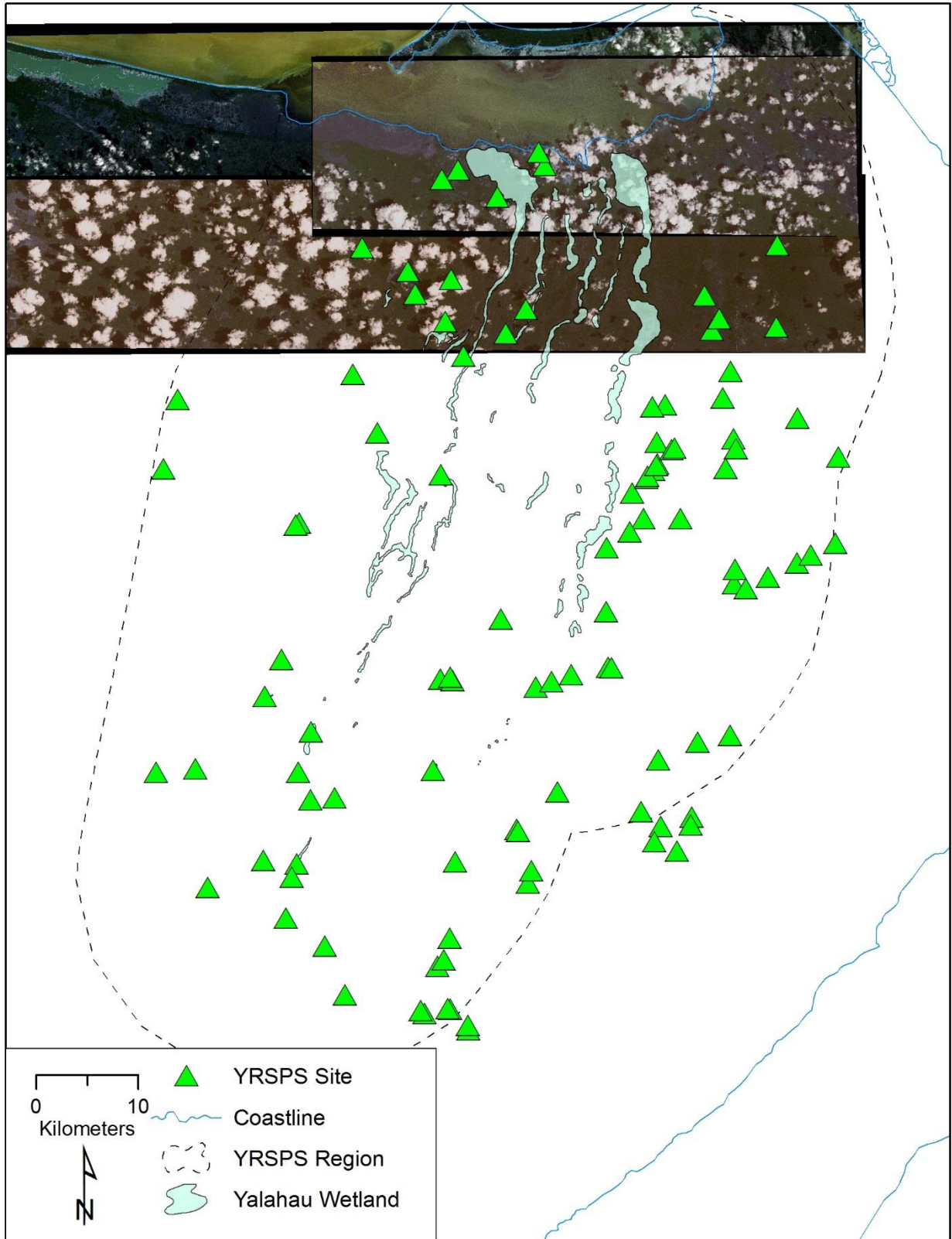


Figure 5 - GeoEye-1 Coverage

conceptualized in contrast with the broad spectral coverage of Landsat sensors. Bands are ranges of light that can be detected by a given sensor. Red, Green and Blue bands correspond with those colors in the visible spectrum. Other ranges like near infrared are beyond human vision. A system that has more bands can detect more ranges of light. Landsat data is available for free through the United States Geological Survey (USGS). The charts below depict the primary bands used with the LANDSAT Sensors (after http://landsat.usgs.gov/band_designations_landsat_satellites.php).

Table 3 - Bands Utilized

Landsat 5	Landsat 7	Landsat 8
Band 1 – Blue	Band 1 –Blue	Band 2 –Blue
Band 2 – Green	Band 2 –Green	Band 3 – Green
Band 3 – Red	Band 3 – Red	Band 4 – Red
Band 4 – Near Infrared	Band 4 – Near Infrared	Band 5 – Near Infrared
Band 5 – Middle Infrared 1	Band 5 – Middle Infrared 1	Band 6 – Middle Infrared 1
Band 7 – Middle Infrared 2	Band 7 – Middle Infrared 2	Band 7 – Middle Infrared 2

Table 4 - Landsat Scenes used for this thesis

Satellite	Date	Scene ID
Landsat 5 TM+	April 17, 1984	LT501904519841
Landsat 5 TM+	January 14, 1985	LT501904519850
Landsat 7 ETM+	October 28, 1999	LE701904519993
Landsat 7 ETM+	April 14, 2003	LE701904520031
Landsat 8 OLI	April 20, 2014	LC801904520141
Landsat 8 OLI	December 16, 2014	LC801904520143
Landsat 8 OLI	February 11, 2015	LC801804620150

4.3 Tasseled Cap

It was at this time that I learned about the Tasseled Cap processing method (Kauth and Thomas 1976) employed by Hixson (2013) near Chunchucmil to locate undocumented sites. Based on Hixson’s successes, this method might well produce similar results in Yalahau. This methodology is a form of principle component meta-analysis (Baig et al. 2014; Crist and Cicone 1984; Hixson 2013; Huang et al. 2002; Kauth and Thomas 1976). This method uses a predefined algorithm to extract subtle categories of pixels that are “brightness”, “greenness” and “wetness”. Each of these categories takes as input all the bands of the LANDSAT sensor except the thermal infrared one, and

in the case of Landsat 8, the coastal aerosol band. It processes them, ostensibly to extract the desired principle component in a grayscale image. This operation, with all the bands as input, is performed three times - once for each of the principle components. By taking those three components, and compositing them together as Red, Green and Blue bands – with brightness being red, greenness being green and wetness being blue. Figure 6 illustrates how each band of spectral data from the Landsat satellite contributes to each of the three principle bands of a tasseled cap, brightness, greenness and wetness.

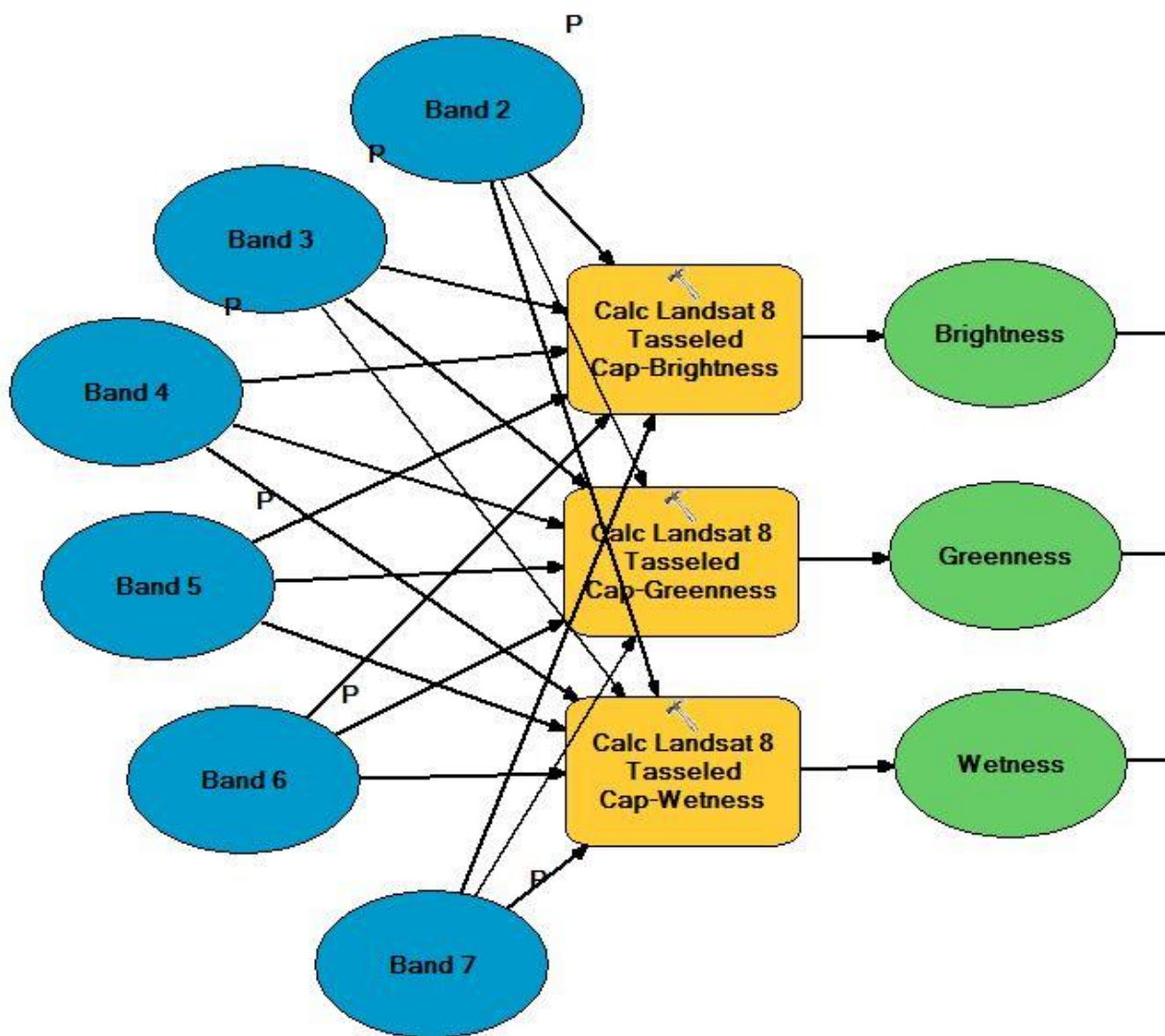


Figure 6 - Tasseled Cap Diagram (after Daniels 2012:15)

The calculation of each of the three bands can be expressed as a function, with each value in each raster band multiplied by a coefficient and then added to the other bands. For different satellites, the calculated coefficient values differ (Baig et al. 2014; Crist and Cicone 1984; Huang et al. 2002; Kauth and Thomas 1976). Building on the Esri ArcMap Model builder toolbox provided by Daniels (2012) for the creation of tasseled cap images – I added the capability to produce tasseled cap results from Landsat 8 imagery – based on the coefficients provided by Baig et al. (2014). The tables below illustrate the tasseled cap coefficients used for various satellite sensors.

The coefficient values for the creation of the tasseled cap raster via the model diagramed above were ascertained by calibrating the Landsat sensor to a very well ground-truthed target area for the calibration of the brightness, greenness and wetness metabands from the discrete spectral bands of the Landsat sensor. Essentially, this method is a specialized pre-calibrated version of principle component analysis, with the variation between bright green and wet bands calibrated to reflect something which in theory meaningfully reflects what is on the ground. As I discuss below, based initially on the work utilizing tasseled cap at Chunchucmil discussed earlier (Hixson 2013), this method did indeed prove to be useful in the location of undocumented sites in the Yalahau region.

Table 5 - Landsat 5 Tasseled Cap Coefficients (Crist and Cicone 1984:257)

TABLE II
THEMATIC MAPPER TASSELED CAP COEFFICIENTS
(present configuration—see text for details)

	TM Band					
<u>Feature</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>7</u>
Brightness	.3037	.2793	.4743	.5585	.5082	.1863
Greenness	-.2848	-.2435	-.5436	.7243	.0840	-.1800
Wetness	.1509	.1973	.3279	.3406	-.7112	-.4572
Fourth	-.8242	.0849	.4392	-.0580	.2012	-.2768
Fifth	-.3280	.0549	.1075	.1855	-.4357	.8085
Sixth	.1084	-.9022	.4120	.0573	-.0251	.0238

Table 6 - Landsat 7 Tasseled Cap Coefficients (Huang et al. 2002:1744)

Table 2. Tasseled cap coefficients for Landsat 7 ETM+ at-satellite reflectance.

Index	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Brightness	0.3561	0.3972	0.3904	0.6966	0.2286	0.1596
Greenness	-0.3344	-0.3544	-0.4556	0.6966	-0.0242	-0.2630
Wetness	0.2626	0.2141	0.0926	0.0656	-0.7629	-0.5388
Fourth	0.0805	-0.0498	0.1950	-0.1327	0.5752	-0.7775
Fifth	-0.7252	-0.0202	0.6683	0.0631	-0.1494	-0.0274
Sixth	0.4000	-0.8172	0.3832	0.0602	-0.1095	0.0985

Table 7 - Landsat 8 Tasseled Cap Coefficients (Baig et al. 2014:428)

Table 2. TCT coefficients for Landsat 8 at-satellite reflectance.

Landsat 8	(Blue)	(Green)	(Red)	(NIR)	(SWIR1)	(SWIR2)
TCT	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7
Brightness	0.3029	0.2786	0.4733	0.5599	0.508	0.1872
Greenness	-0.2941	-0.243	-0.5424	0.7276	0.0713	-0.1608
Wetness	0.1511	0.1973	0.3283	0.3407	-0.7117	-0.4559
TCT4	-0.8239	0.0849	0.4396	-0.058	0.2013	-0.2773
TCT5	-0.3294	0.0557	0.1056	0.1855	-0.4349	0.8085
TCT6	0.1079	-0.9023	0.4119	0.0575	-0.0259	0.0252

4.4 Shuttle Radar Topography Mission (SRTM)

The Shuttle Radar Topography Mission was an attempt to build a global digital elevation model using Synthetic Aperture Radar flown on the Space Shuttle by NASA (Bamler 1999; Koch and Heipke 2001; Koch et al. 2002). The digital elevation data from this mission is freely available from the USGS Earth Explorer Platform (USGS.gov/earth_explorer). SRTM has been used previously in the region (Fedick 2014; Glover 2006; Leonard 2013). Because of the limited area covered by the LiDAR provided by INEGI, the SRTM data are still the only available elevation data for much of the Yalahau region (Figure 7).

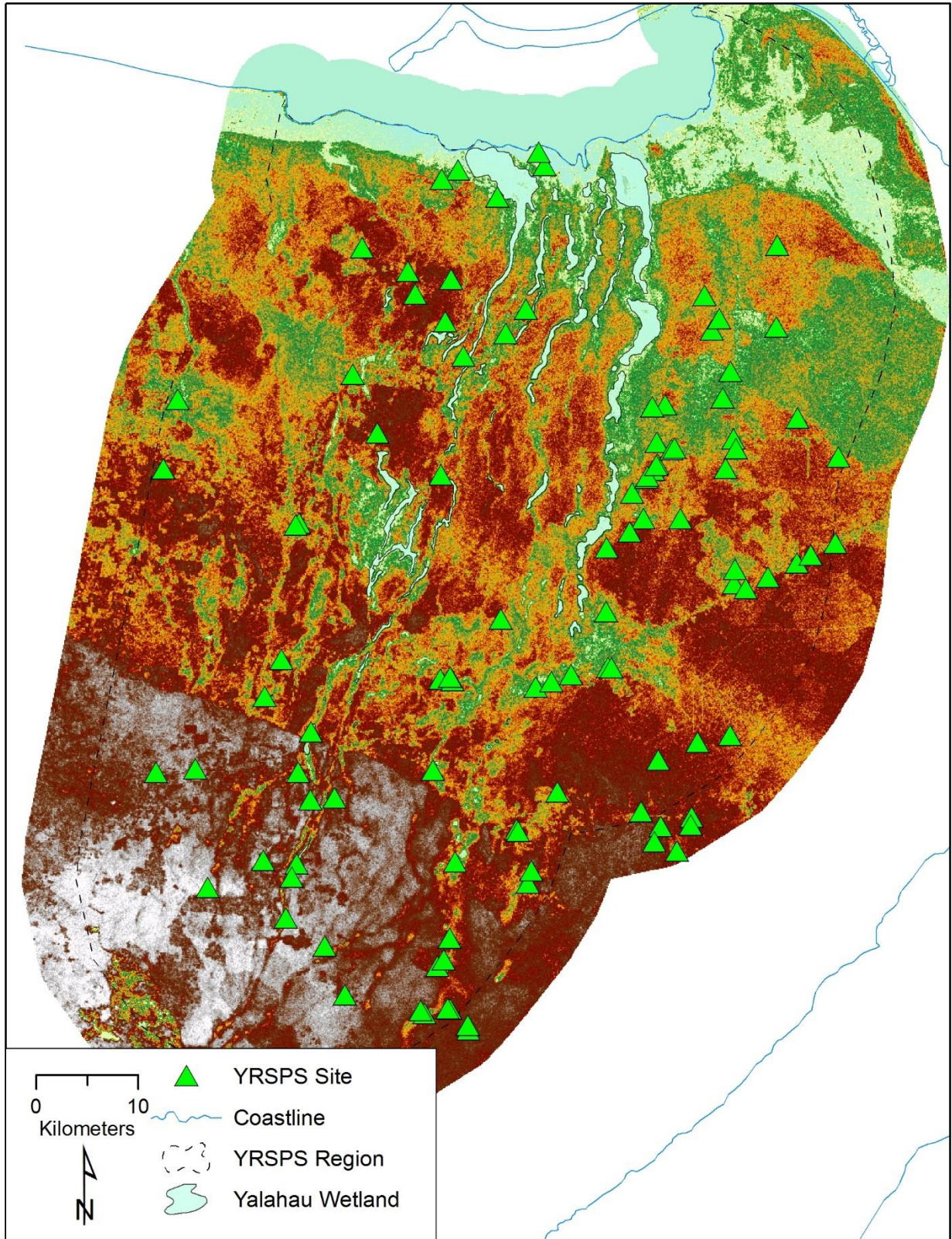


Figure 7 - SRTM DEM (USGS/NASA)

4.5 Airborne LiDAR

The availability of a state maintained LiDAR (Light Detection and Ranging, after Opitz and Cowley 2013) data set for a portion of our study area came as some surprise, but the *Instituto Nacional Estadística y Geografía* kindly provided access to one of the first such data sets collected in Mexico (Instituto Nacional de Estadística y Geografía). LiDAR utilizes electronic distance measurement or phase variance to ascertain the direction and distance of a given point from the LiDAR device. When deployed on an aircraft, LiDAR also becomes known by another acronym – ALS (Airborne Laser Scanning). This greatly increases the speed of coverage available, if the data is accessible. The LiDAR data available for the Yalahau region does not cover the entire study area (Figure 8) but was focused on the heavily populated Caribbean coastal area.

INEGI delivered the data in three forms, two digital elevation models (DEMs) and a *nube de puntos* (point cloud). Full waveform LiDAR data (Doneus et al. 2008) was not available from INEGI. The Digital Elevation Models derived from the LiDAR data were labeled *superficie* (surface) and *terreno* (terrain). These elevation models have a resolution of ten meters per pixel. According to the metadata provided with the data, the superficie DEM was generated based on the raw point cloud with no vegetation or human build structures removed. The terreno DEM was post-processed to automatically remove all vegetation and structures. Due to the known limited utility of large footprint LiDAR for archaeology (Chase et al. 2011:390) the point cloud provided by INEGI was not reprocessed. Large footprint data like that for the northern part of Quintana Roo has a density of much less than 1 point per meter. By contrast, the small footprint LiDAR data obtained by the Chase's at Caracol is exceptional at identifying structures (See Figure 9) even through dense forest canopy, with a point cloud density much greater than one point per meter.

The previously mentioned LiDAR based work at Caracol (Chase et al. 2011, 2012; Chase, Chase, et al. 2014) does represent a fundamental improvement in the ability to rapidly survey large

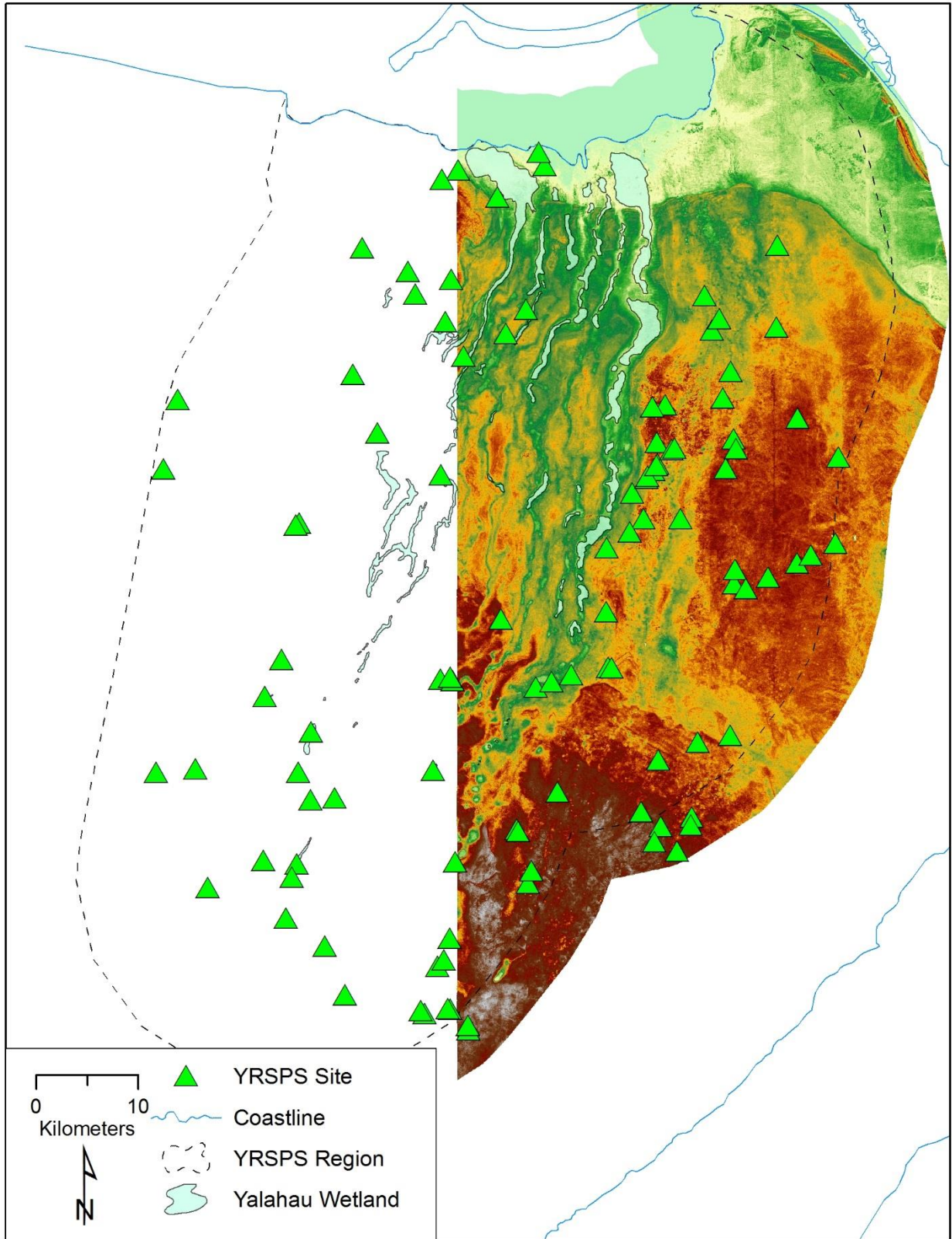


Figure 8 - LiDAR Terreno DEM (INEGI)

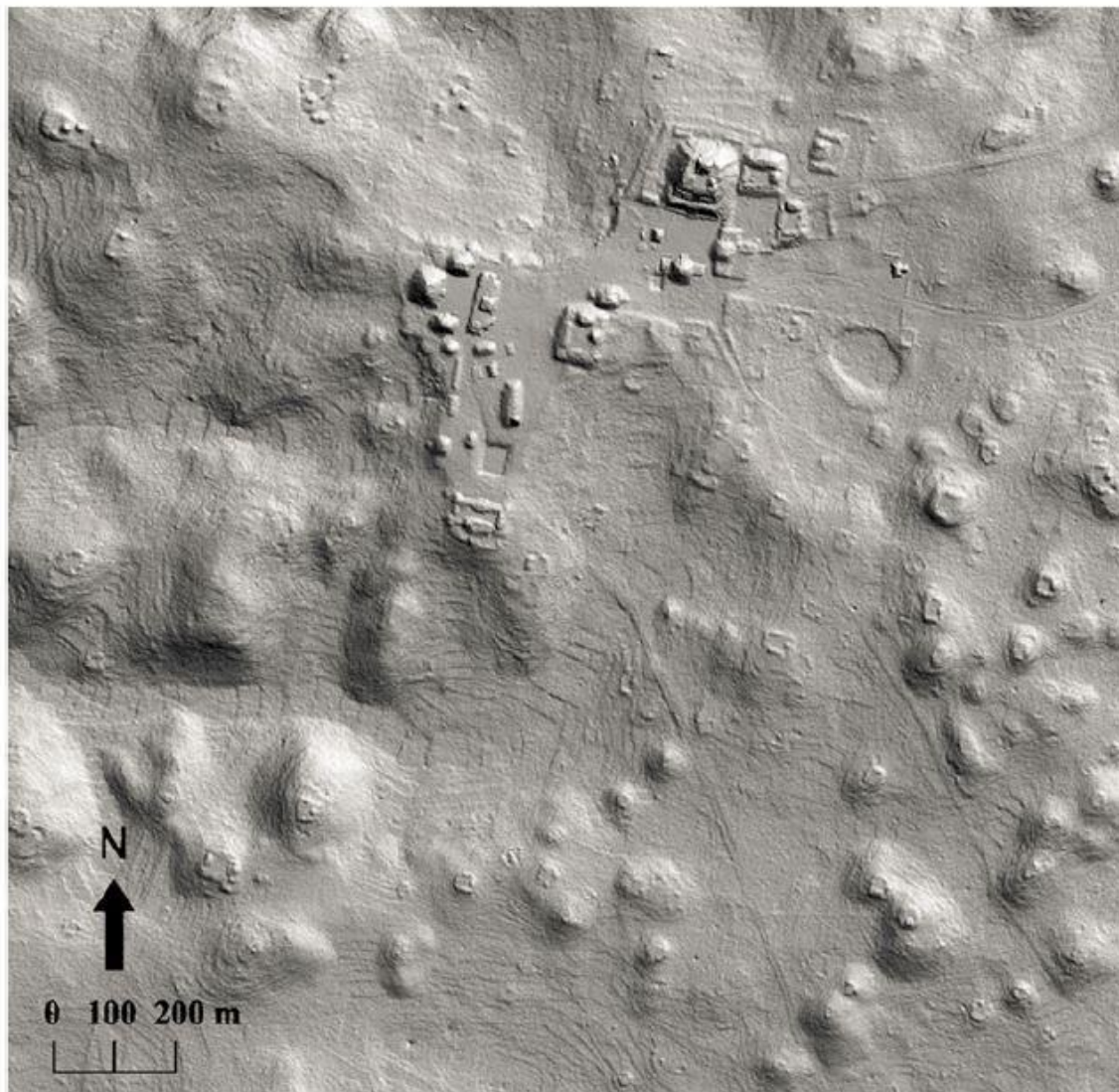


Figure 9 - Example Small Footprint LiDAR (Chase et al. 2012:12918)

segments of the earth's *surface* quickly. However, there are significant questions about the true efficacy of surface survey in Mesoamerica. Johnston (2002) and Sweely (2005) in particular offer interesting perspectives on this question. Johnston examined the classification and terminology surrounding surface survey and surface architectural detection, elucidating categories of visible, hidden and invisible architecture – separating the concept of protrusion from visibility. Johnston clarifies that a hidden structure which is nonetheless protrusive from the earth's surface can

eventually be detected by increasing the intensity of survey, while invisible structures can never be detected from the surface alone, but will require ground disturbing activity or at least subsurface sensing to detect. LiDAR does represent what is currently the most intensive survey method possible without having to result to costly stripping excavations.

Sweely successfully utilized electromagnetic resistivity to guide excavation in the search for buried dwellings and other features invisible from the surface. Unfortunately, geophysical methods are not equally applicable or efficacious around the world, or even throughout Mesoamerica (e.g., Kvamme 2003; Sweely 2005). Further, variable soil depths in the already shallow northern lowlands are even lower within the Yalahau region, meaning surface architecture may date to the Preclassic (as early as 700 B.C.), so buried structures are less of a concern specifically within the Yalahau region. Neither LiDAR results, nor the middle range theory used to situate such results differ significantly from conventional archaeological survey used to assess settlement in Mesoamerica – claims of total coverage with regards to remote sensing and settlement should be examined closely. The questions posed by Johnston and Sweely with regards to the presence of invisible dwellings or structures within the Maya are not resolved through the use of LiDAR remote sensing.

4.6 Topographic Position Index

The Topographic Position Index (TPI) method is one way of analyzing the position of sites on the landscape. At the simplest level, TPI assesses whether a given cell is above or below a neighborhood average – the size of which is variable (Weiss 2001). I applied TPI at variable distances to both the SRTM and Airborne LiDAR derived digital elevation models, as described above. While the application of TPI is subject to the specific topography in question (De Reu et al. 2013), the validity of the method for detecting potential below canopy karst openings has been established elsewhere in the world (Doctor and Young 2013; Kobal et al. 2015) as well as within the Maya area (Weishampel et al. 2011). This method has also been used to detect terracing in both the

Maya area (Hightower et al. 2014) and in Asia (Sas Jr et al.). However, this method was applied to much higher quality digital elevation models than those made available from the INEGI LiDAR or the SRTM data. Because the TPI only takes as input elevation data, the quality of that elevation data dictates the quality of the resultant TPI raster. TPI was also assessed for all known sites in the Yalahau region, as a corollary to Glover (2006), who analyzed the elevation of sites on the landscape. Rather than simply looking at the elevation – TPI allows one to assess a sort of qualitative status of the position of a given archaeological site on the landscape – whether it is on terrain which is higher or lower on average than the surrounding terrain. As Weiss (2001) points out, TPI is scale dependent, meaning it is suitable for multi-scalar analyses. TPI can assess this metric with a neighborhood reference of 10 meters or 10 kilometers.

4.7 Methodological Limitations and Concluding Thoughts

Previous attempts to remotely sense settlement within the Maya region have met with mixed success. Saturno and colleagues (2007) found great utility in using the IKONOS sensor to detect undocumented archaeological sites in the area immediately around San Bartolo, from major centers to smaller settlements. However, when Garrison and colleagues (2008) reapplied the techniques used by Saturno to the broader region, the results were much less useful. Garrison and colleagues (2008) attribute this difference in effectiveness to regional variation and temporal differences in the imagery. Further research by Hixson (2013) also supports this conclusion, although Hixson was dealing with Landsat imagery. Hixson found that only one image out of dozens showed any sign of a spectral signature in the area around Chunchucmil.

Because this thesis is a remote sensing project, the major limitation of this project is in the availability of data. Neither Landsat, nor GeoEye-1 has complete coverage of the Yalahau region free of cloud cover and the LiDAR coverage is limited as well. As this thesis relies upon multiple lines of evidence – including each of the remote sensing platforms as well as first hand survey and

second hand collegial reporting (made by peers working in the region) – the interpretative strength relies upon the agreement and coherence of multiple lines of evidence. It is towards these lines of evidence that I now turn in the next chapter.

5 Results

This thesis presents the results of a pilot study into the efficacy of remote sensing to both complement and enhance other methods of settlement pattern survey in Yalahau region of the northern Maya Lowlands. This chapter utilizes the following sources of site location data – the Yalahau Region Settlement Pattern Survey (Glover 2006) and the Yalahau Region Wetland Survey (Leonard 2013). Specifically, I developed and calibrated my understanding of the ways in which archaeological sites manifest in remotely sensed data using the data of the Yalahau Region Settlement Pattern Survey, cited above. The work of the Yalahau Region Wetland Survey has contributed in two ways – first in helping to understand the possible ways in which human activities in relation to the wetlands have developed over time, up to and possibly including the depopulation of the Yalahau region, as discussed in Chapter 3. Second, the Yalahau Region Wetland Survey identified a number of new sites in the region – three of which had already been marked as possible sites and candidates for field verification through my remote sensing results.

During the summer 2014 field season, I visited and verified the presence of prehistoric Maya structures at two such anomalous sites. As discussed in Chapter 4, despite, high resolution and useful visual and near infrared spectrum bands, GeoEye-1 did not prove to be useful for distinguishing patterns in the imagery useful for remotely detecting sites. As such, GeoEye-1 is not discussed further in this chapter, except where applicable as a base layer.

In sections 5.1 and 5.2, I address the use of digital terrain models from SRTM and Airborne LiDAR data sets for the detection of cenotes and other subsurface openings due to the sociocultural importance of these features in Maya culture. I utilize the Topographic Position Index (TPI) tool as

a possible model for the extraction of culturally significant cenote features. In section 5.3 I present the results of the use of LANDSAT data for the remote detection of archaeological features using the Tasseled Cap transformation in the Yalahau region, examining the YRSPS (Glover 2006) the YRWS (Leonard 2013) and this study, the Yalahau Region Space Settlement and Environment Project.

Table 8 shows the status of the YRSPS in the context of this project. Twenty-five of the 104 YRSPS showed signatures strong enough that I am reasonably certain I would have been able to identify their location based on the remotely sensed data. Twenty-seven of the 104 YRSPS sites were unable to be located by the remotely sensed data, either due to cloud coverage or due to the lack of a visible signature. Fifty-one YRSPS sites were located in terrain too disturbed to be confident of the presence or absence of a signature. The significance of these results I return to below.

Table 8 - Status of YRSPS Sites

Status	Number of Sites
Located	25
Not Located	27
Disturbed	51

5.1 LiDAR

As discussed in Chapter 4, the LiDAR data available for the Yalahau region (Figure 8) is not entirely suitable for the detection of structures. The coarse resolution and filtering algorithms used by INEGI can obscure site architecture. The, the analysis in this section presents the results of the assessment of the INEGI LiDAR data for the detection of prehistoric archaeological remains.

The two DEMs yield different results at different sites, likely due to differences in vegetative cover and effects from the filtering algorithm utilized in the production the DEM's. As discussed in

Chapter 4, the LiDAR point cloud were not reprocessed due to the low density of points. Figures 10 and 11 show the site of Kimin Yuk. The 1 m contour lines are from Glover's (2006:404) total station map of the major architectural features at the site. Figure 10 shows Kimin Yuk in the superficie DEM. Figure 11 shows the same site in the terreno DEM. The differences here are stark. Neither DEM captures the two *corchales* - east and west of the site core. The surface DEM does show elevation that appears to correspond with what was mapped by Glover. This detail is lost in the processing required to produce the terrain model; however, we should consider that this is by design – both architecture and vegetation are supposed to be removed in the production of the terrain model without regard to age.

While the structures can be seen within the superficie DEMs at both Vista Alegre and Kimin Yuk, Figures 12 and 13 show the island site of Vista Alegre overlaid on the superficie and terreno DEMs. Interestingly, in the terreno DEM the structure at Vista Alegre remains visible, though with much lower relief relative to with the surrounding terrain.

Figures 14 and 15, depicting the site of Ox Mul, exhibit an opposite signal from that seen at Kimin Yuk. At Ox Mul the site appears to be more visible in the terreno processed DEM, though the site still appears to be visible in the Superficie DEM. Despite this, it would be incredibly difficult to claim in any of the above images that the architecture that can be seen would be identified as such did we not already know that they were structures. The LiDAR DEM as provided by INEGI is unsuitable for reliably detecting surface architecture in the Yalahau region. There are however, other uses for the LiDAR data.

As discussed in Chapter 4, the Topographic Position Index (TPI) is a method that assesses whether a given pixel is above or below a neighborhood value, the size of which is determined by the researcher. TPI Rasters were calculated using the Land Facet Corridor tools in Esri ArcMap 10.1 (Weiss 2001) on the terreno digital elevation model. In this case, the neighborhood was set to

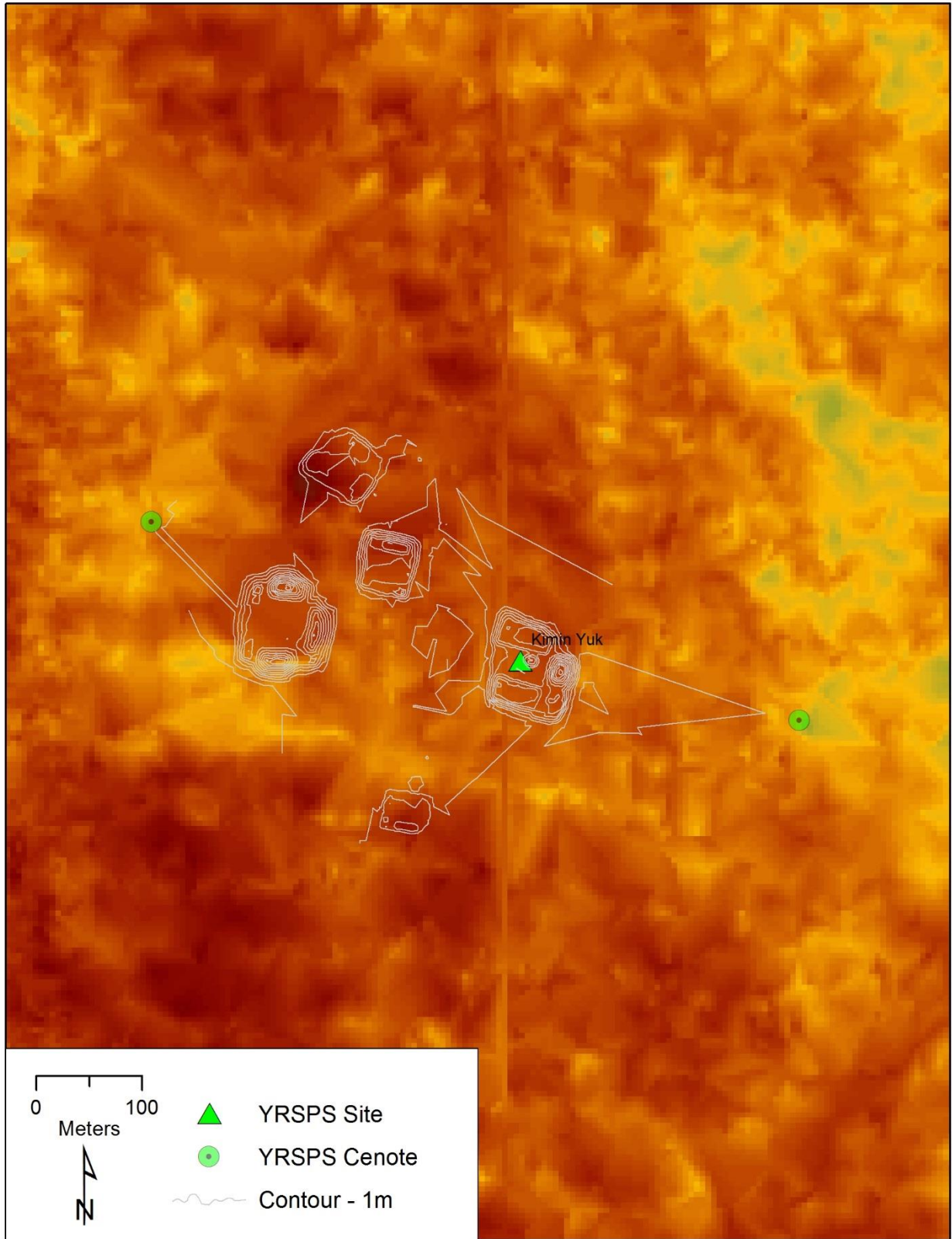


Figure 10 - Kimin Yuk 1m Contour, Terreno DEM

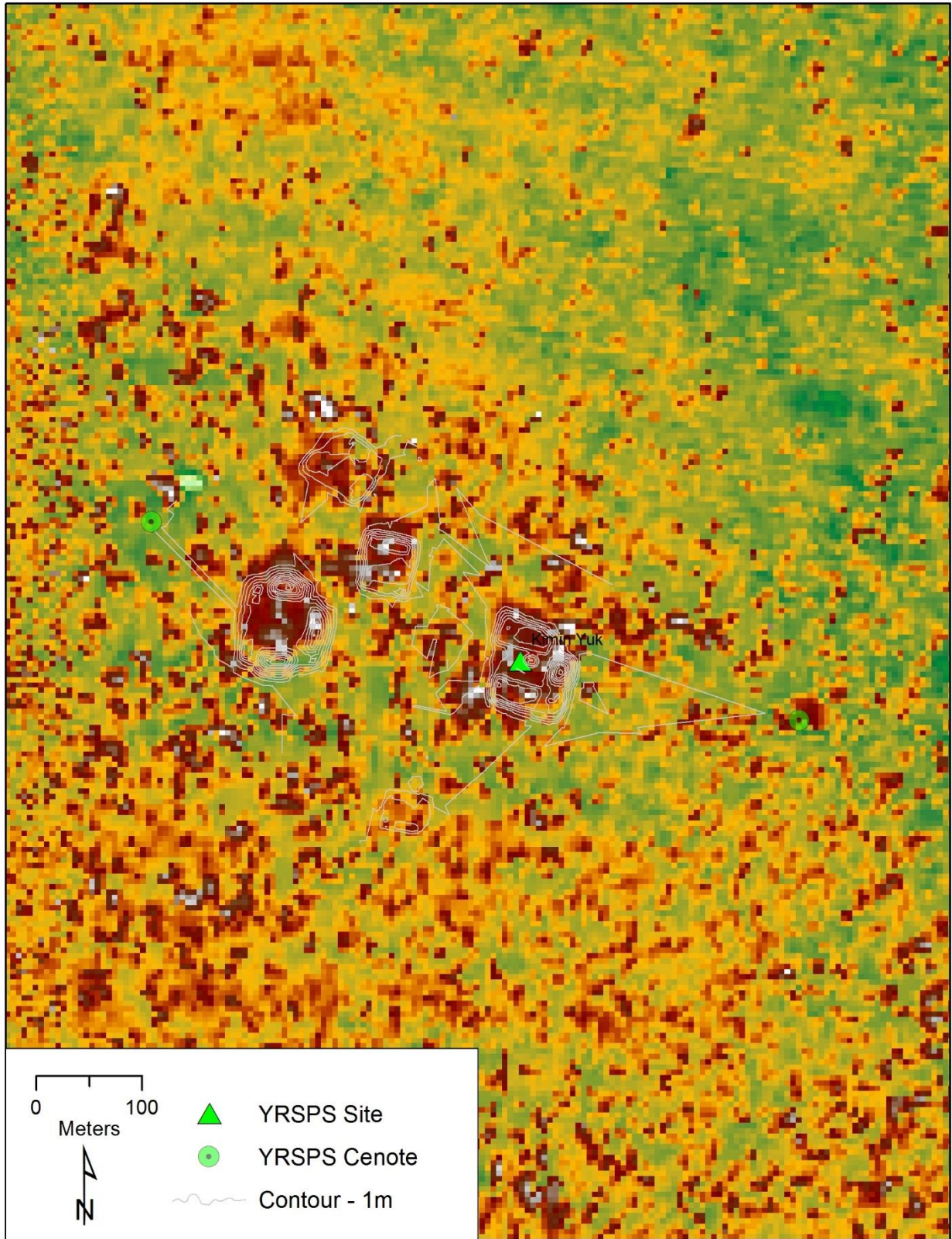


Figure 11 - Kimin Yuk 1m Contour, Superficie DEM

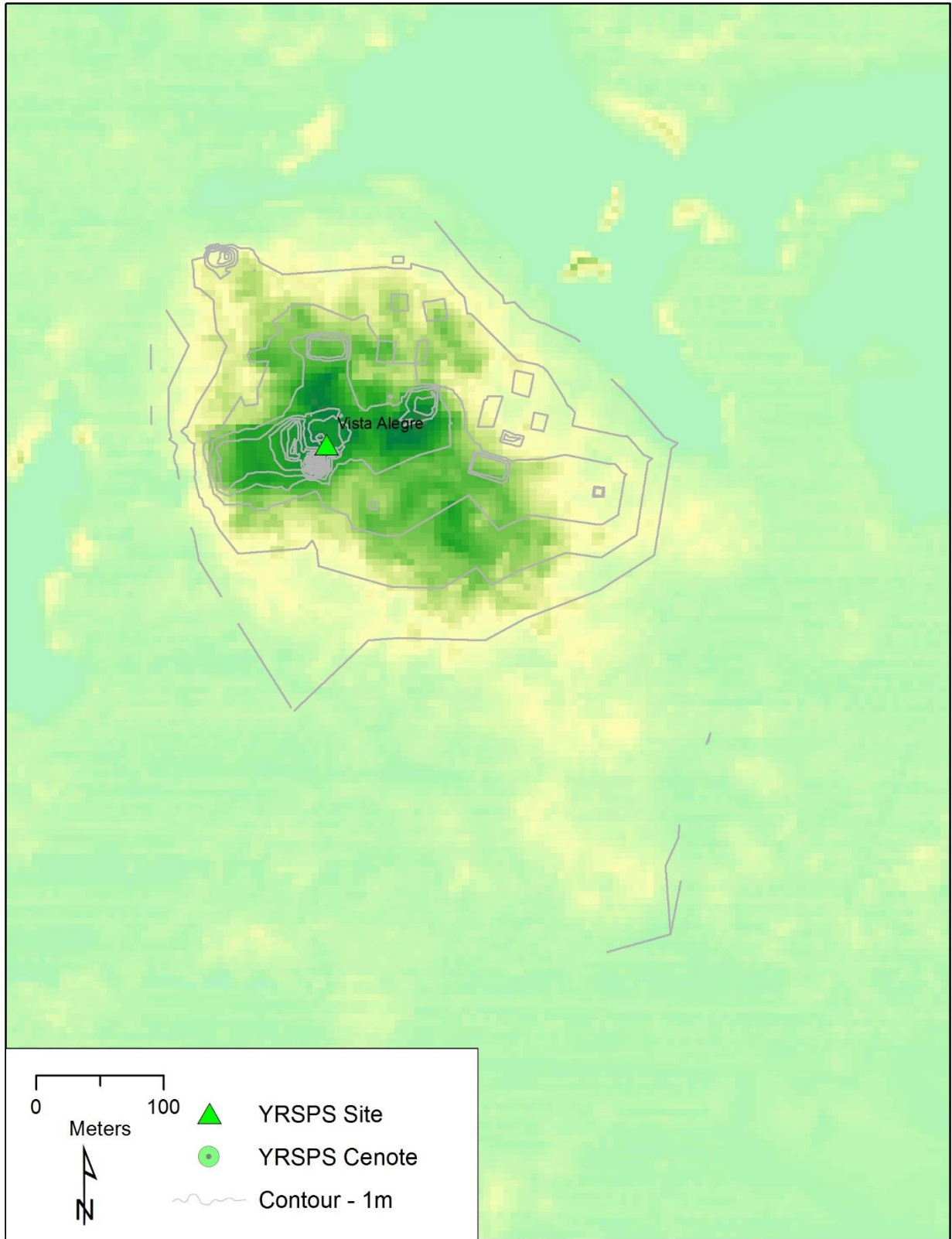


Figure 12 - Vista Alegre 1m Contour, Terreno DEM

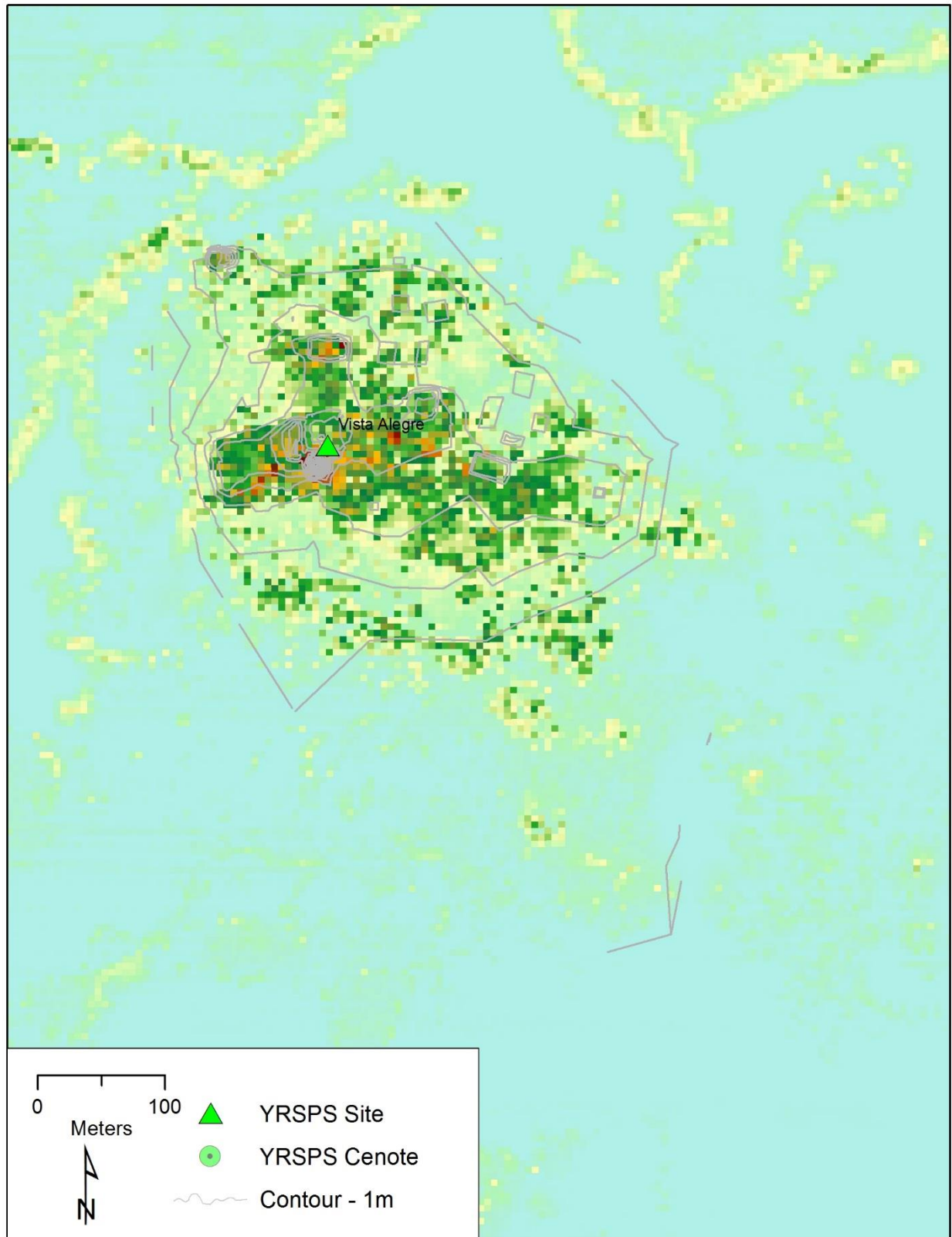


Figure 13 -Vista Alegre 1m Contour, Superficie DEM

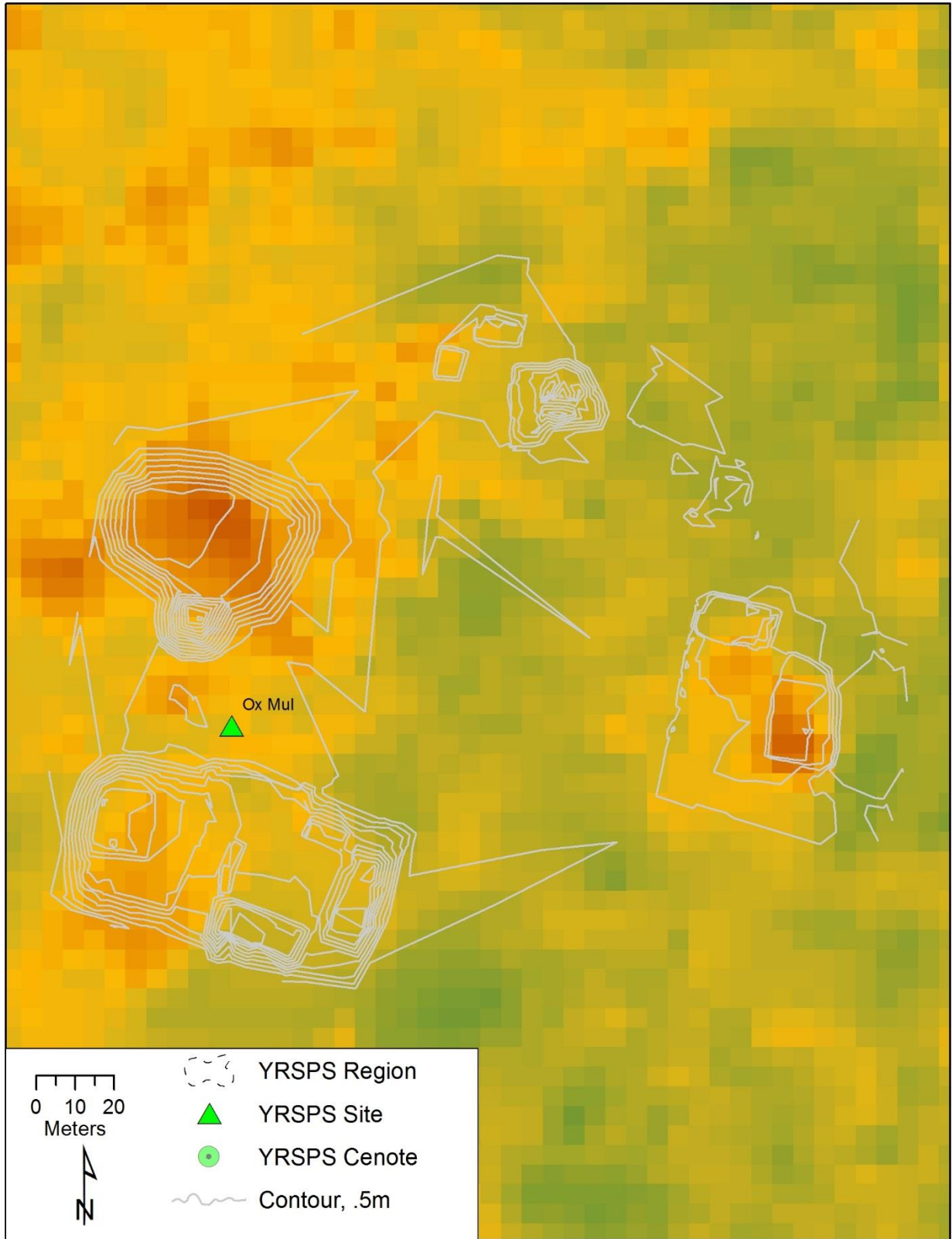


Figure 14 - Ox Mul .5m Contour, Terreno DEM

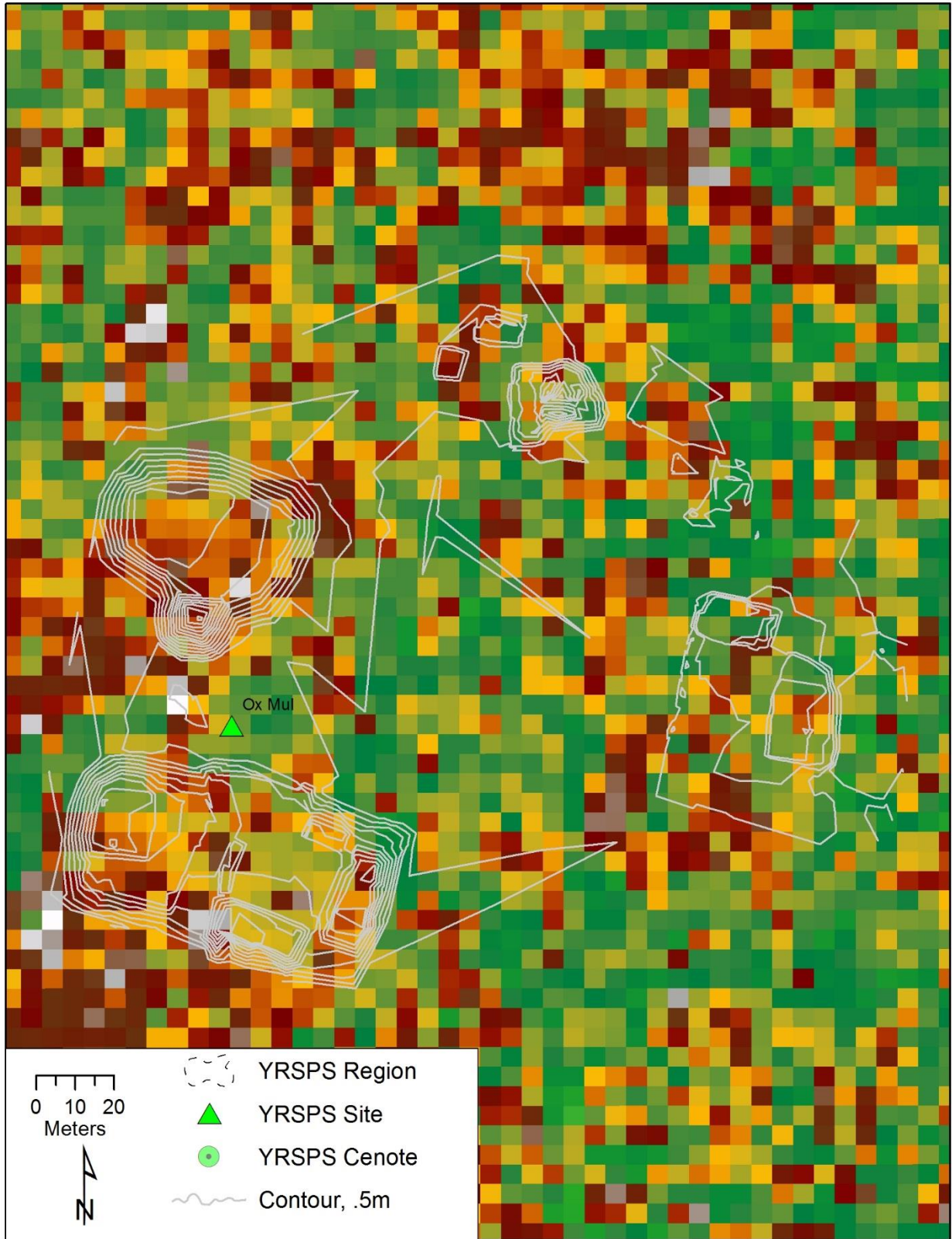


Figure 15 - Ox Mul .5m Contour, Superficie DEM

Circular and the range set to 200 meters. The purpose of this was to test whether or not TPI could be used to detect karstic features of interest – generally depressions such as *rejolladas* and *corchales* as well as proper *cenotes*, with water at the bottom.

Figure 16 is the terreno DEM of a known cenote. By extracting the values present in the TPI data, the TPI value associated with features of interest could be outlined. Figure 17 shows the same region classified with TPI. Figure 18 is the classified anomaly representative of the karstic feature of interest, based on the TPI value. The overall result of this operation is a map of locations likely to yield karstic depressions. Figure 19 shows a selection of the LiDAR terreno DEM along the eastern portion of the wetlands. Figure 20 shows the 200m neighborhood TPI and Figure 21 is the *classified* TPI with a circular neighborhood of 200 meters.

TPI also indicates the presence of an apparent feature rich zone, coincident with a zone containing a large number of sites. A corresponding feature free zone also exists within the regional wetlands (Figure 22). However, a combination of factors may have conspired to create this area as an artifact of the *chaîne ouverte* rather than a true effect. The relatively shallow water table (Fedick 2014; Leonard 2013) means that the water level (and the lowest elevation) in any karstic features forming in the wetland zone would present as shallow *lagunas*, with little to no surface relief making them undetectable by TPI, and is one possible explanation for the cenote free zone.

Of the 67 Cenotes recorded in the region by Glover (2006), 18 were not covered by the LiDAR. Of the 59 features within the LiDAR coverage 17 were identified using TPI. However, the lack of size data with regards to the cenotes in the YRSPS data hinders a more precise assessment of the efficacy of this method using that data. The resolution of the DEM means that smaller features would be difficult to detect. Figures 23 and 24 depict a further possible high-density zone further south. The primary efficacy of this method is in the location of undocumented karstic features

across the entire range of such manifestations in the Yalahau, including cenotes, rejolladas and corchales, which have been shown to have a variety of culturally significant associations.

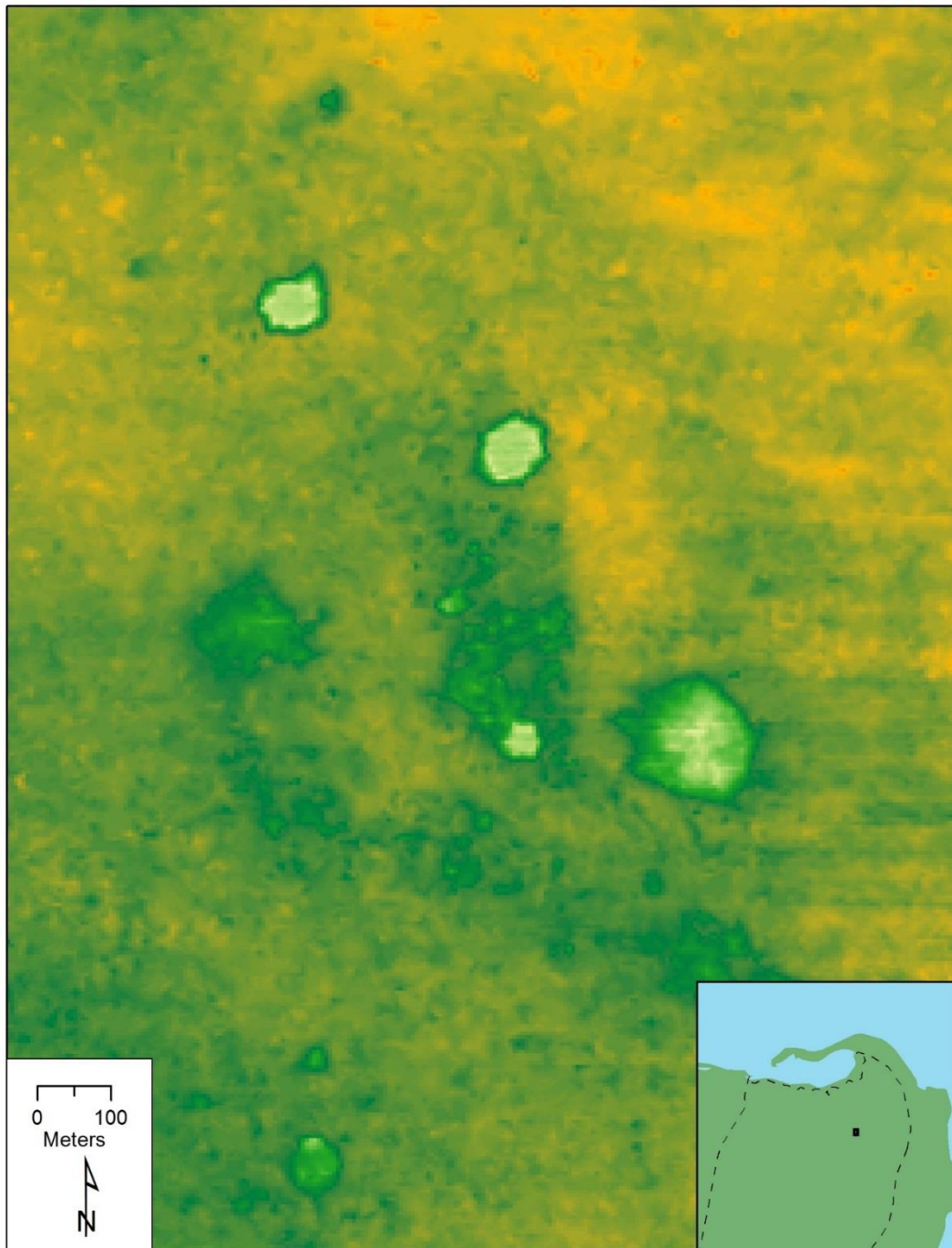


Figure 16 - Cenote Detail, Terreno DEM

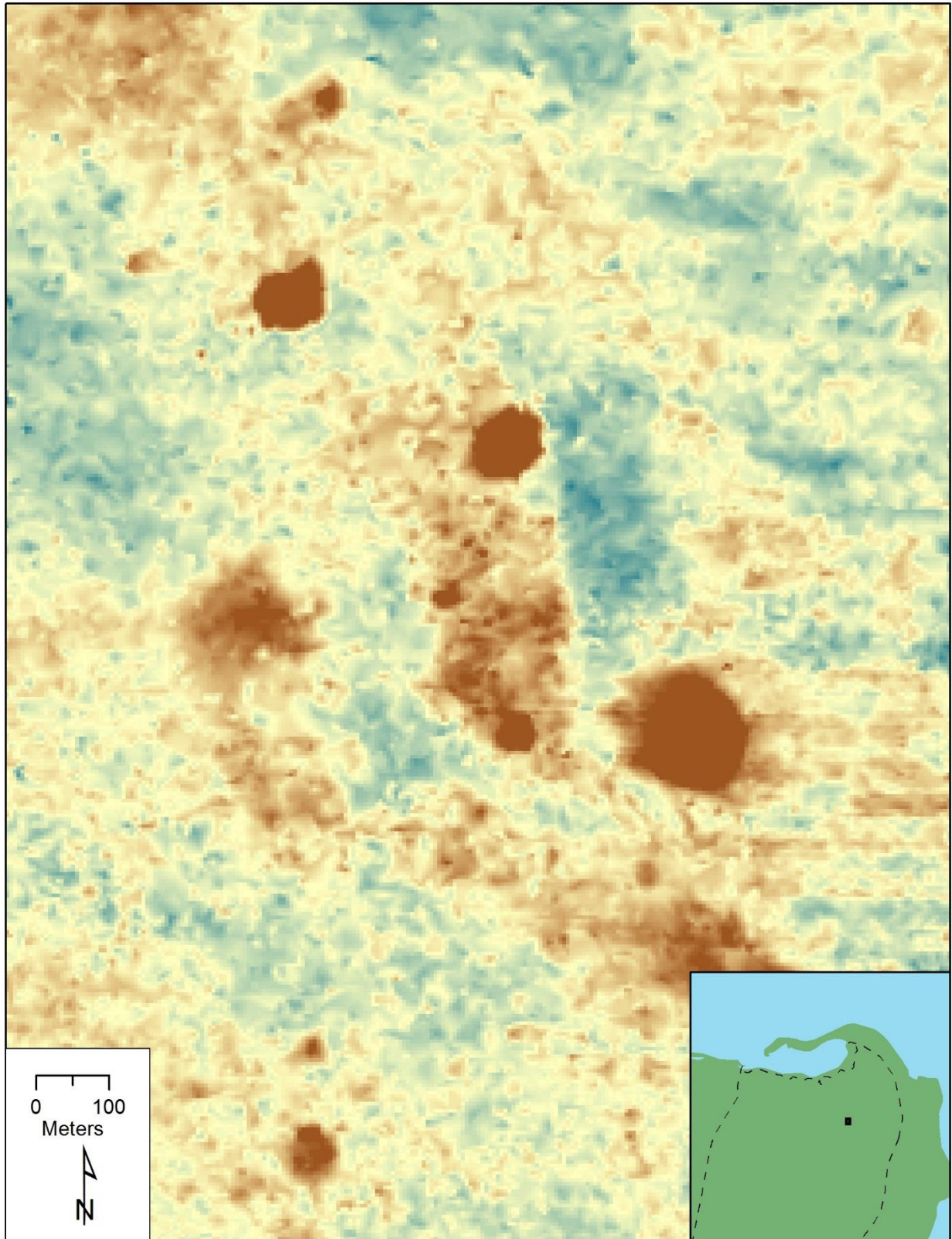


Figure 17 - Cenote Detail, TPI

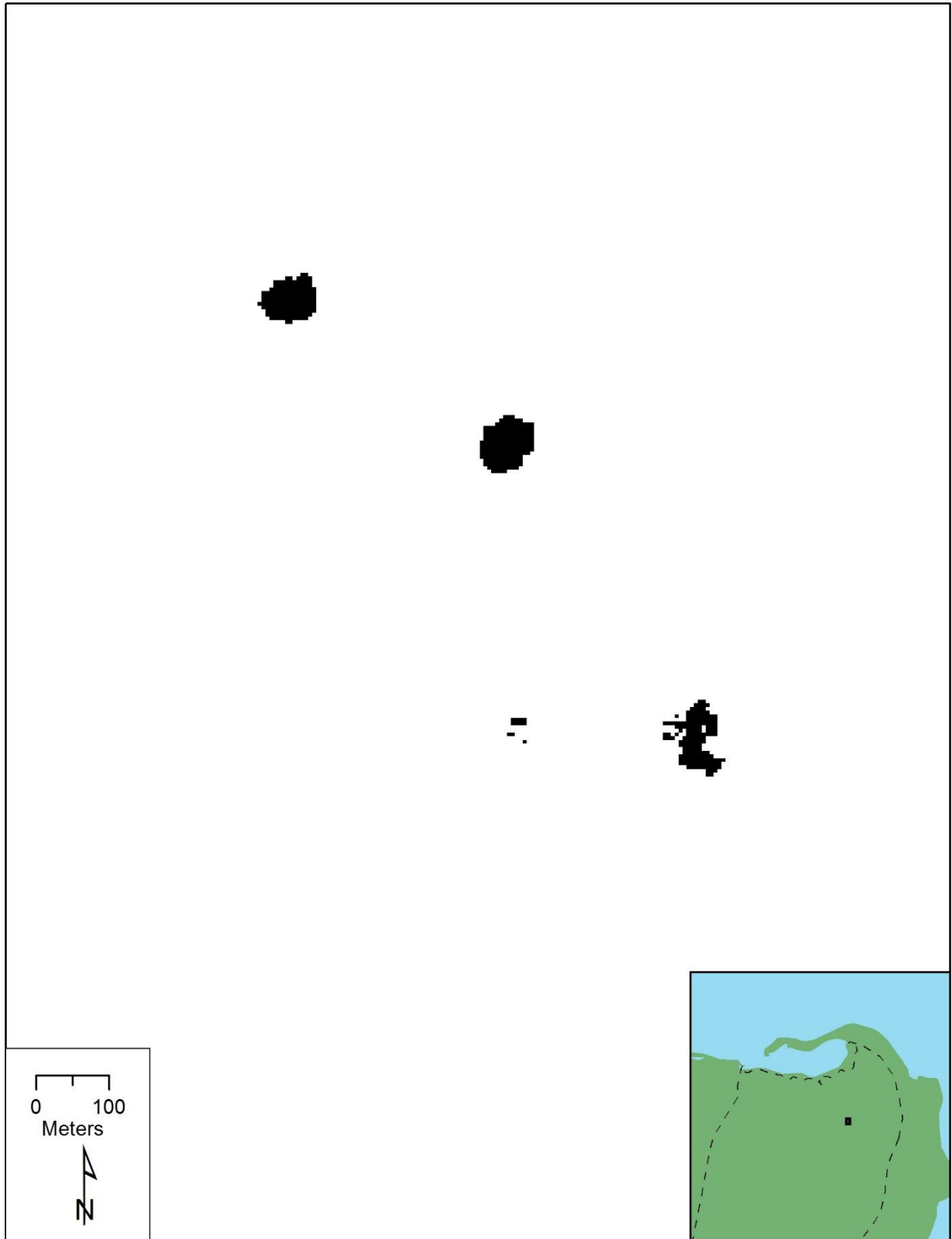


Figure 18 - Cenote Detail, Classified TPI

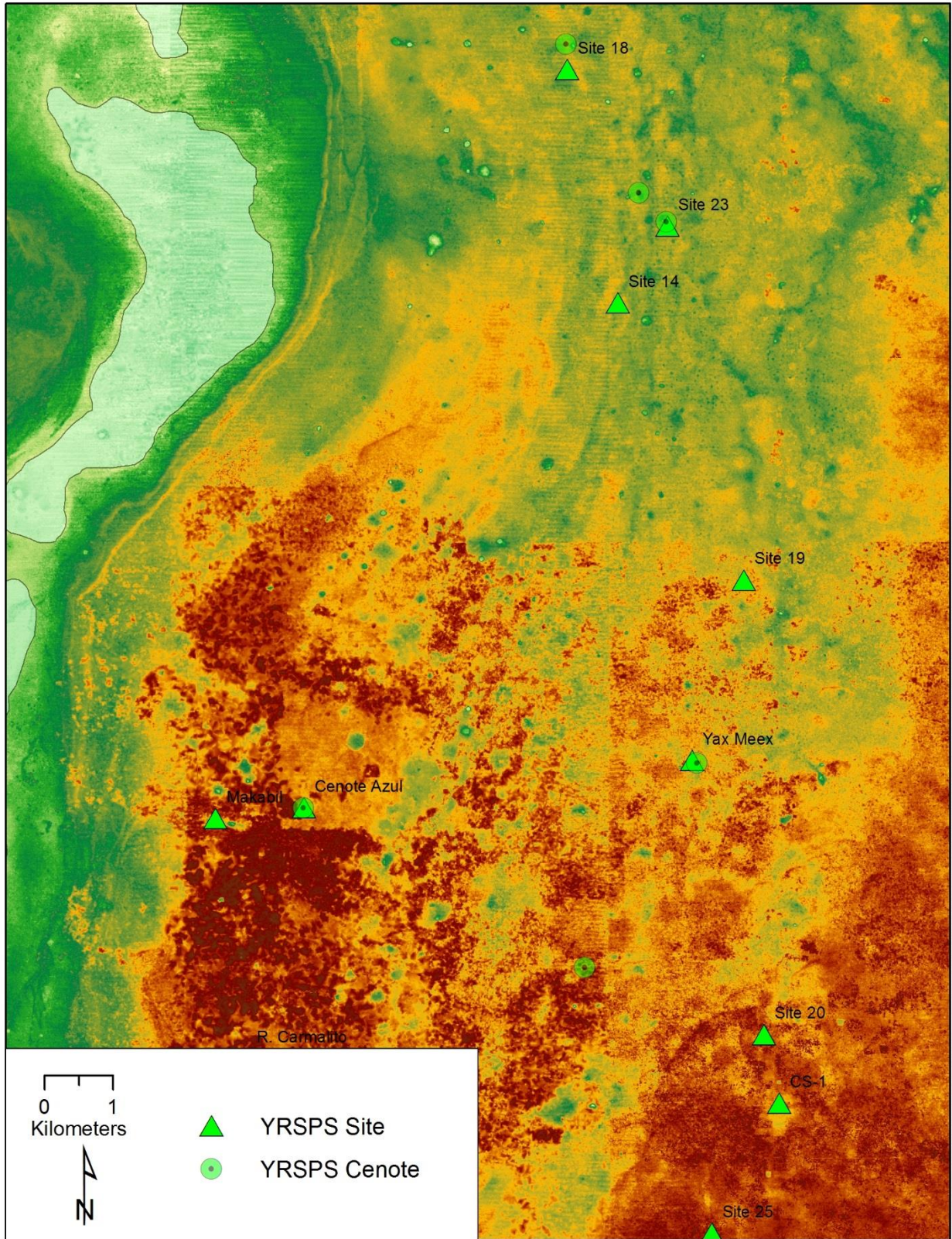


Figure 19 - LiDAR Selection, Terreno

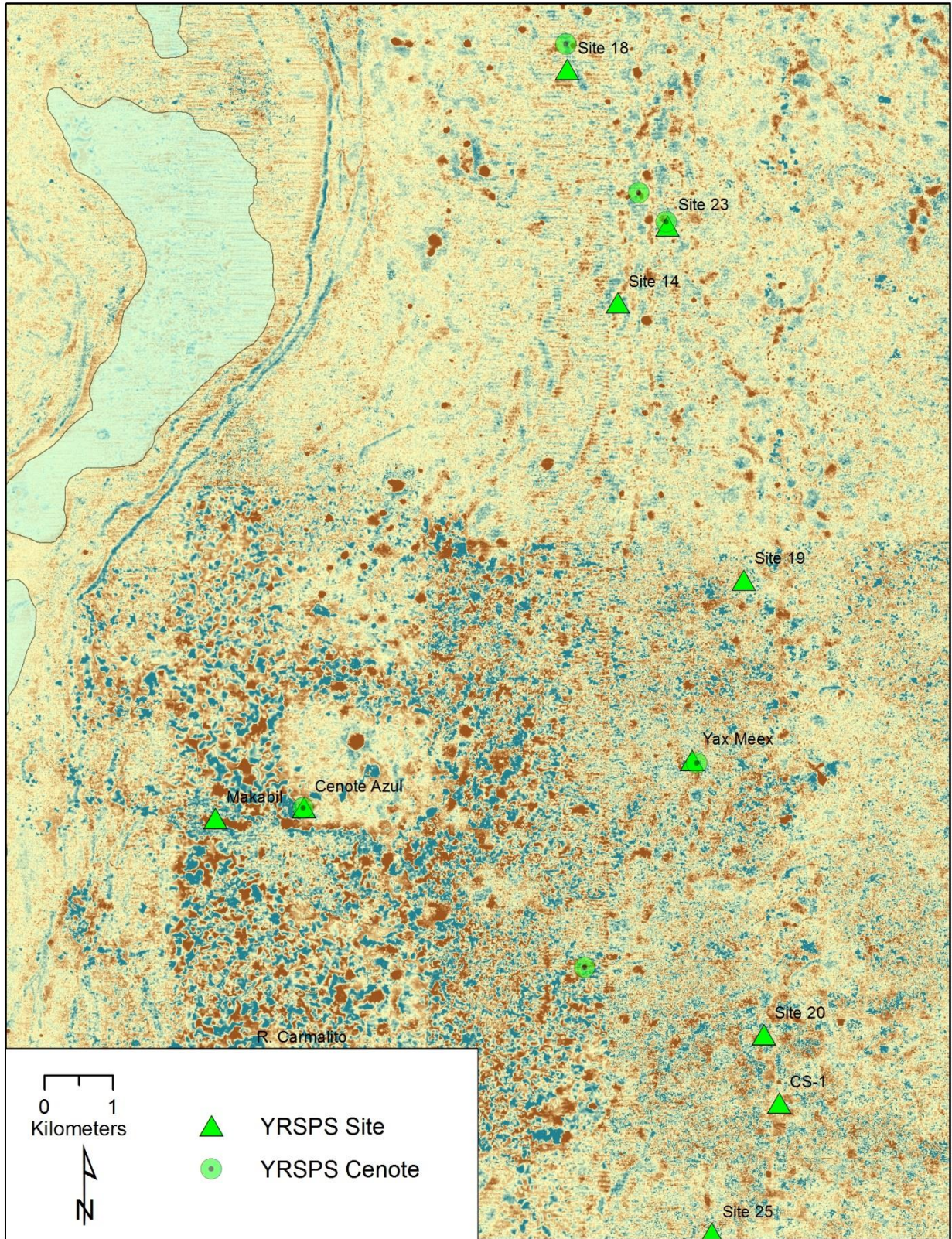


Figure 20 - Topographic Position Index, TPI 200m - LiDAR Terreno

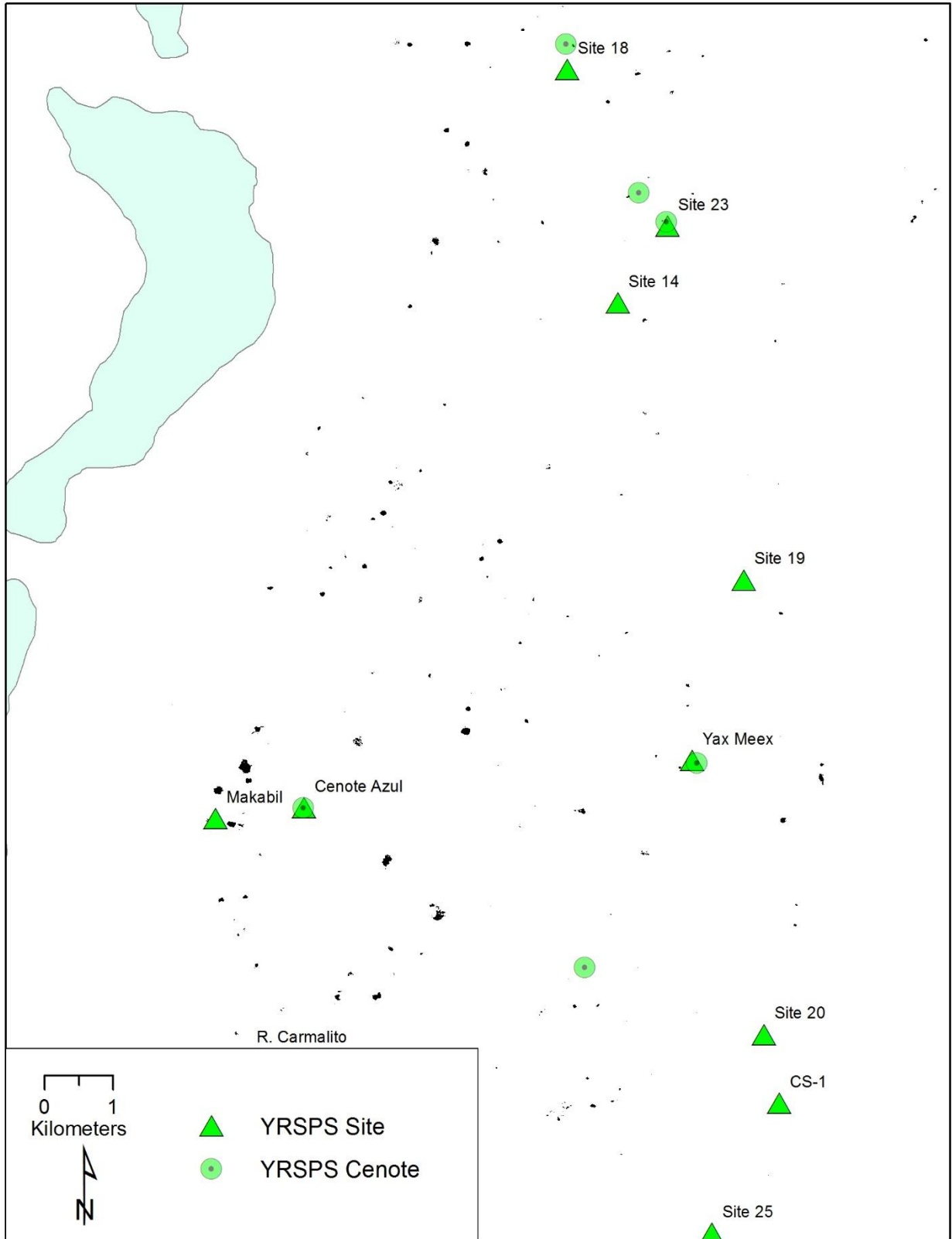


Figure 21 - TPI Classified

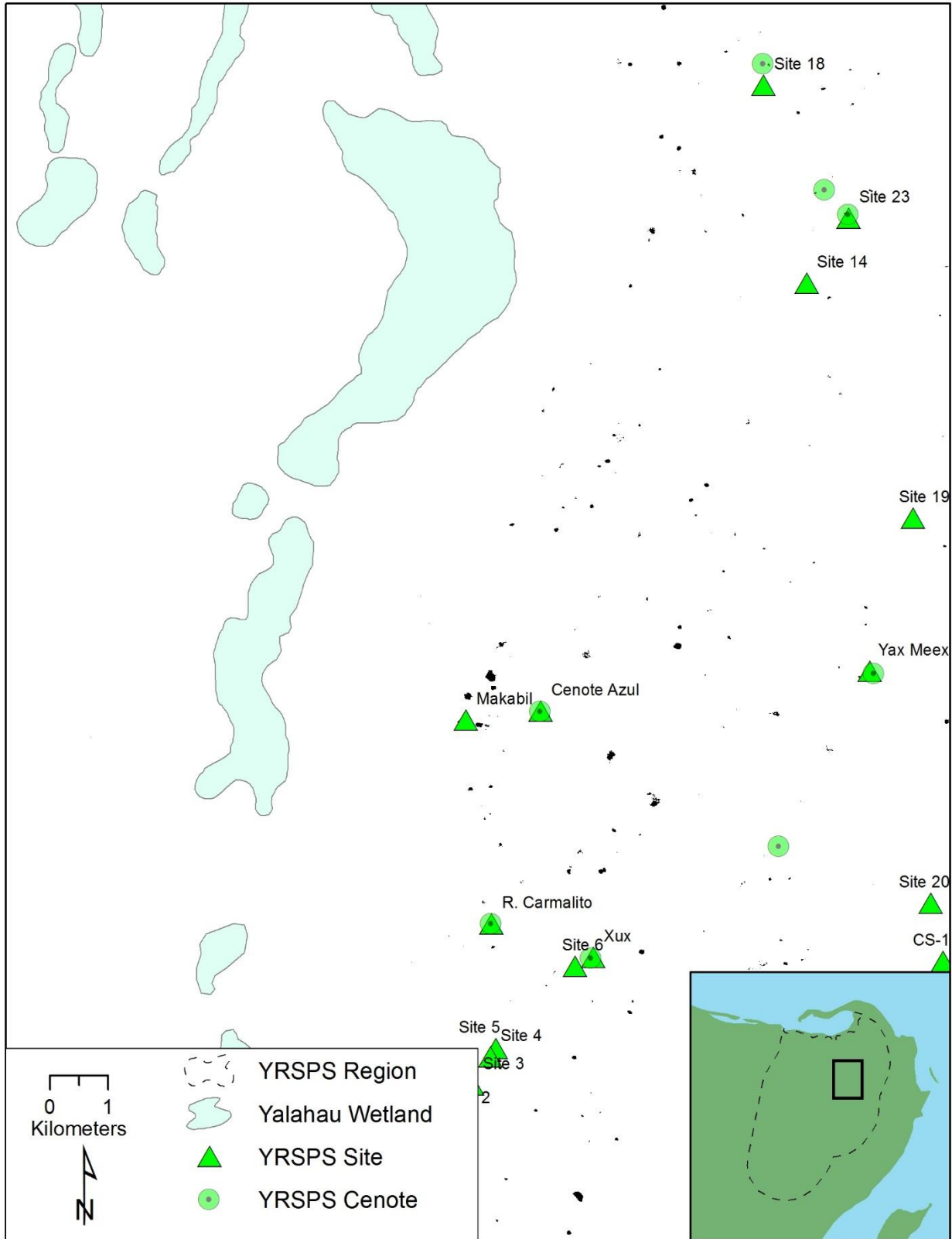


Figure 22 – Lack of Features in Wetlands?

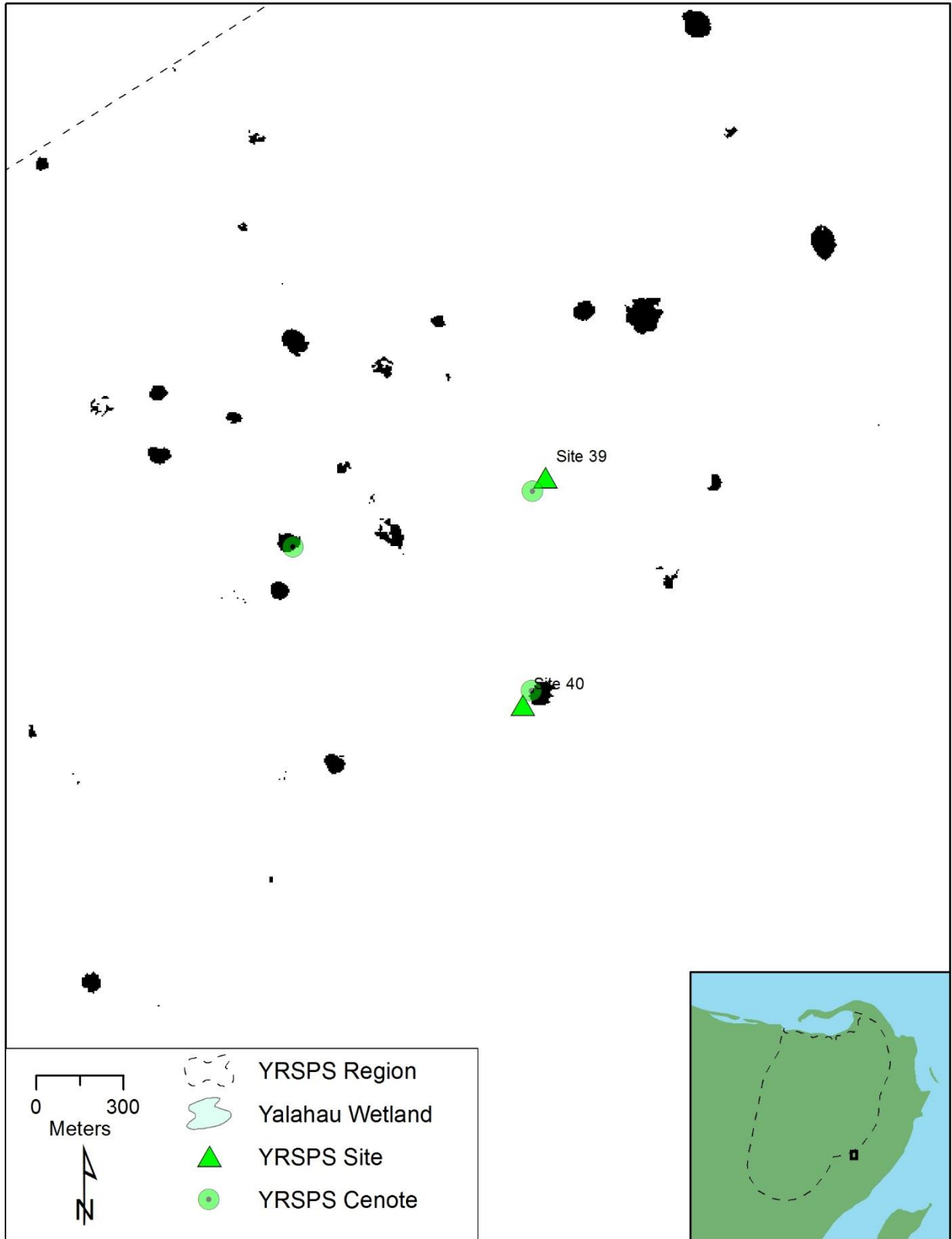


Figure 23 - YRSPS Cenotes and Classified TPI

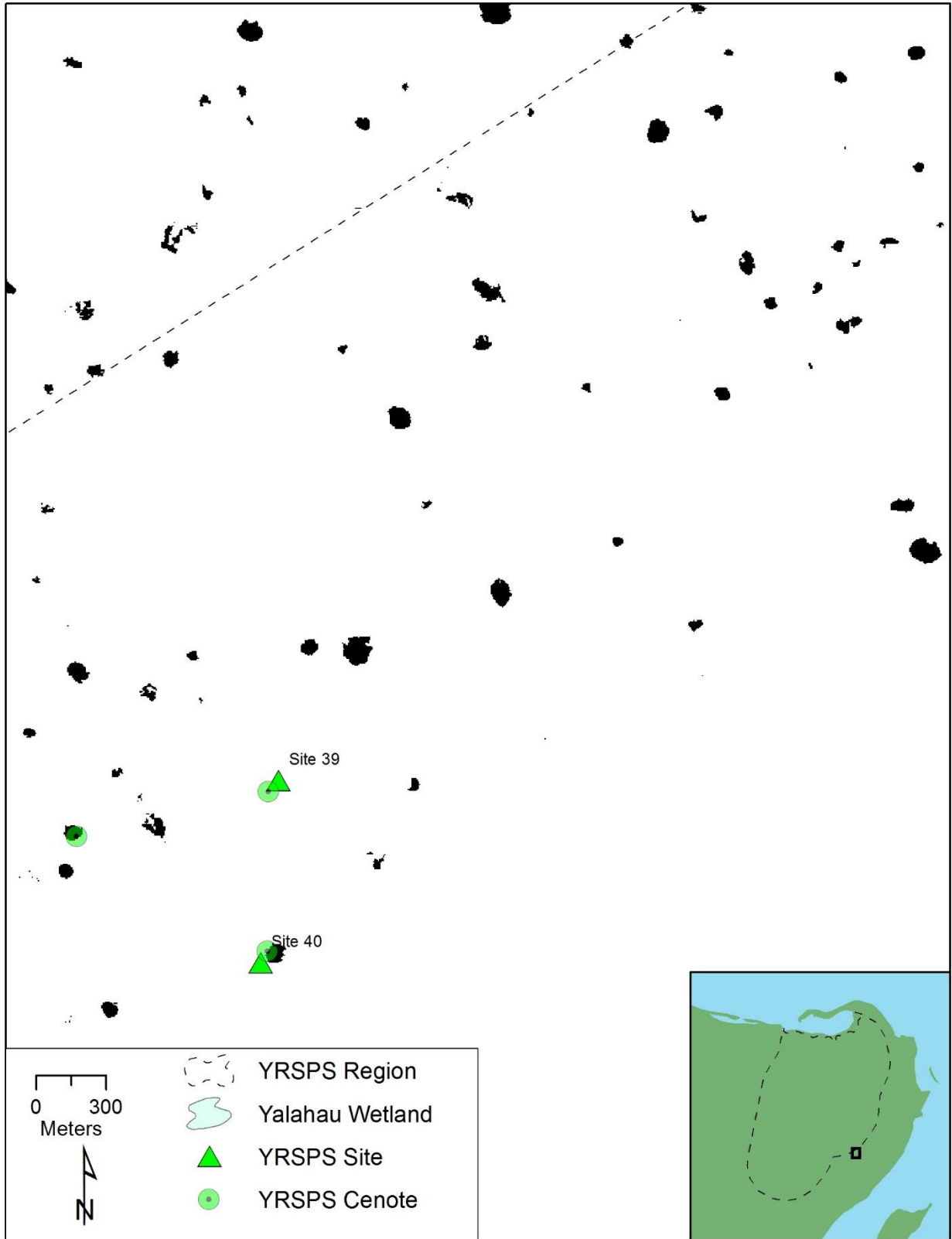


Figure 24 - YRSPS Cenotes, Classified TPI. Possible High Density Zone

5.2 SRTM

The figures discussed in this section demonstrate how prehistoric sites in the Yalahau region appear in the SRTM DEM data. The site of Kimin Yuk is visible only as a general rise in the terrain – individual buildings are not distinguishable in the 90 m resolution DEM (Figure 25). Vista Alegre (Figure 26) is similarly generalized – just a few pixels higher than the surrounding terrain but the individual structures are too small for the pixel resolution. The SRTM DEM was the only available source of elevation data for the entire region at the time of the YRSPS (Glover 2006) to examine site elevation.

As can be seen from Figures 25 and 26, the low resolution limits the utility of the data for making meaningful interpretations of archaeological data – interpretations would be generalized, with only a few pixels representing complex architecture. In addition, when compared with the LiDAR DEM (Figures 27 and 28), the triangular low elevation area on the eastern margins of the Yalahau region, bordered by Kimin Yuk to the south and Ox Mul to the north in the SRTM DEM disappears. This zone, which Glover (2006) identified, may be an artifact of vegetation and not necessarily resultant of true elevation change. While the SRTM data was never seen as an ideal data set, the primary premise of synthetic aperture radar is that vegetation is penetrated and minimally reflected in the resultant digital elevation model. At least for the Yalahau region this is thrown into question by the LiDAR data available in the eastern half of the region. Further examination of this region via Landsat in section 5.3 sheds more light on this situation.

5.3 Landsat Results

The analysis of Landsat imagery forms the bulk of this thesis. This section reports the results of this analysis in the context of both the aforementioned Yalahau Regional Settlement Pattern Survey (Glover 2006) data and the Yalahau Region Wetland Survey Project (Leonard 2013) data. This section also contains results from the field verification component of this project. The primary

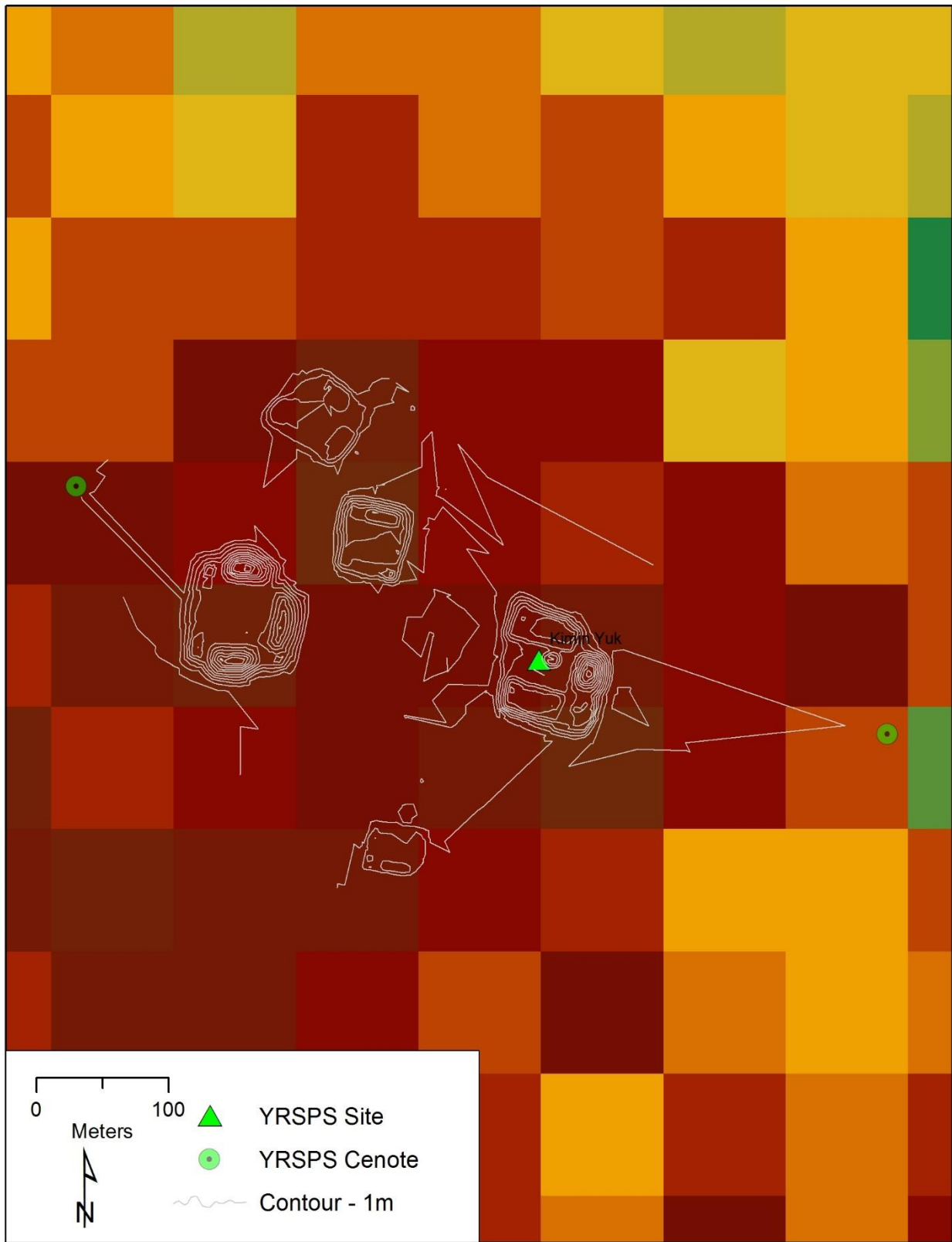


Figure 25 - Kimin Yuk, SRTM DEM

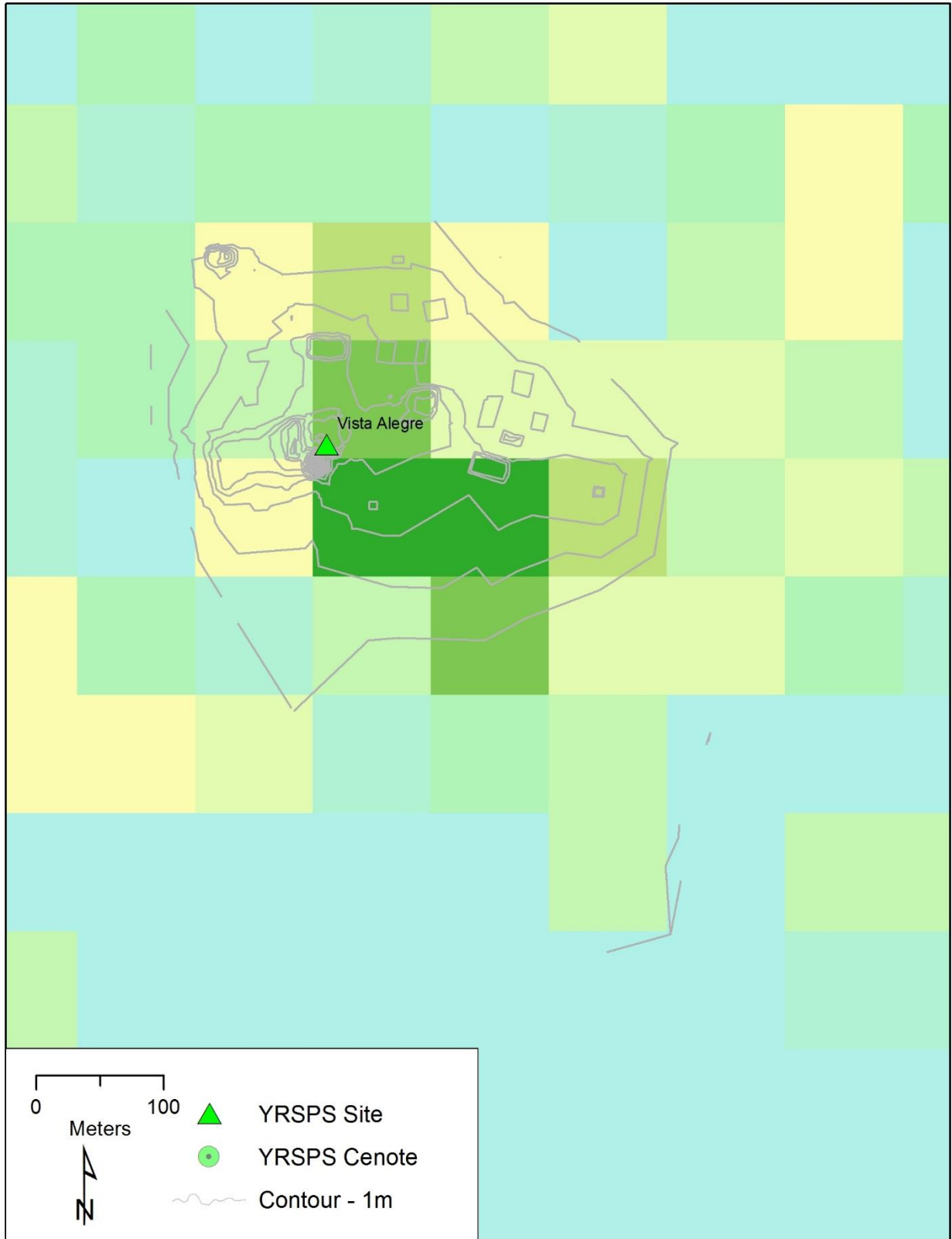


Figure 26 - Vista Alegre, SRTM DEM

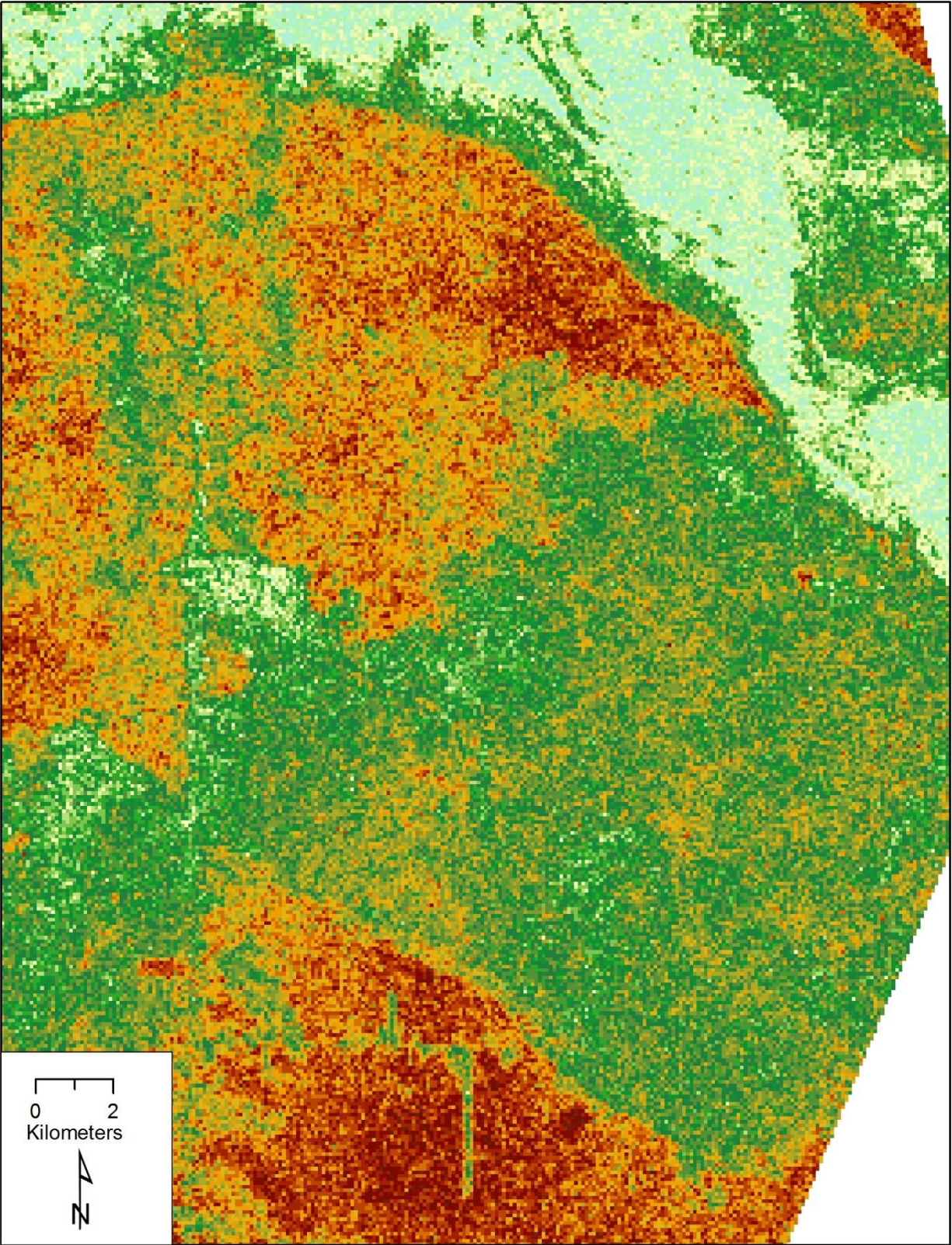


Figure 27 - SRTM DEM for Comparison

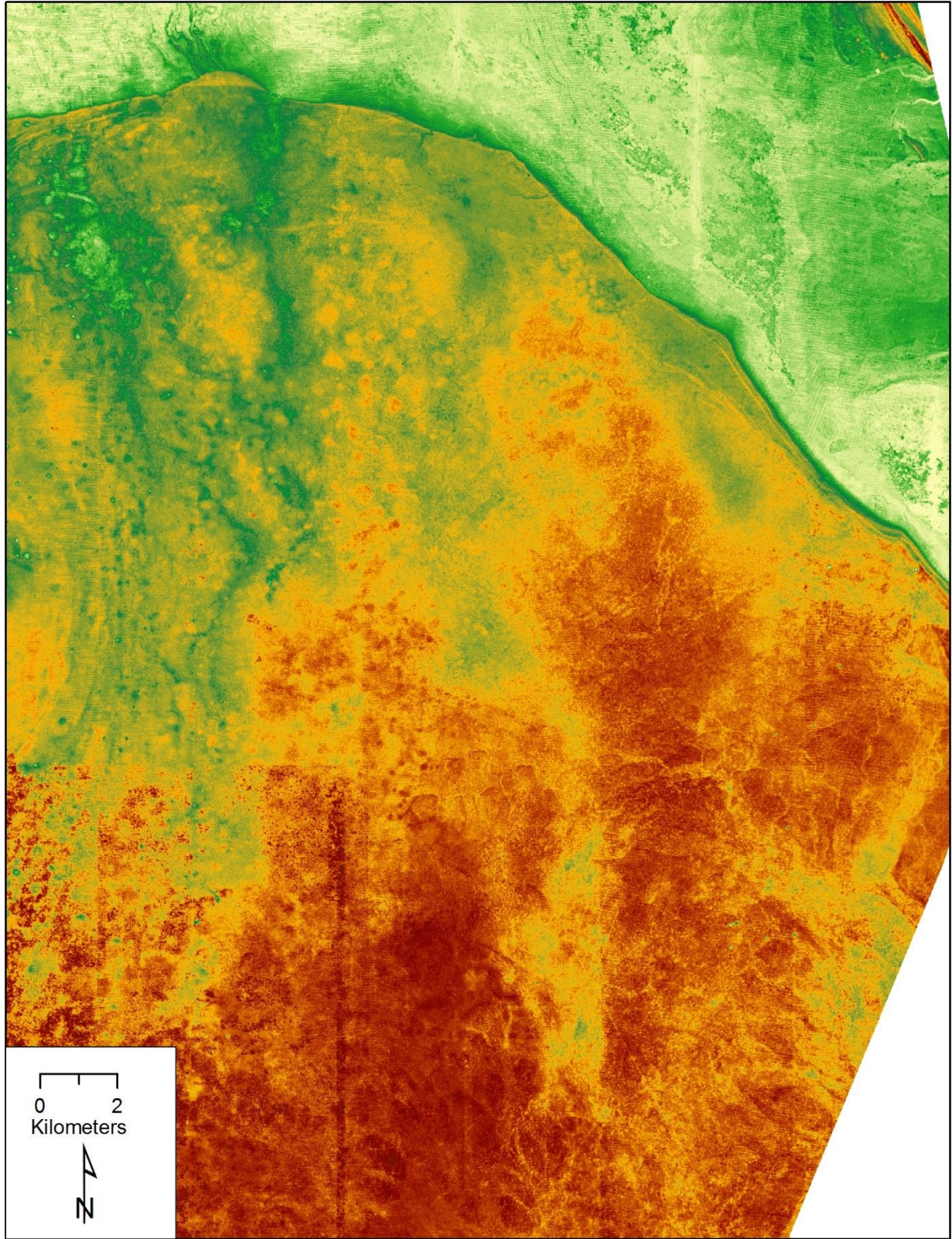


Figure 28 - LiDAR (Terreno) DEM for Comparison

method used for the analysis of Landsat data was the Kauth-Thomas transformation, also known as Tasseled Cap, described in detail in Section 4.3 (Baig et al. 2014; Crist 1985; Huang et al. 2002; Kauth and Thomas 1976).

Landsat 5, Landsat 7 and Landsat 8 imagery processed into band composite tasseled cap images were examined visually for evidence of any sort of contrasting spectral signature associated with known archaeological sites. Anthropogenic impacts on tropical forest vegetation have been detected elsewhere in the Maya region with approximate dates of 1000 years or more before present (Hightower et al. 2014), as a result of agricultural terracing. I present in section 5.4.1 a selection of sites from the YRSPS representing the different ways in which sites manifest in tasseled cap imagery. Following the work seeking site-correlated spectral signatures utilizing the known sites of the YRSPS data, a number of anomalous locations were identified. Recent work in the regional wetlands by Leonard (2013) resulted in three of those anomalous locations being confirmed as having archaeological remains, described in section 5.4.2. Further field verification work for this thesis confirmed the locations of two other sites, reported on in section 5.4.3.

5.3.1 Yalahau Region Settlement Pattern Survey Sites

Utilizing the YRSPS sites and wetland outlines as a baseline, I examined tasseled cap (TC) images derived from the Landsat scenes detailed in Table 4, the only scenes out of dozens examined which showed any contrast at all (see Garrison et al. 2008; Hixson 2013). In total 9 anomalies were identified from the data available, their locations are in Figure 29. Figure 30 was derived from the Landsat 5 scene dated April 17, 1984. The image shows the sites Conil and San Ramon along with wetland Sabana Zanja, along the right side. As described in Chapter 4, the Wetness, Greenness, and Brightness bands are composited as blue, green, and red respectively. The wetlands appear red in this image likely due to a dry season condition. Figure 31 from October of 1999 shows the wetlands as blue and thus wet. The differences between dry season and wet season imagery can be drastic, and

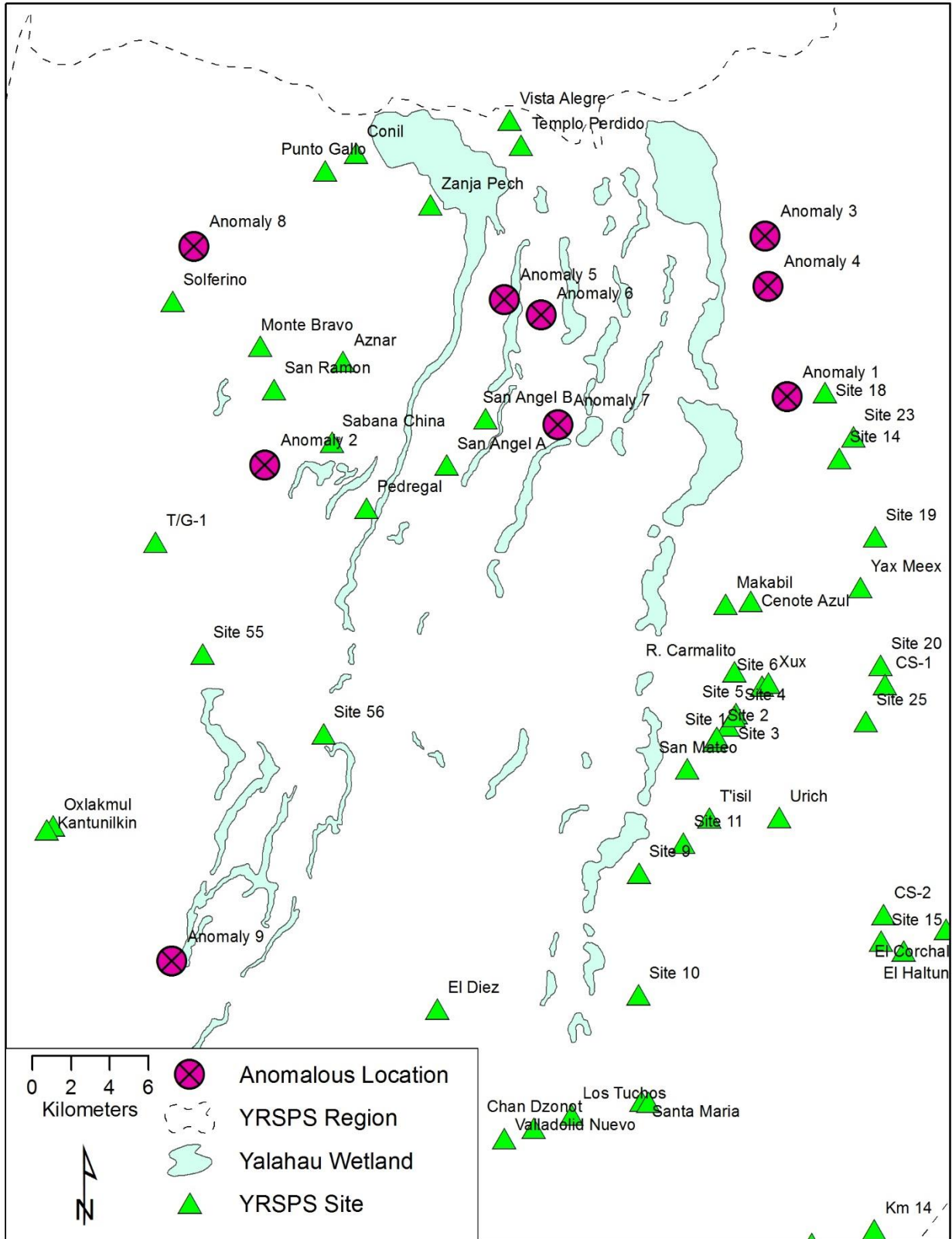


Figure 29 - Anomalies

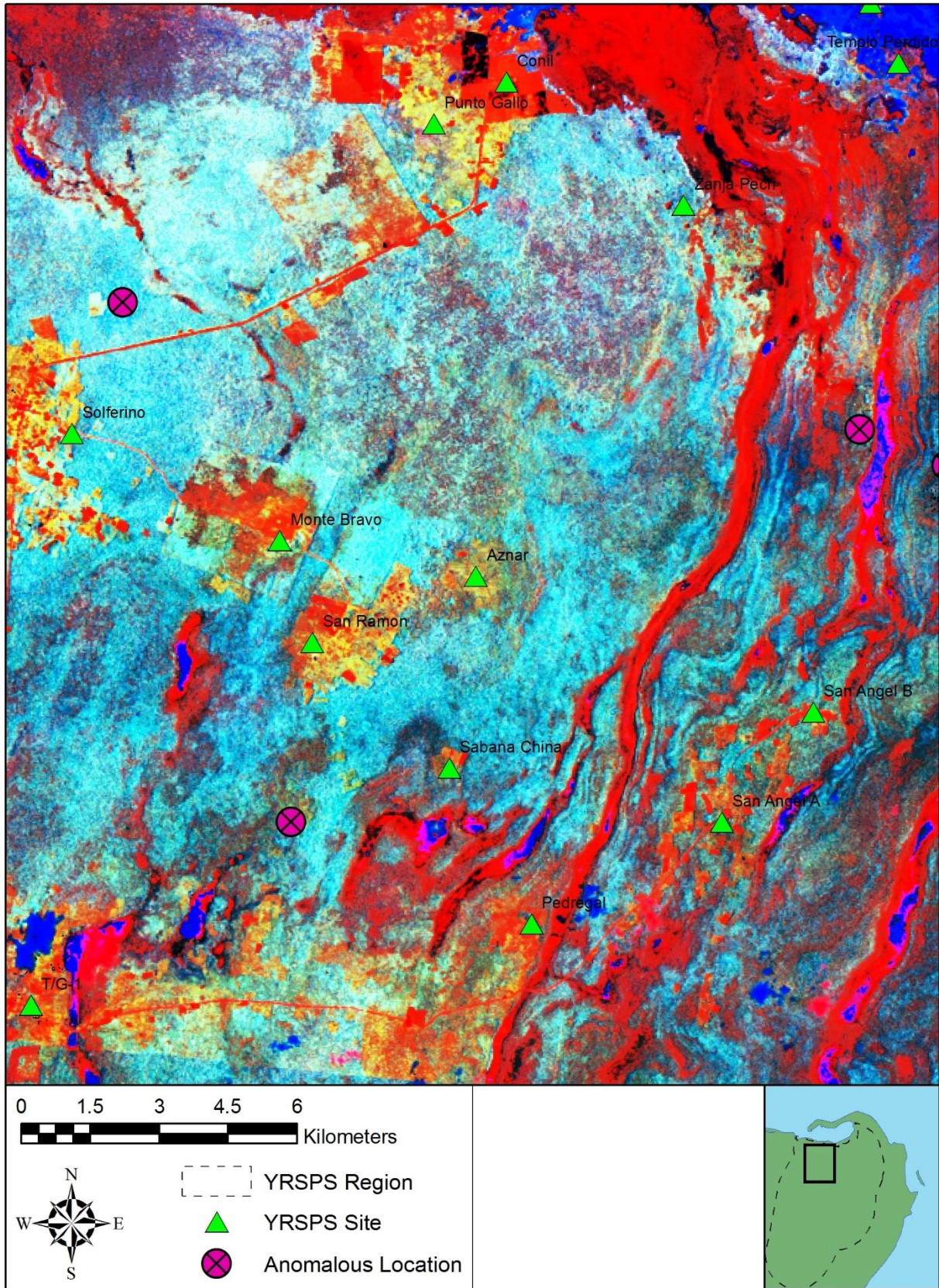


Figure 30 - Sabana Zanja Area, 1984 TC

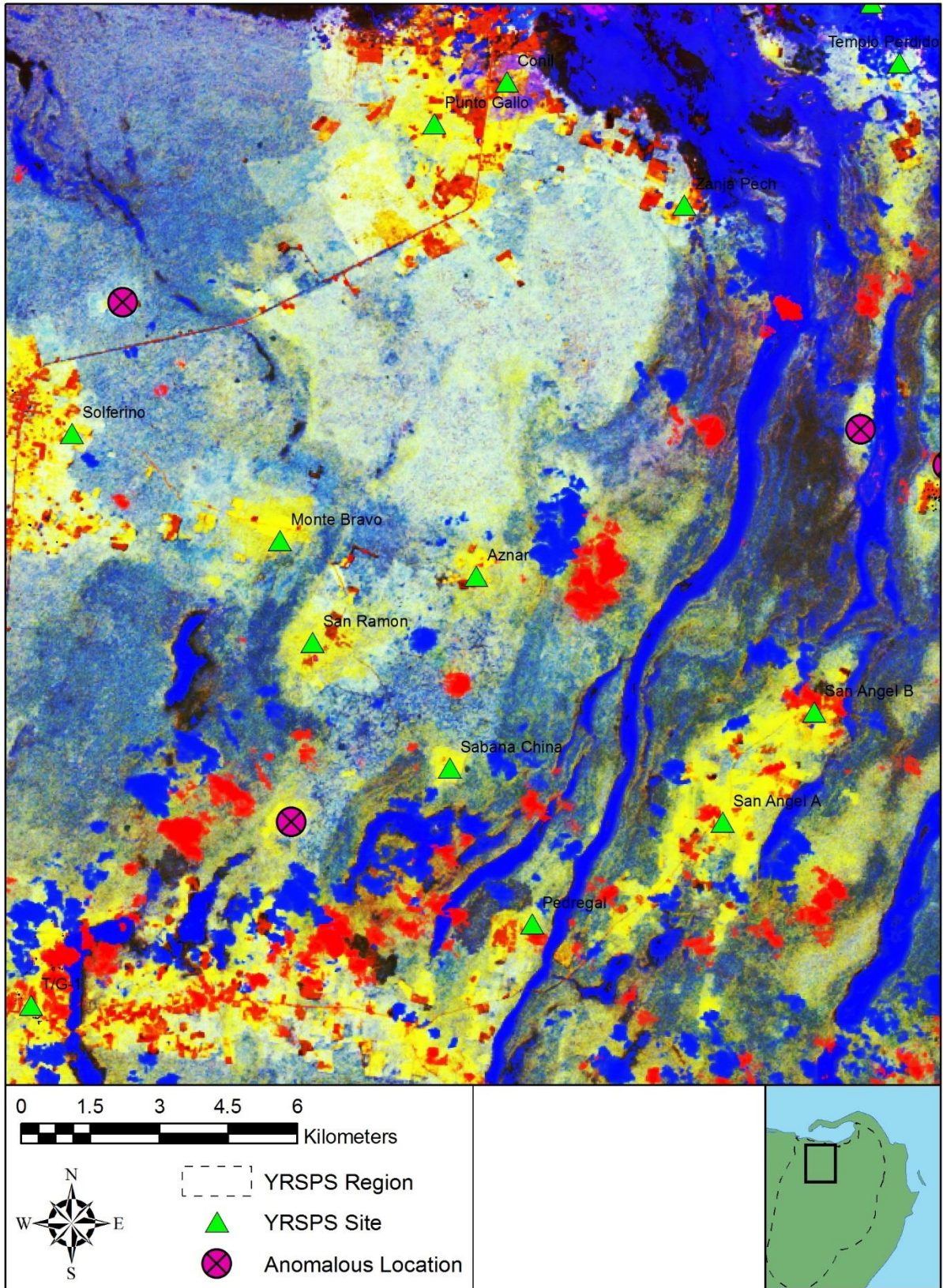


Figure 31 - - Sabana Zanja Area, 1999 TC

as was suggested by Hixson (2013), rainy season imagery did yield generally brighter and greener signatures (which would show up as yellow in the tasseled cap) over known sites, as well as over some locations where there were not known to be sites.

The first location where this phenomenon was noticed was on the eastern side of the wetlands. In Figure 32, there are several smaller sites identified by Glover for the YRSPS, along with Anomaly 1. Site 14, Site 23 and Site 18 are near Anomaly 1. This tasseled cap image from 1999 was used to target the area for further investigation due to the striking similarities between the signatures of the forest over Site 18. Site 23 appears to have had some more recent event resulting in the hard edges of the anomaly seen to the north and west of Site 23 in Figure 33. Site 14 has some sort of contrast as well. This signature is bluer and thus indicative of generally wetter conditions. Also of note in this image are the number of potential cenote features – at this scale they show-up as only a few very intense wet pixels in the area surrounding these features. Figure 34 shows a known karstic feature in TC, overlaid with the TPI outline of the feature.

The interior zone of the wetlands was another area where the lack of informant knowledge gathered by Glover was seen as a possible hindrance for a complete understanding of the settlement patterns in the Yalahau region. Examination of this zone resulted in a number of anomalous candidates beyond Anomaly 1 and 2, mentioned already. The area south of Vista Alegre contains three anomalous signatures, Anomalies 5, 6 and 7 as seen in Figure 35. In this image the sites of San Ángel A and B are visible in addition to Vista Alegre. The intense signature present over these sites guided the interpretation of the anomalous signatures in this zone. Anomalies 3 and 4 are shown in Figure 36. Further west and north of the modern town of Solferino, I spotted another anomaly, Anomaly 8. This is shown in Figure 37 in relation to Anomaly 2.

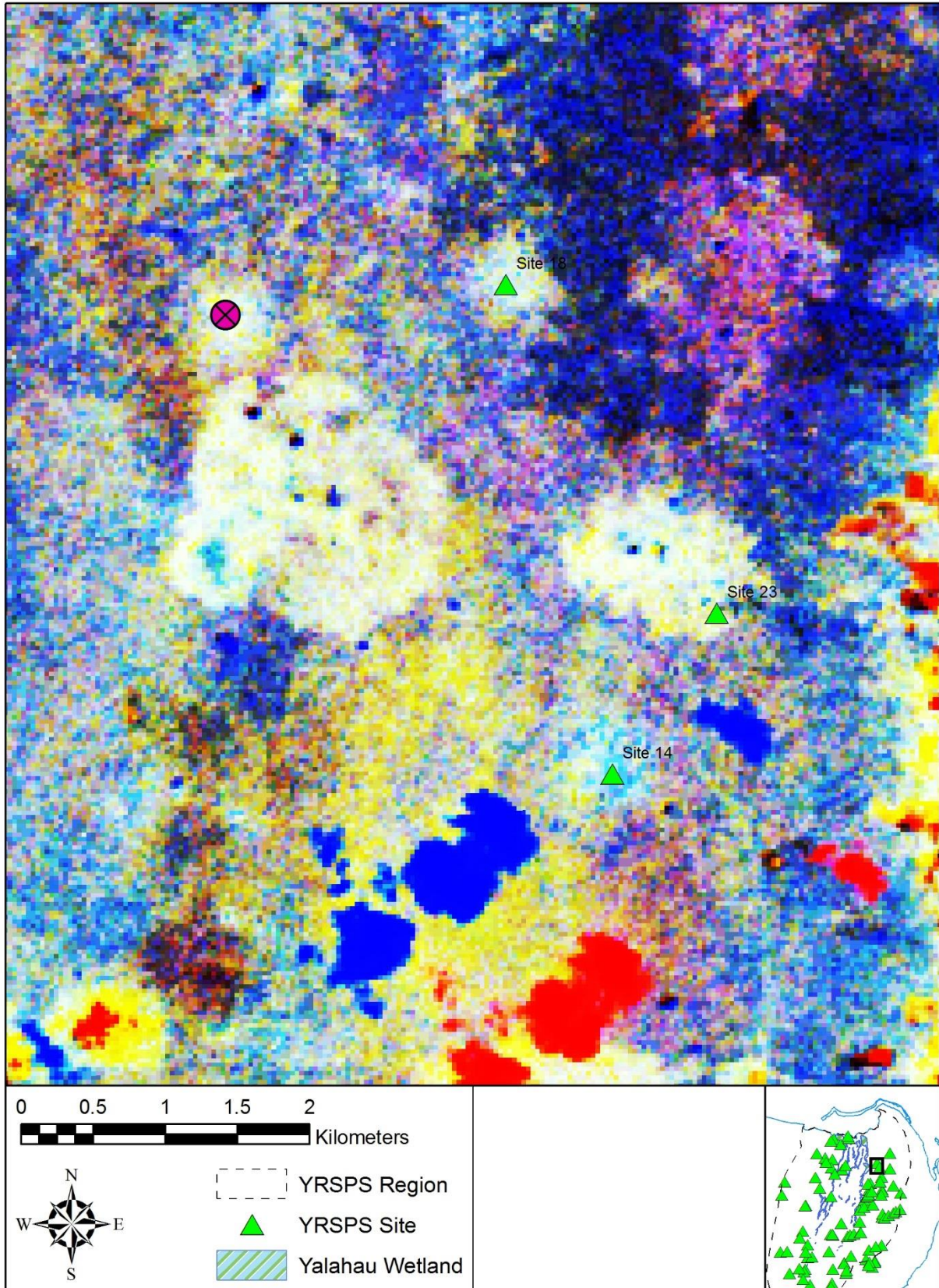


Figure 32 - Anomaly 1 and Nearby Sites

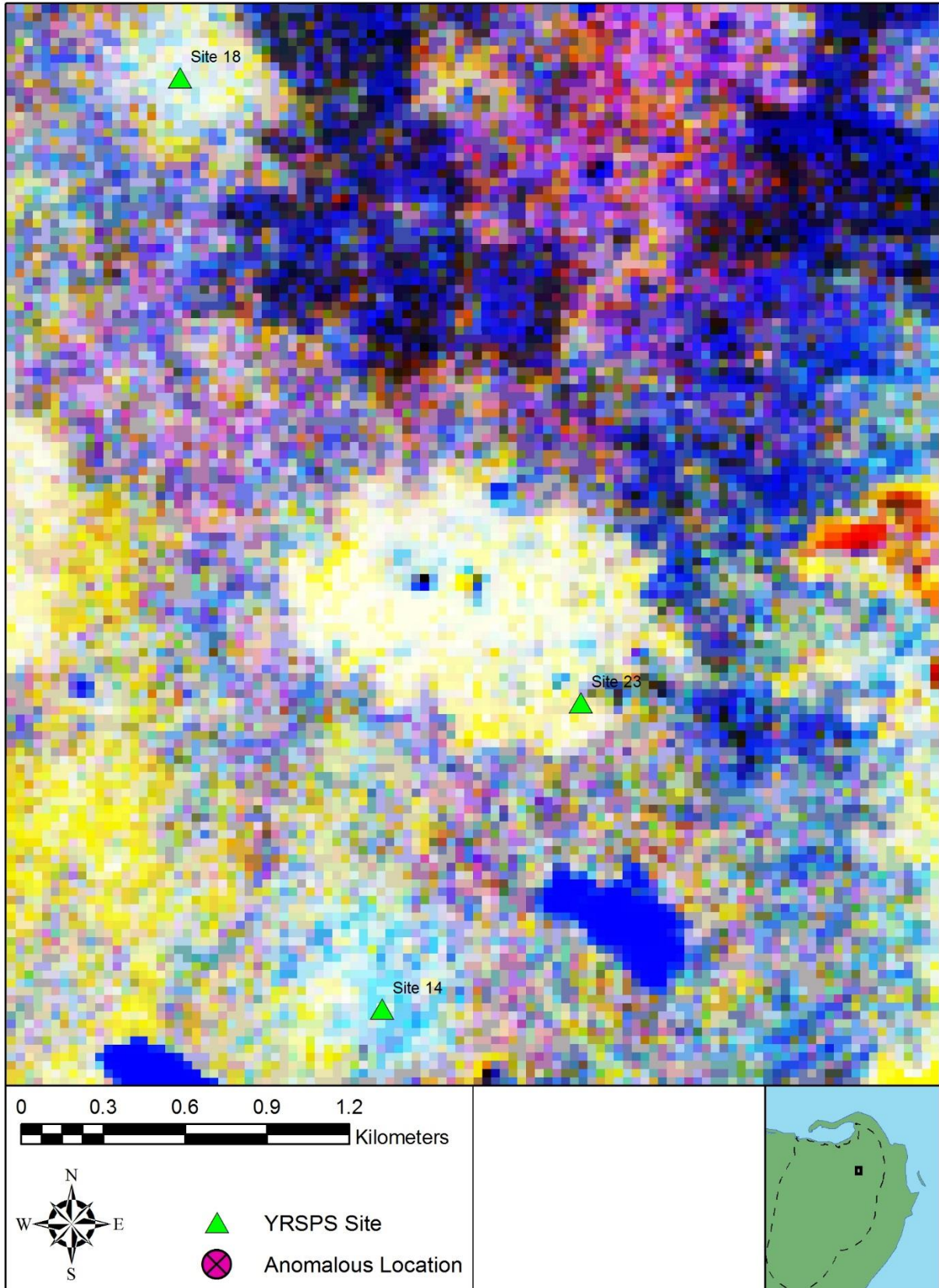


Figure 33 - Differing Signatures near Anomaly 1

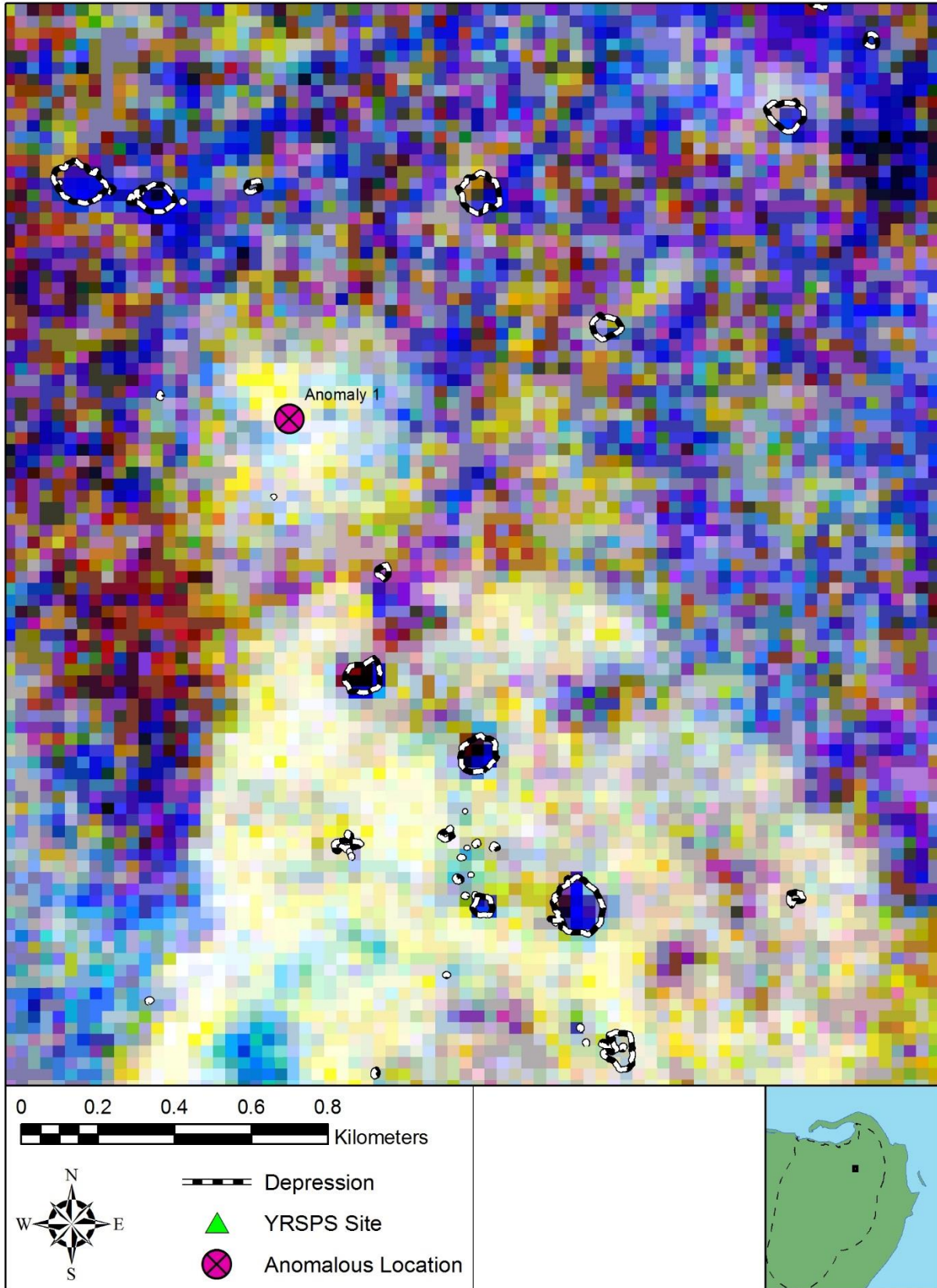


Figure 34 - Depressions from TPI, 1999 TC

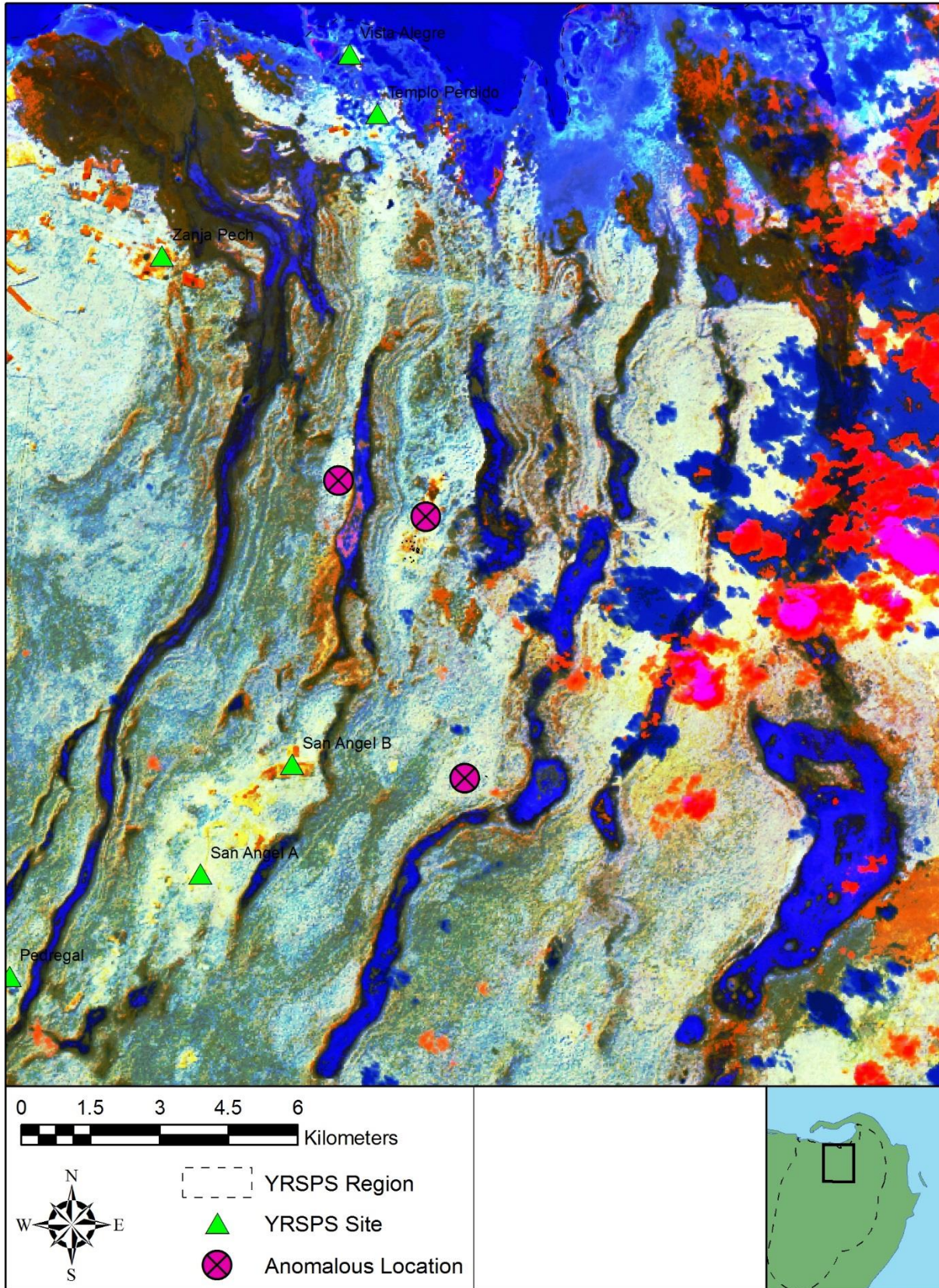


Figure 35 - Anomalies 5, 6 and 7; 2014 TC

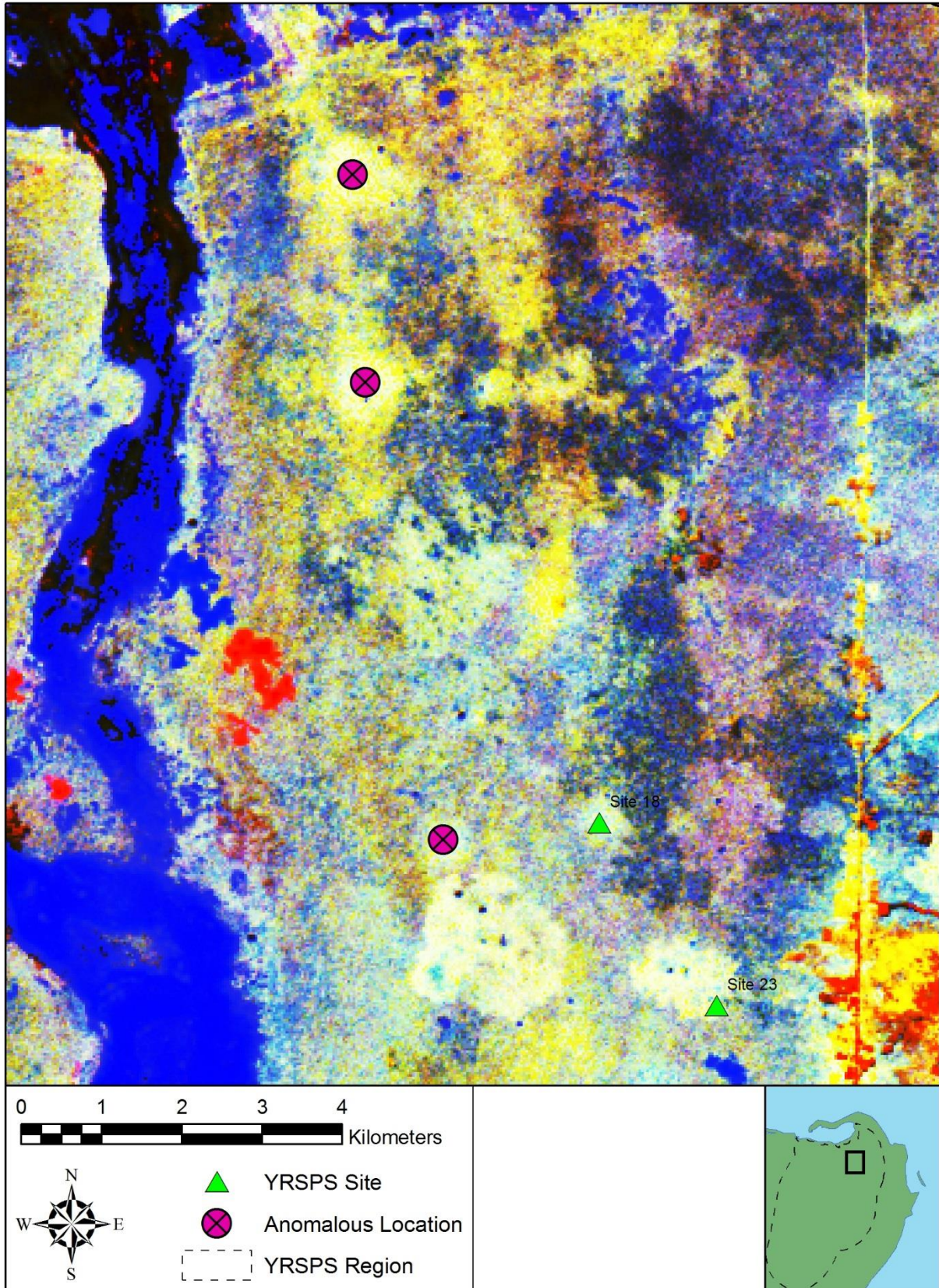


Figure 36 - Anomalies 1, 3 and 4; 1999 TC

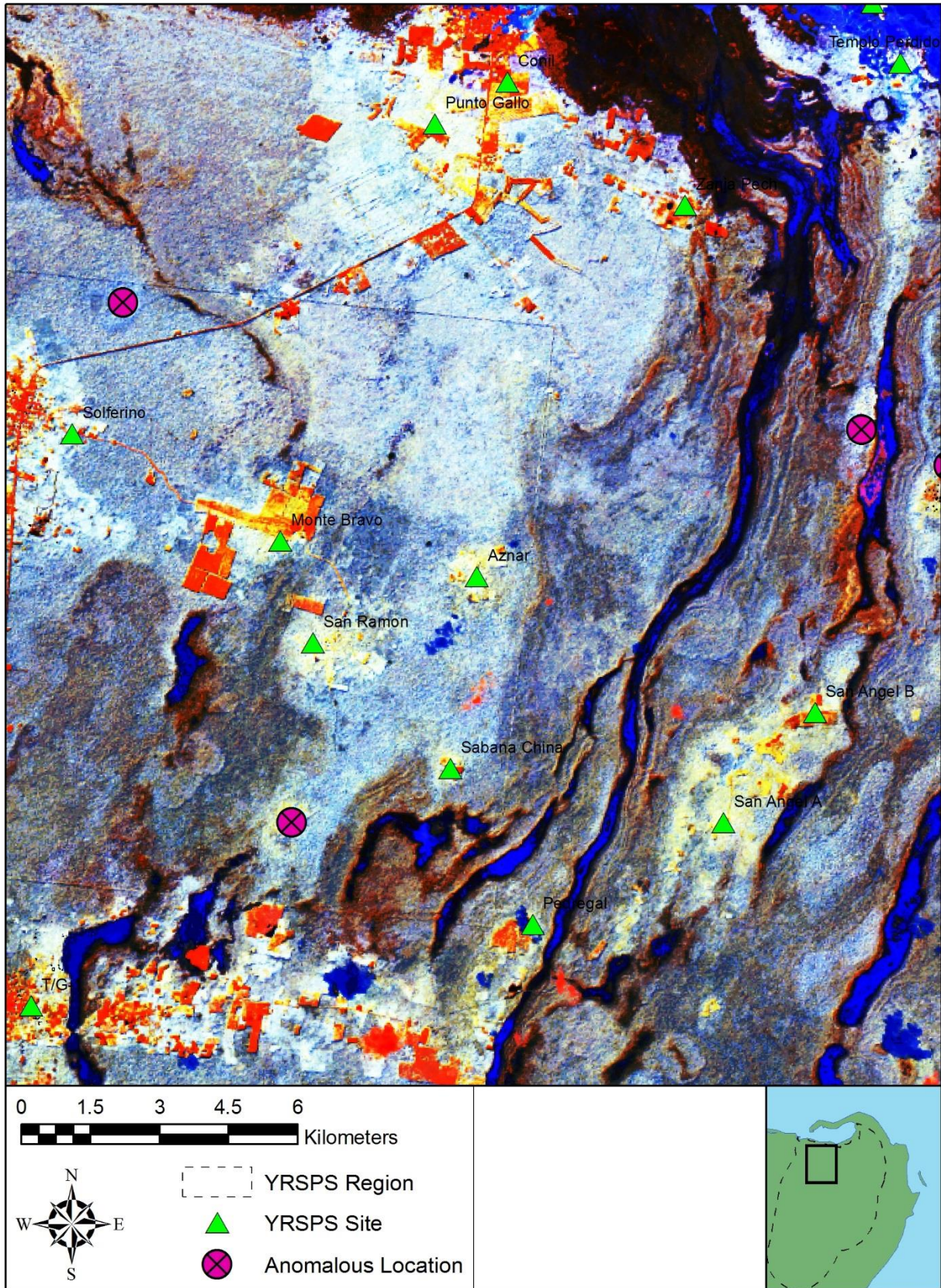


Figure 37 - San Ramon Area and Anomalies 2, 5 and 8 2014 TC

5.3.2 Yalahau Region Wetland Survey Sites

The dissertation research of Daniel Leonard (2013) provided an excellent opportunity to validate a number of the anomalous signatures identified in section 5.3.1. During the course of his research Leonard identified 5 previously undocumented sites (Figure 38). Of these sites, Tio Feliz was located near anomalies 5 and 6 and Esperanza Chico was located near Anomaly 7. Two others, La Mensura and Sakakal were not identified as possible sites in the remotely sensed data. Sakakal consists of a single structure on the banks of a wetland. Leonard comments (Leonard 2013:487-497) that there were no other apparent structures nearby. This site is beyond the LiDAR coverage, and does not show up in the Landsat TC images, likely due to the presence of only a sole structure. The last site identified by Leonard, Xpalma, is likely the site reported by Glover as Site 56.

5.3.2.1 Tio Feliz (Anomalies 5 and 6)

The site of Tio Feliz is on the banks of the wetland known as San Pastor. This wetland was surveyed as part of the YRWS. In addition to the site core depicted in the figures, another mound was located on the other side of the San Pastor wetland at the rough location of anomaly 6, but was not mapped (Leonard 2013:183-196). The site, the wetland and the anomaly are both shown in relation to the Landsat Tasseled cap (Figure 39) and LiDAR superficie (Figure 40) and terreno (Figure 41) DEMs. The site of Tio Feliz does not appear significantly anomalous in terms of elevation, however, it is clear from the superficie DEM (Figure 42) that the area was in fact cleared at the time of the acquisition of that data. Unpublished photos of the area from Daniel Leonard (Figures 43, 44, and 45) show the zone relatively cleared.

5.3.2.2 Esperanza Chico (Anomaly 7)

South of Tio Feliz is another location indicated as a possible site, which was identified as a site through the work of Leonard (2013:213). Anomaly 7 is the site of Esperanza Chico and adjacent

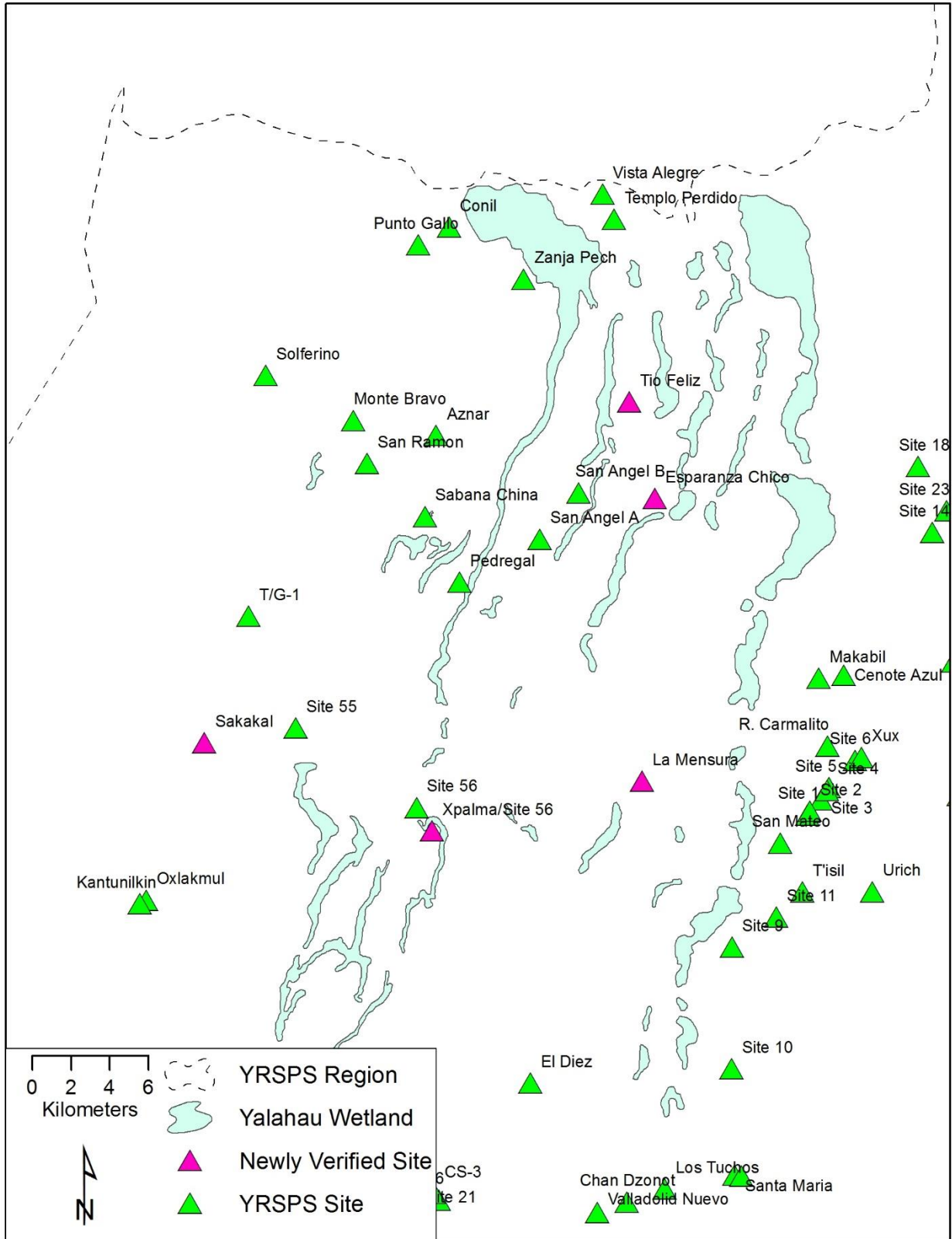


Figure 38 - Sites Identified by Daniel Leonard

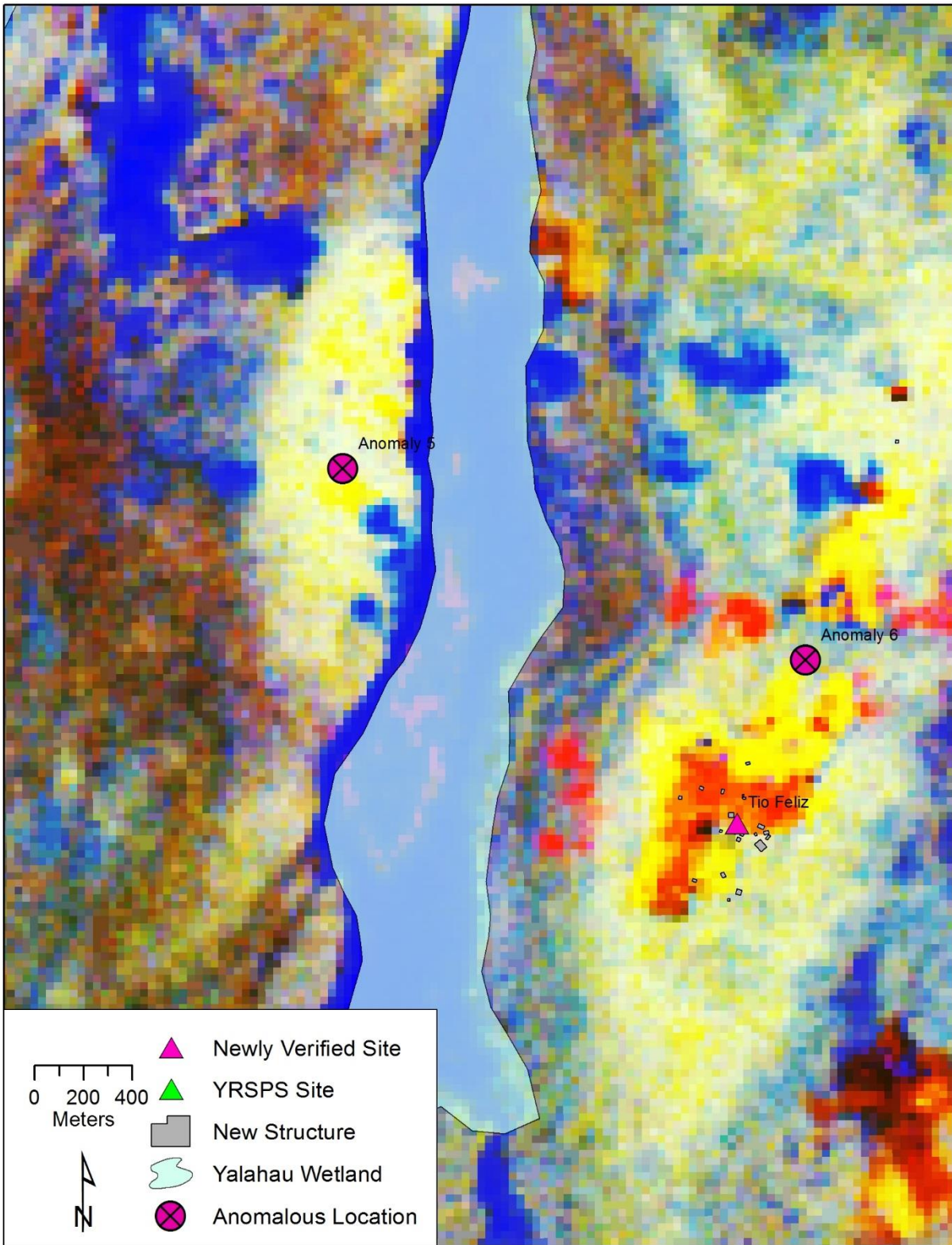


Figure 39 - Tio Feliz, 1999 TC

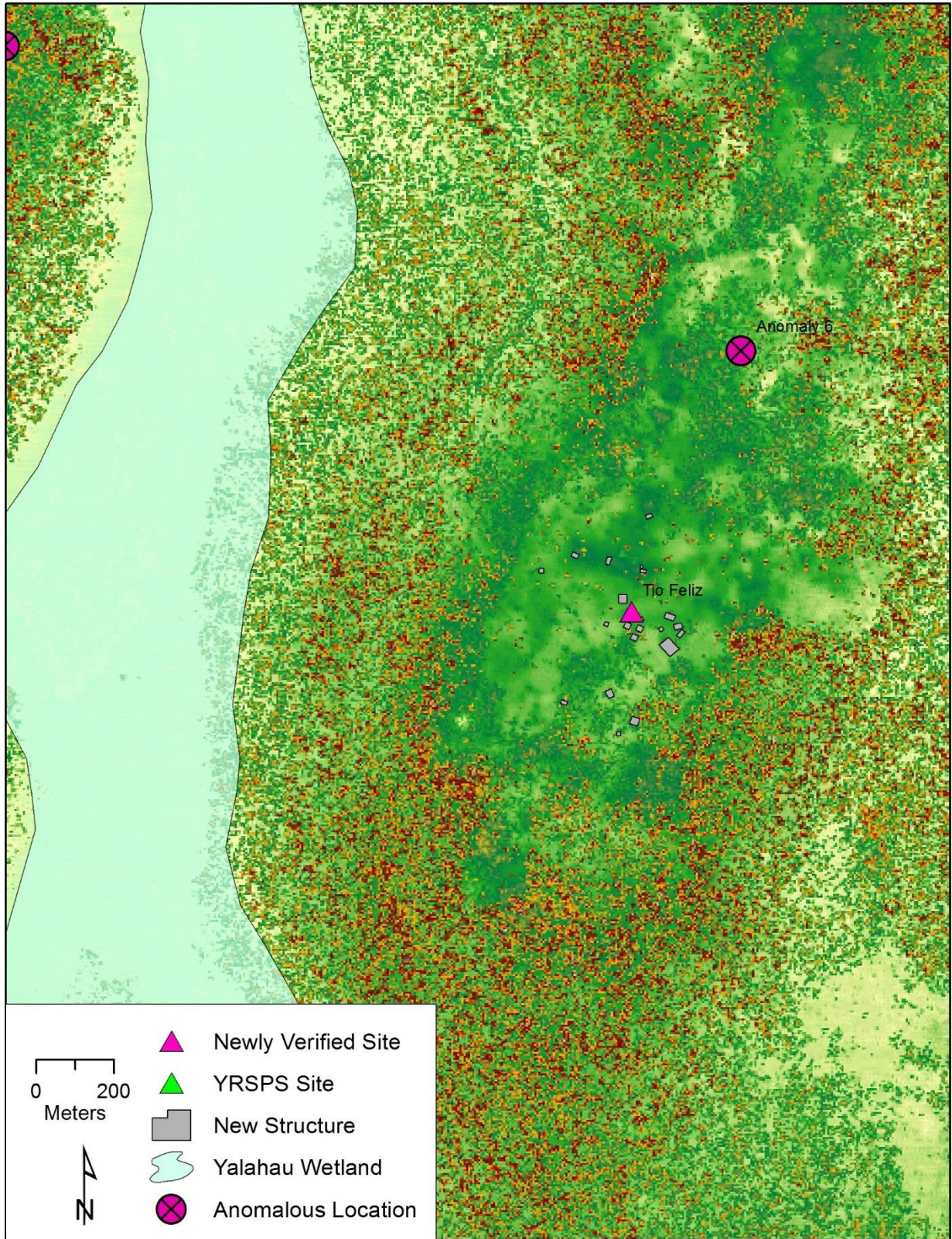


Figure 40 - Tio Feliz, Superficie DEM

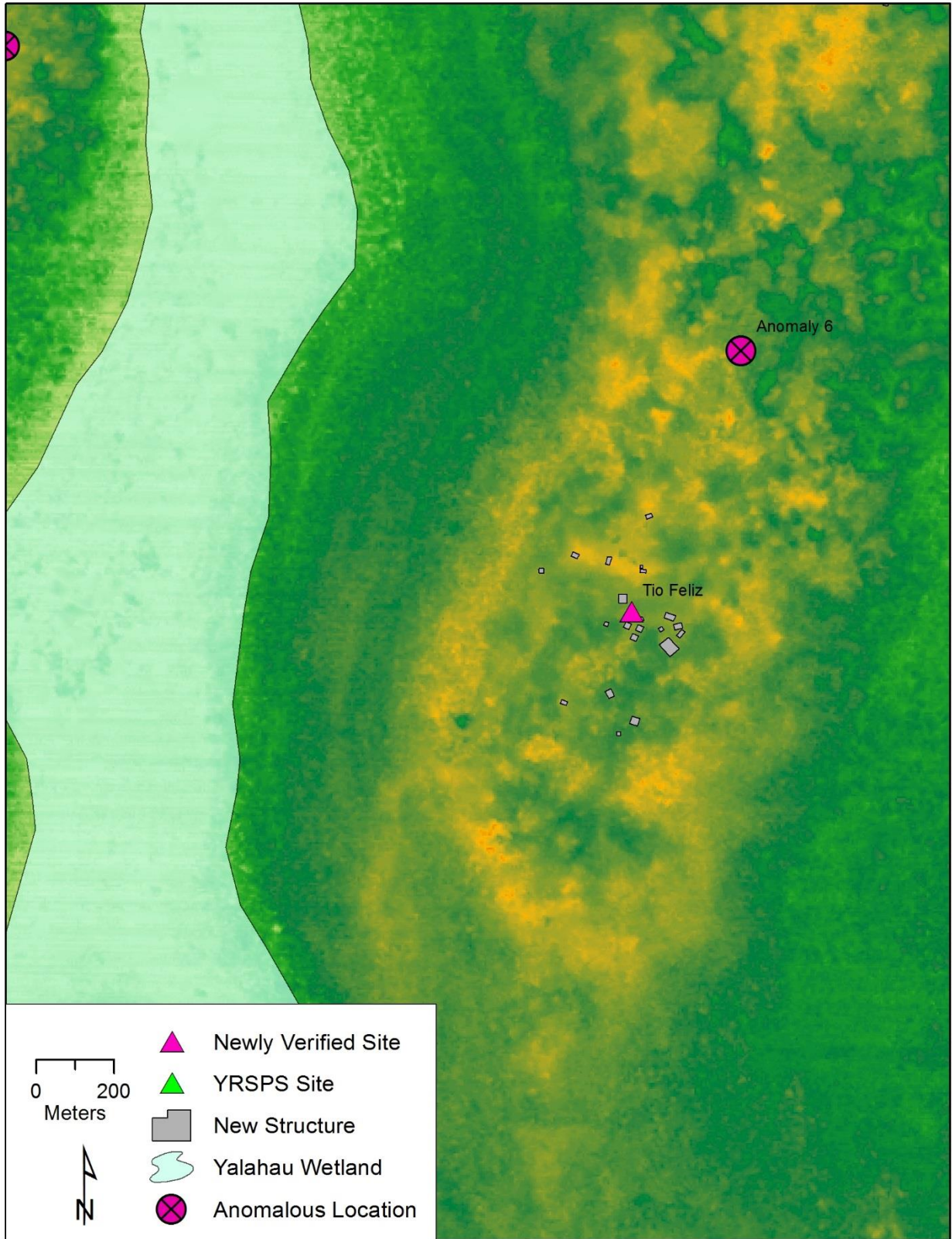


Figure 41 - Tio Feliz, Terreno DEM

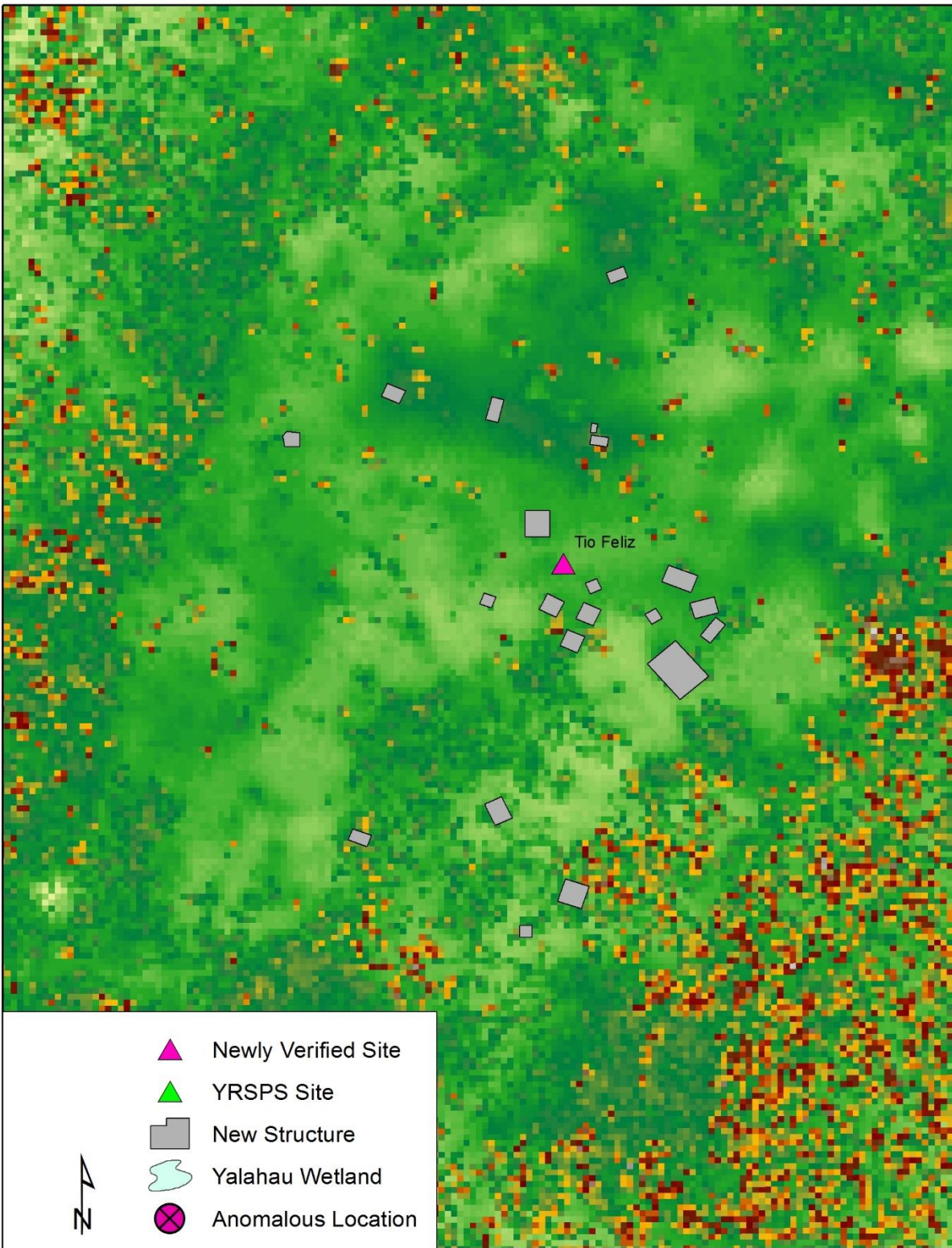


Figure 42 - Tio Feliz Detail, Superficie DEM



Figure 43 - Tio Feliz, Str-4 (Photo from Daniel Leonard)



Figure 44 - Tio Feliz, Str-5 (Photo from Daniel Leonard)



Figure 45 - Tio Feliz, Str-5 and Srt-6 (Photo from Daniel Leonard)

to the wetland of the same name. Figure 46 shows the site in relationship to Tio Feliz. The site of Esperanza Chico is located on the banks of an L shaped wetland extending along the east and south of the site, as show in Figure 47, the terreno DEM, and Figure 48, a Landsat TC image. Leonard identified a number of structures at Esperanza Chico (Figures 49 and 50).

5.3.2.3 La Mensura

Another site, La Mensura (Leonard 2013:410), is located in the interior wetland zone, and was not identified from any remotely sensed data, even though this site was within the LiDAR coverage area. It is possible that the terreno LiDAR model (Figure 51) does show STR-1 at La Mensura (Figure 52). However, with the terreno DEM there are the issues with relying on the detection of structures in a DEM which has been post processed to explicitly remove (modern)

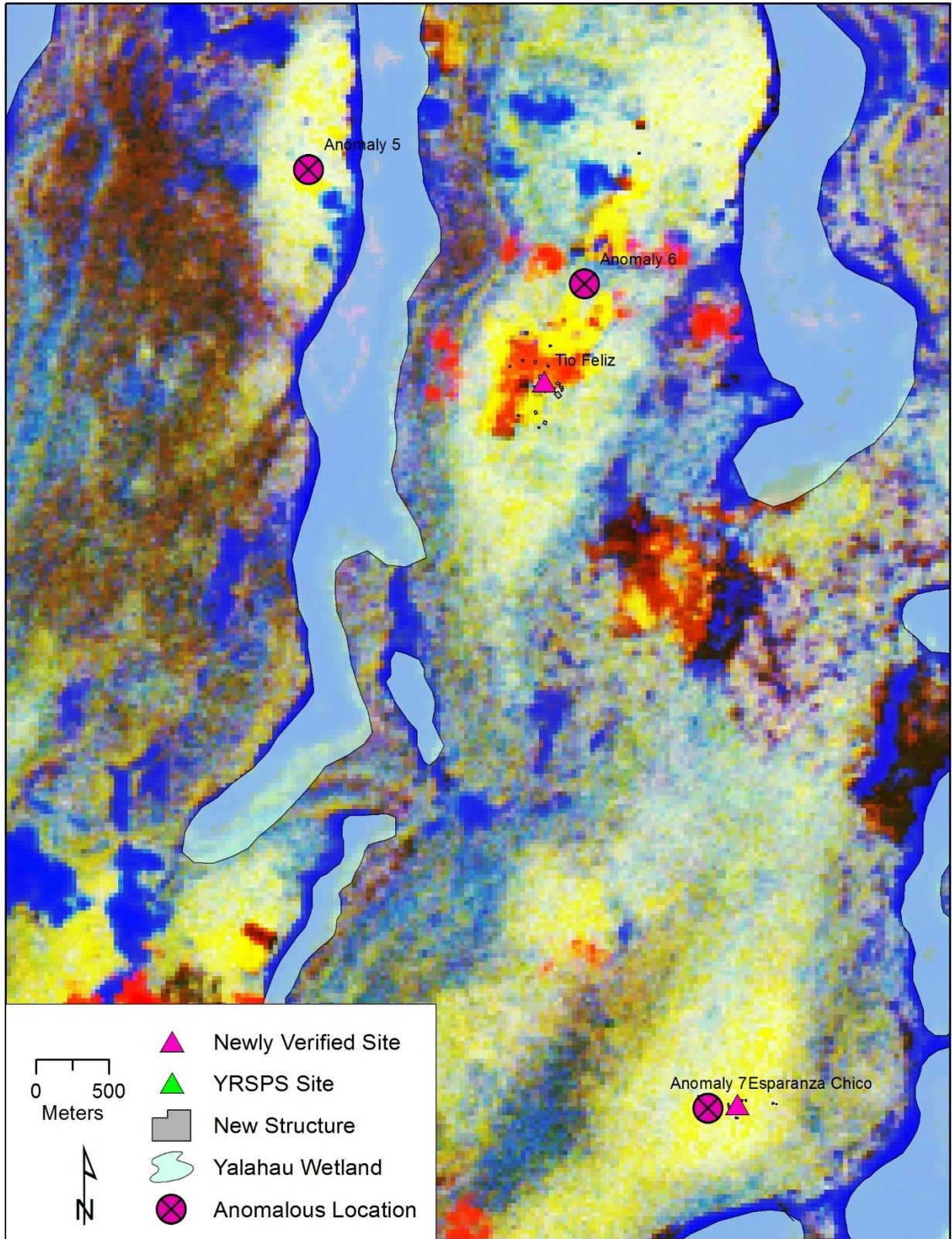


Figure 46 - Esperanza Chico and Surrounding Area

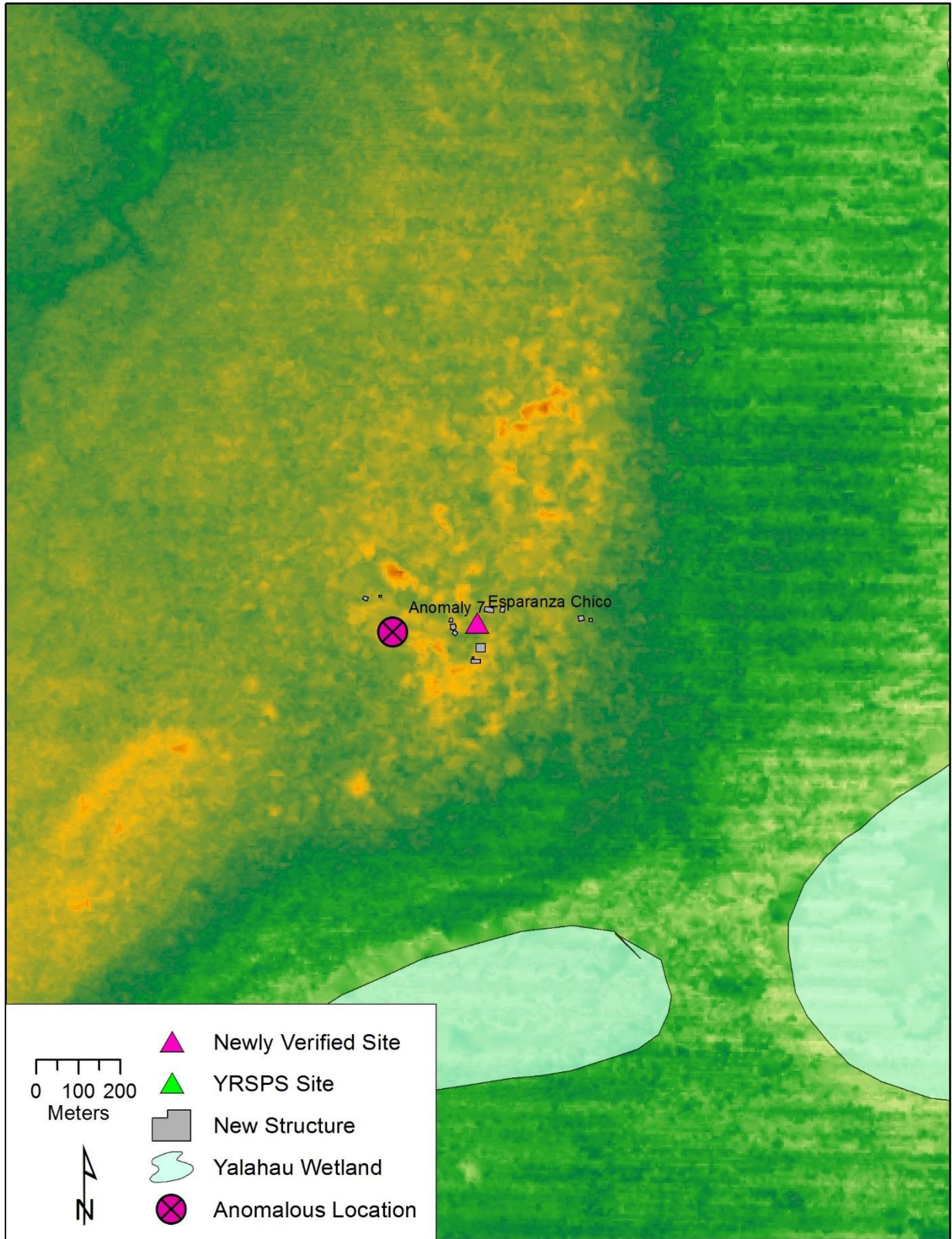


Figure 47 - Esperanza Chico, Terreno DEM

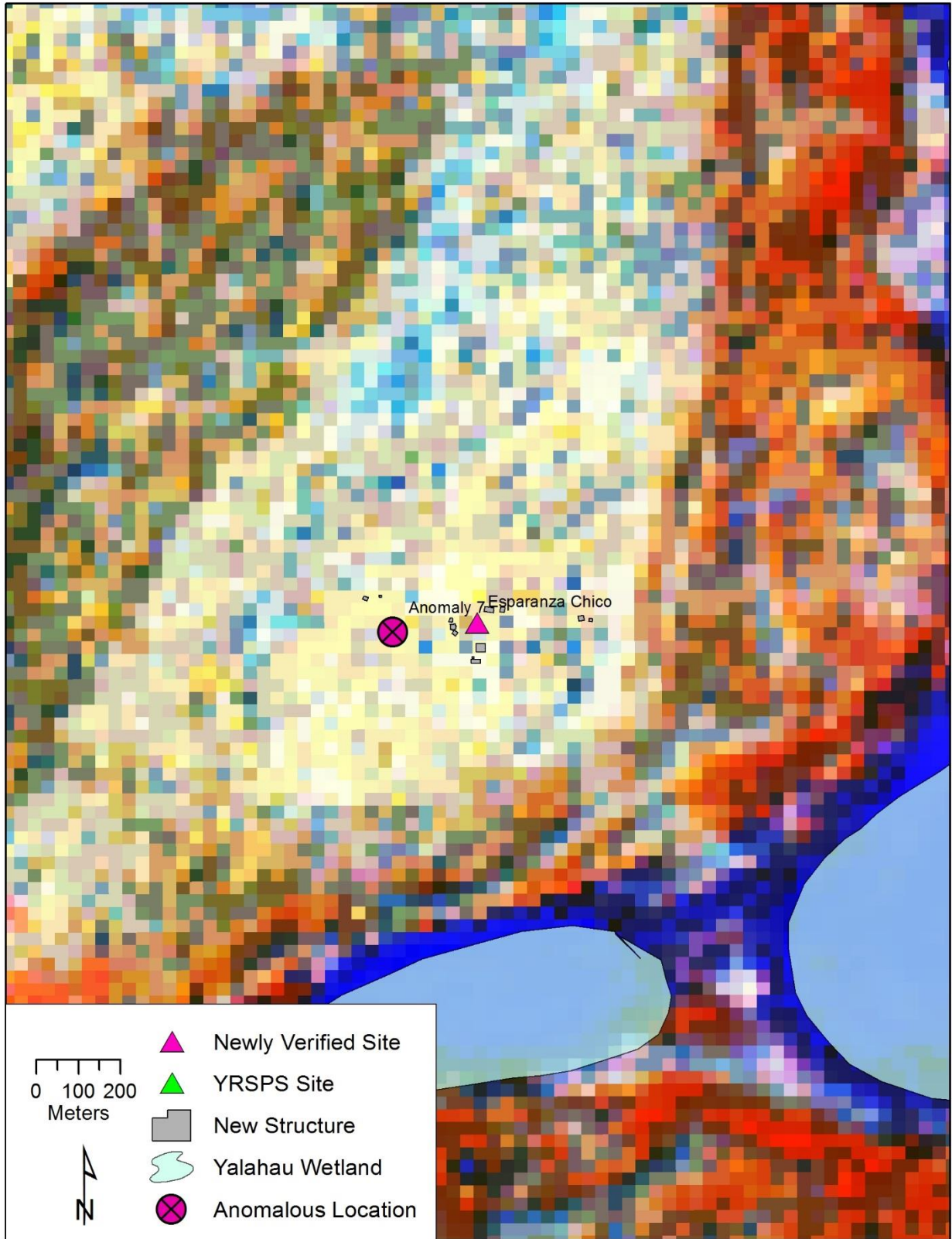


Figure 48 - Esperanza Chico, 2014 TC



Figure 49 - Esperanza Chico, Str-1 (Photo from Daniel Leonard)



Figure 50 - Esperanza Chico, Str-5 (Photo from Daniel Leonard)

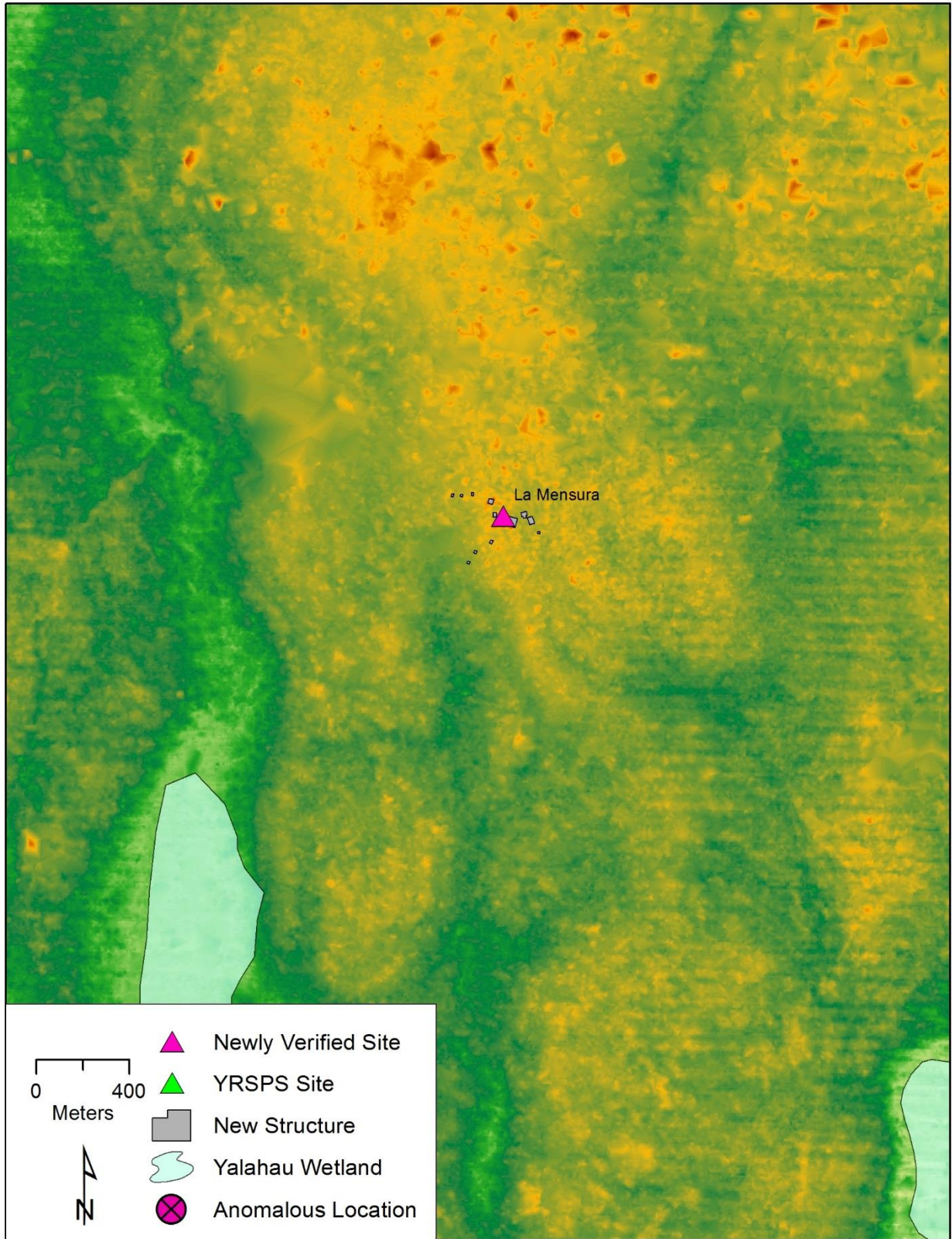


Figure 51 - La Mensura, Terreno DEM

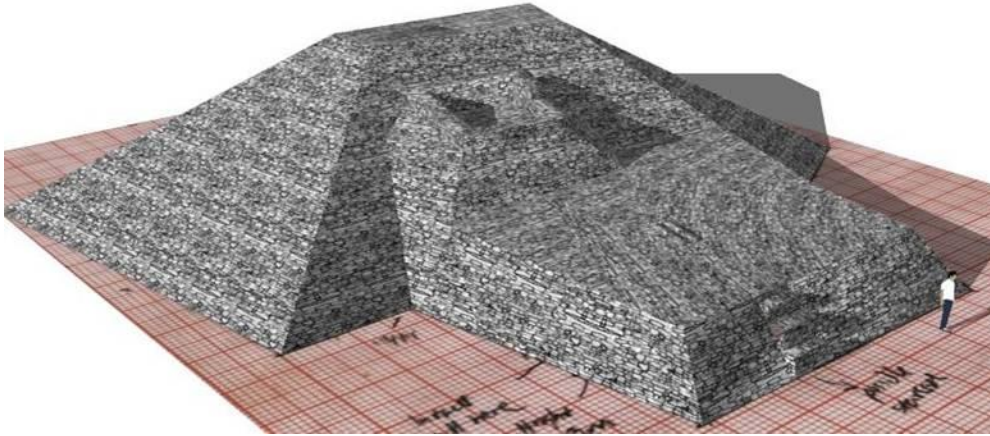


Figure 52 - La Mensura, Str-1 3D (Created by Jeffrey Vadala; Leonard 2013:418)

structures, as was described in Section 4.5. Structures are not distinguishable in the superficial DEM (Figure 53). Only one TC image (Figure 54) was available for this area due to cloud coverage and the lack of visibility from a suitable season. The single TC image which shows the area around La Mensura does have a possible signature visible, however this was very near to an area of cloud cover, and as a result the area of La Mensura was not closely examined until the data from Leonard documented the site there, as the cloud cover obscures nearby areas and makes the picking out of signatures difficult.

5.3.2.4 Xpalma

Xpalma (Leonard 2013:394) was likely previously identified by Glover (personal communication) as Site 56 during the course of the YRSPS, yet this site was never reached. This site also lies outside the zone of LiDAR coverage. The only available DEM is the SRTM DEM (Figure 55). Landsat coverage of Xpalma is challenged due to cloud cover. The 1984 image proves the only real un-obscured view of Xpalma, and no signature is apparent (Figure 56). It is possible this site does have a signature that is as of yet undetected, as cloud coverage was present in most of the Landsat scenes.

5.3.3 Space, Settlement, and Environment Project Sites (This Thesis)

Anomaly 1 was the first unknown site identified for this thesis. Anomaly 1 is located near Sites 14, 18 and 23, which were previously identified as part of the YRSPS. This site was identified with the assistance of Johnny Bogle, a fellow GSU student and Ignacio Sancho Torres, our local guide. Anomaly 1 consists of at least two small, low mounds and at least one possibly modified depression (Figure 57). This site was identified through the use of Landsat 7 imagery processed utilizing the tasseled cap. Based upon my visual inspection, the structures at Anomaly 1 appeared to rise no more than two meters in elevation, however brush cover, time and labor constraints

prevented me from making an accurate map of the structures observed and the underlying topography.

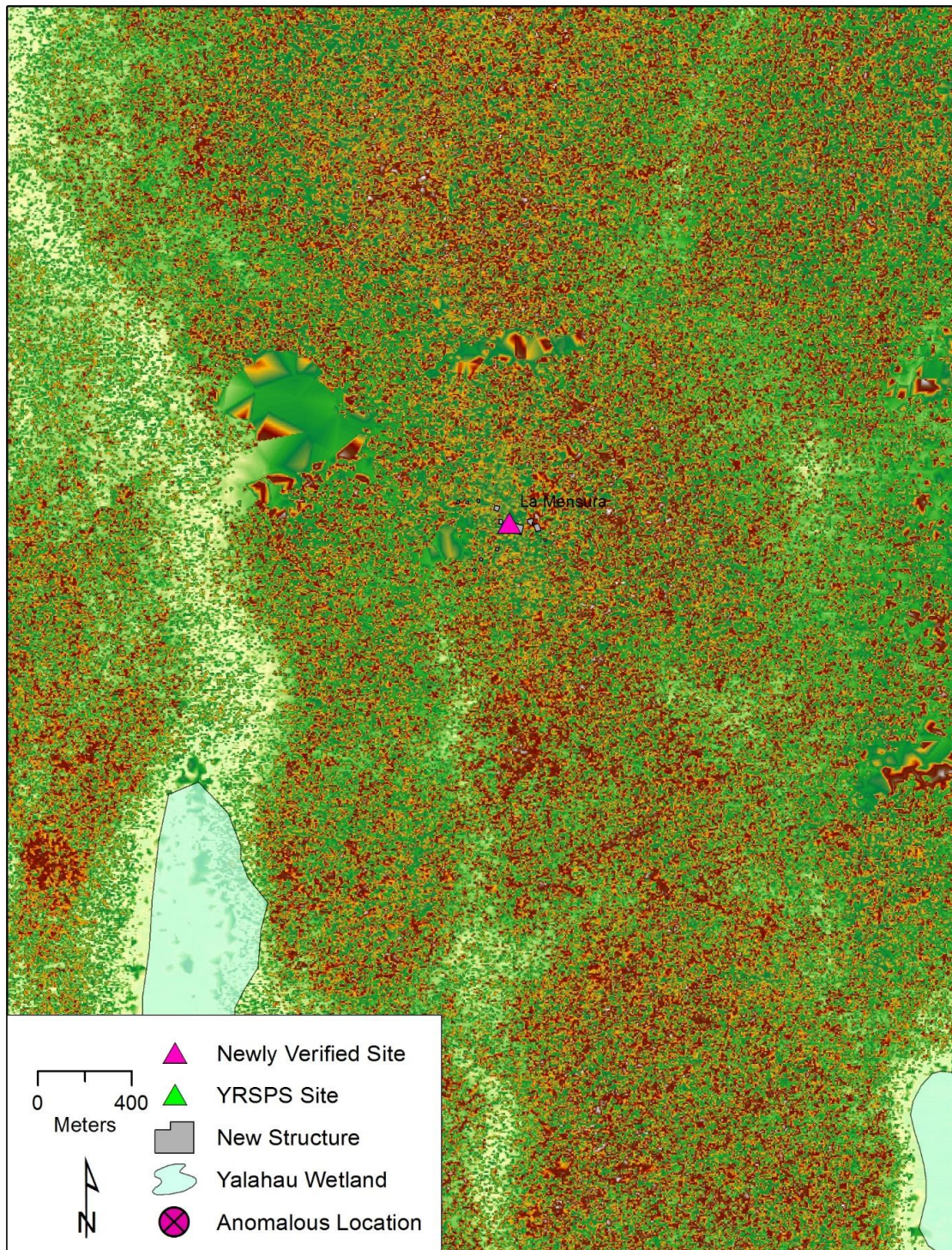


Figure 53 - La Mensura, Superficie DEM

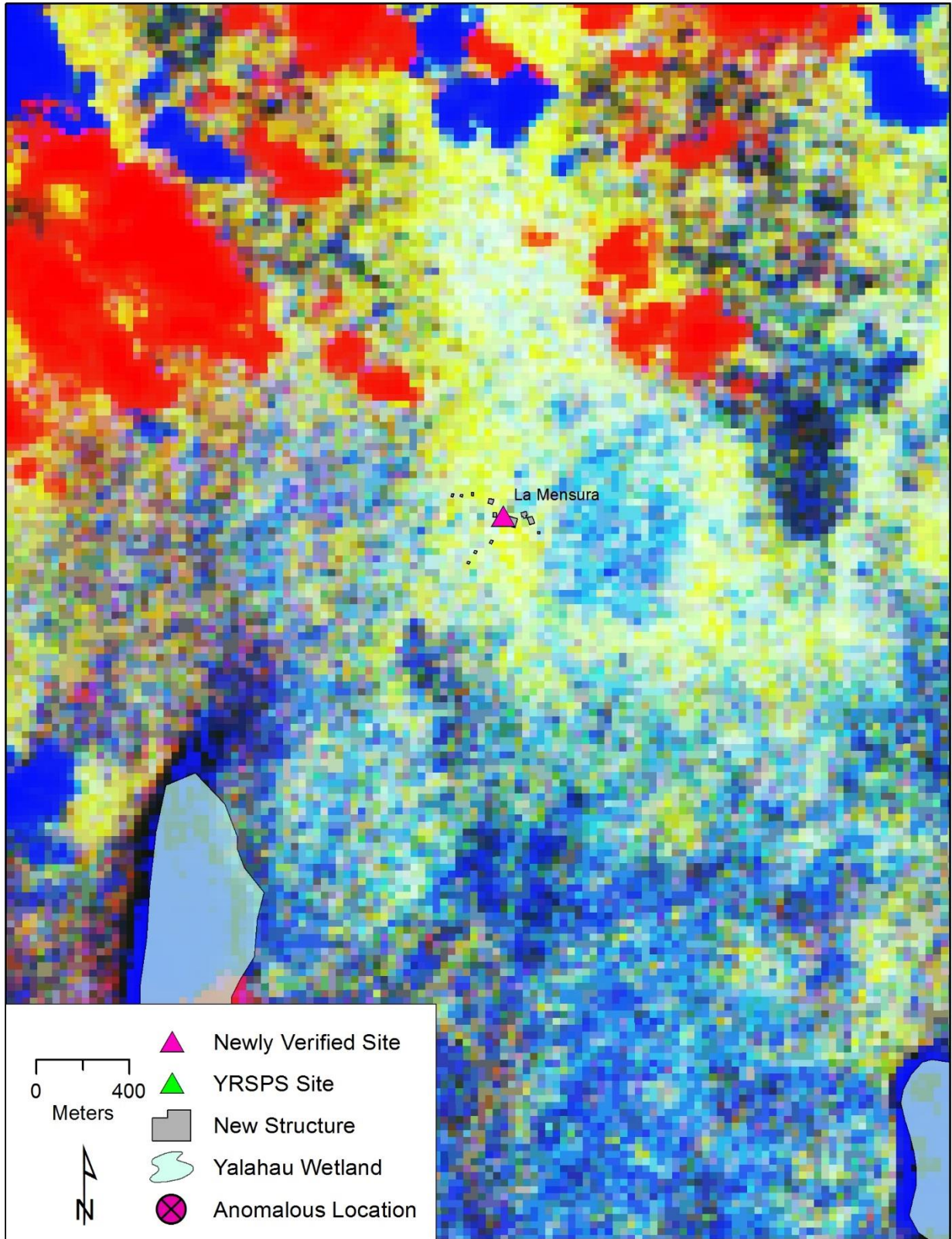


Figure 54 - La Mensura, 1999 TC

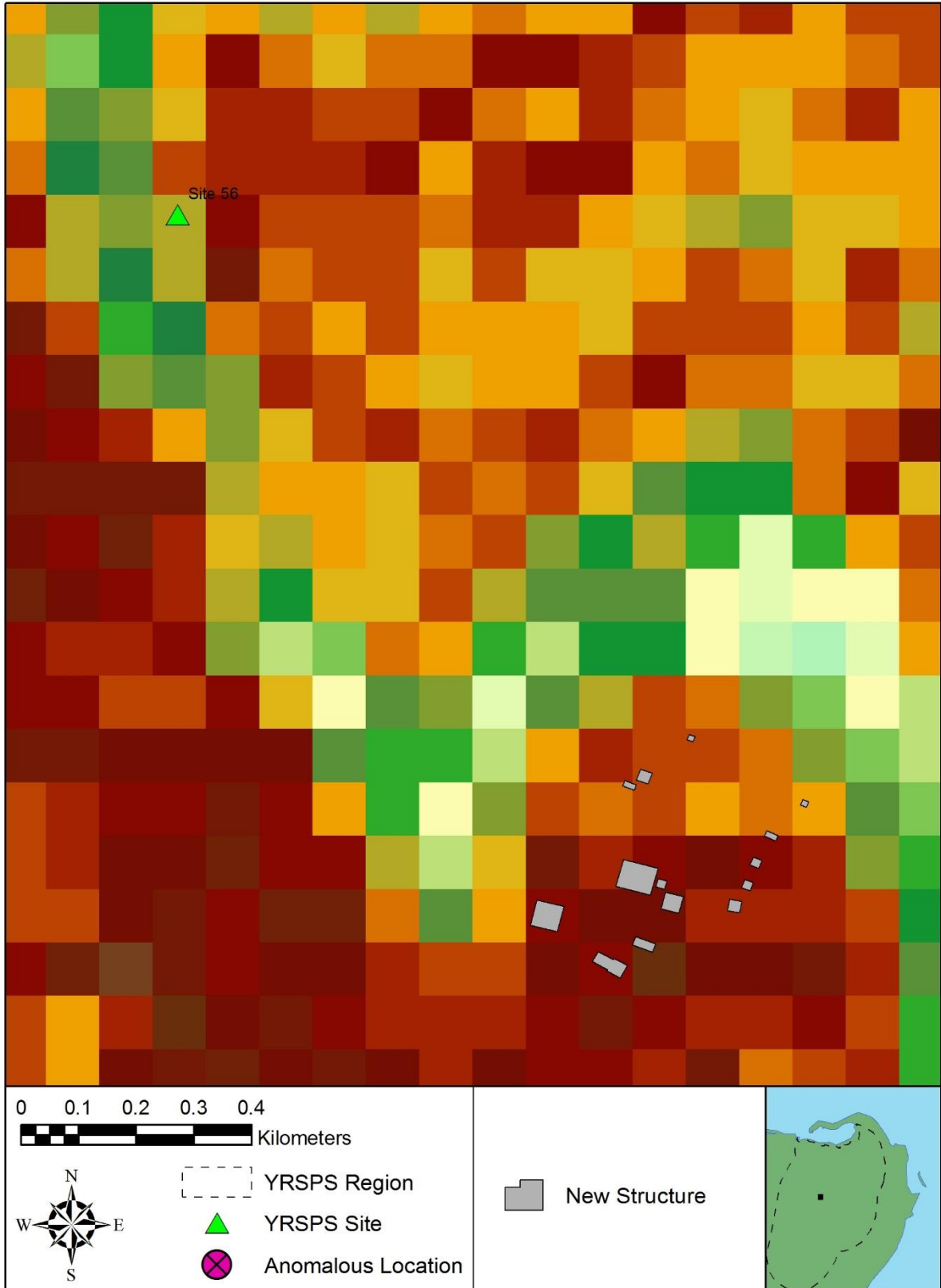


Figure 55 - Xpalma, SRTM DEM

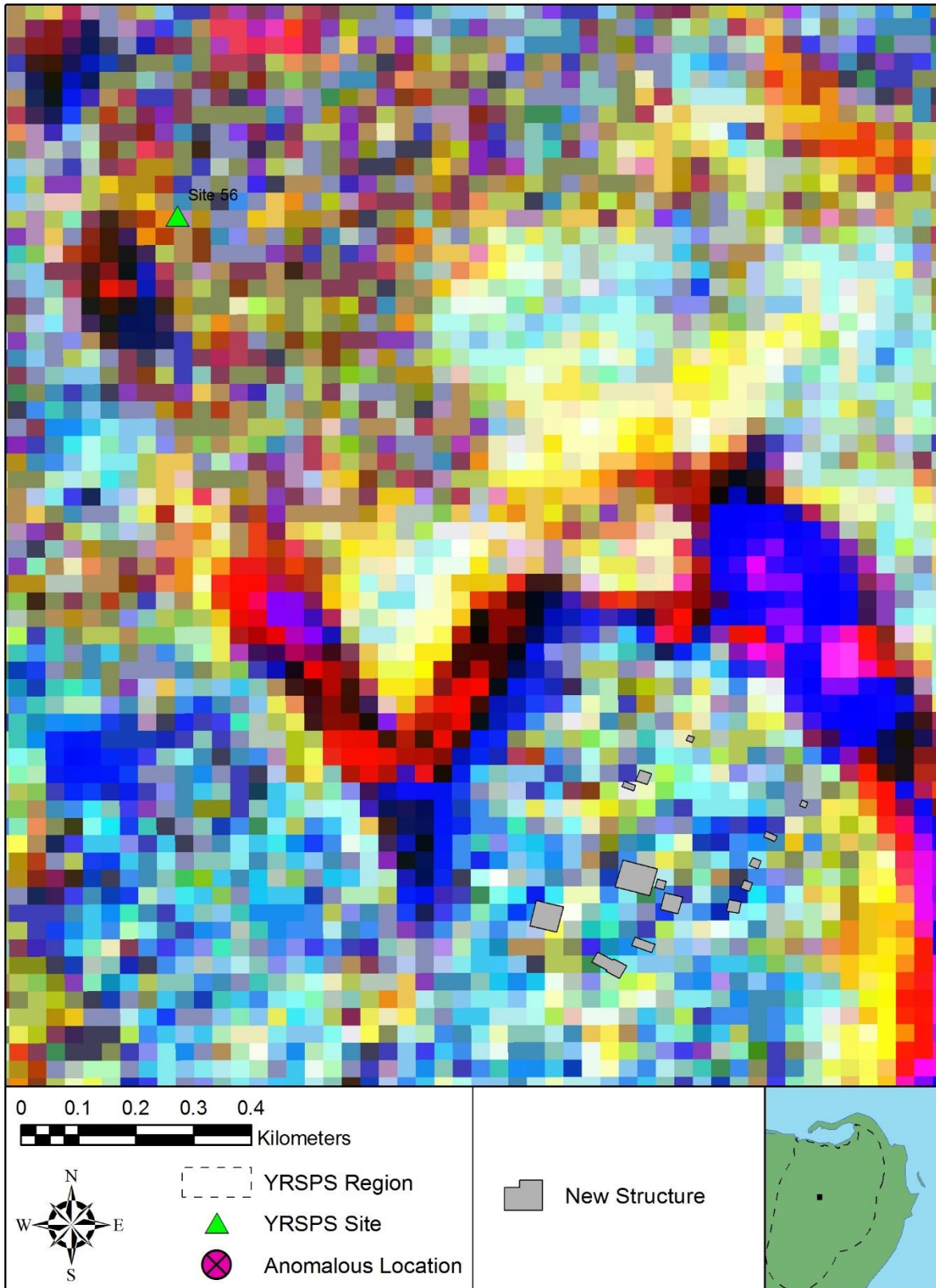


Figure 56 - Xpalma, 1985 TC



Figure 57 – Anomaly 1 Depression, Don Ignacio Right for Scale



Figure 58 - Anomaly 1 - Coursed Stones

Structure 1 measured approximately 30 m by 30 m, using tape and compass to measure and was less than 1 m in height, based on visual inspection. This structure was low, flat and broad. The limits of this structure were difficult to delineate due the vegetative cover, which also hindered

photography of such a platform. Because I was unable to clear the structure proper maps were not possible. Some cut stones were observed in place on Str-2 (Figure 58), and a broken cut stone was observed within a depression or possible aguada (see Figure 59). The second structure was somewhat taller, approximately 1.5 meters tall but was smaller in area. In addition, some potsherds were located on the surface (Figures 60-62), but not collected for further analysis due to the limitations of the permit under which the reconnaissance was being performed – no artifacts were to be collected, photographs only.



Figure 59 - Anomaly 1 Depression, Cut Block Left



Figure 60 - Anomaly 1, Probable Striated Sherd



Figure 61 – Anomaly 1, Rim Sherd



Figure 62 – Anomaly 1, Eroded Sherd

5.3.3.1 Anomaly 2

The site located at Anomaly 2 is a small site located almost due south of the site of San Ramon, a Rank 2 site identified by Glover (2006). The site was identified through the use of Landsat VII imagery processed utilizing the tasseled cap methodology. Anomaly 2 has at least one low mound. The present height of this mound was difficult to assess due to the vegetative coverage and some past disturbance. Access to this site is via a highly over-grown road. According to Don Samuel (Figure 63), my guide for the day, the location to which we traveled was the location of a ranch some number of decades in the past, but within his living memory. I saw evidence of this. Fences, barbed wire and even what appeared to be an outhouse were all covered in vegetation, but still present on the site. In addition to this, Don Samuel pointed out where he said he had previously

seen what he knew to be Maya ceramics. Here, Don Samuel and I found a few potsherds on the surface that I photographed but did not collect (Figure 64). He indicated that what I interpreted be a mound (presently a raised area of rocky soil where we had found the ceramic material) had been much larger initially, perhaps a meter and a half high, but that the people responsible for the previous ranch had used heavy equipment and had essentially bulldozed the structure. My visual inspection of this site supports this claim. The present status of the mound and the claim of a previous height of more than one meter coupled with the clear presence of Maya ceramic material all support this argument. The rainy conditions at the site limited photography to the ceramic material.



Figure 63 - Don Samuel



Figure 64 - Anomaly 2 Sherds, Probable Carolina Bichrome Right

5.4 Conclusions

Utilizing the methods outlined in Chapter 4, I analyzed the existing regional settlement data, the YRSPS (Glover 2006), through the lens of remote sensing. Though LiDAR was not effective for the prospection of archaeological sites, it was successful in delimiting the location of possible cenotes and other karstic features, which are often connected with Pre-Columbian settlement. SRTM Data was also problematic in terms of elevation. The most effective remote sensing tool, of those available for use in the Yalahau, was Landsat imagery utilizing the Tasseled Cap transformation. Nine anomalies were defined (Table 9) as part of the SSEP. Of these, three were shown to correspond with two sites recently identified during the YRWS (Leonard 2013). Two more anomalies were confirmed as newly identified sites through the SSEP. Four anomalies identified during this thesis have yet to be accessed due to time and budget constraints.

Table 9 – Anomalies

Anomaly	Status
1	SSEP New Site
2	SSEP New Site
3	Anomaly – Unable to access
4	Anomaly – Unable to access
5	YRWS Site - Tio Feliz
6	YRWS Site - Tio Feliz
7	YRWS Site - Esperanza Chico
8	Anomaly – Unable to access
9	Anomaly – Unable to access

6 Discussion

This section discusses the integration of the results of this thesis with the previously existing research in the region. The questions posed in section 1.1 can be summed up thusly: What can be gained in the understanding of settlement pattern from the inclusion of remote sensing data for research in the Yalahau region. More specifically, do the areas perceived during the course of Glover's(2006) informant led YRSPS to be lacking archaeological sites actually lack sites, or was this an artifact of the methods used. The claim of depopulated status for the region during the Classic period is unfortunately reliant on a lack of evidence – a tenuous position when archaeological sites can be completely missed as a result of 5 meters of thick jungle. This position requires there be no other sites in the region that might yield significant Classic period occupations. Glover (2012) is certain that the survey methodology employed in the YRSPS captured all sites with architecture larger than residential, and a sample of those with only residential features. This contention is further supported for the northern portion of the Yalahau by the results presented in this thesis, though the relatively small anomaly at Kimin Yuk allows for the possibility that a large site could be present at one of the as of yet unverified anomalies. Two other secondary questions, about the lack of settlement in the area around Kantunilkin as well as the presence of a low elevation area on the eastern side of the study are also addressed in sections 6.1 and 6.2 respectively.

Anomalies that have been physically verified all fall into Glover's Yalahau site ranking scheme as Rank 4 sites, which are the smallest sites composed of dispersed residential architecture. Anomaly 1 was hypothesized to be comparable in size to the nearby unnamed distributed residential groups, Sites 14, 18 and 23 based on the apparently comparable magnitudes of their respective signatures. When physically verified, the architecture located at Anomaly 1 was in fact comparable to the architecture reported at Sites 14, 18 and 23. Anomaly 5 was predicted to be the same, and the physical verification of the site resulted solely in house mounds. If this comparison holds true for sites of larger scale, then the largest anomaly which has yet to be verified in person has the potential to yield architecture comparable in size to a Rank 3 site in the Yalahau regional rankings – the addition of which would not significantly alter the current understanding of the sociopolitical relations within the region.

6.1 Kantunilkin Area

One caveat to Glover's (2012) analysis of settlement pattern was the possibility of sampling error with regards to the presence of smaller centers and residential sites around Kantunilkin, which may have been one of the largest regional centers but is now mostly beneath the modern town of the same name. Figure 65 depicts the area to the east of the site and modern town of Kantunilkin. The anomalous location (Anomaly 9) in this image is based upon the report of a mound somewhere southwest of the wetland at that location (Daniel Leonard, personal communication 2015). This led to a more intensive examination of the area in question and the

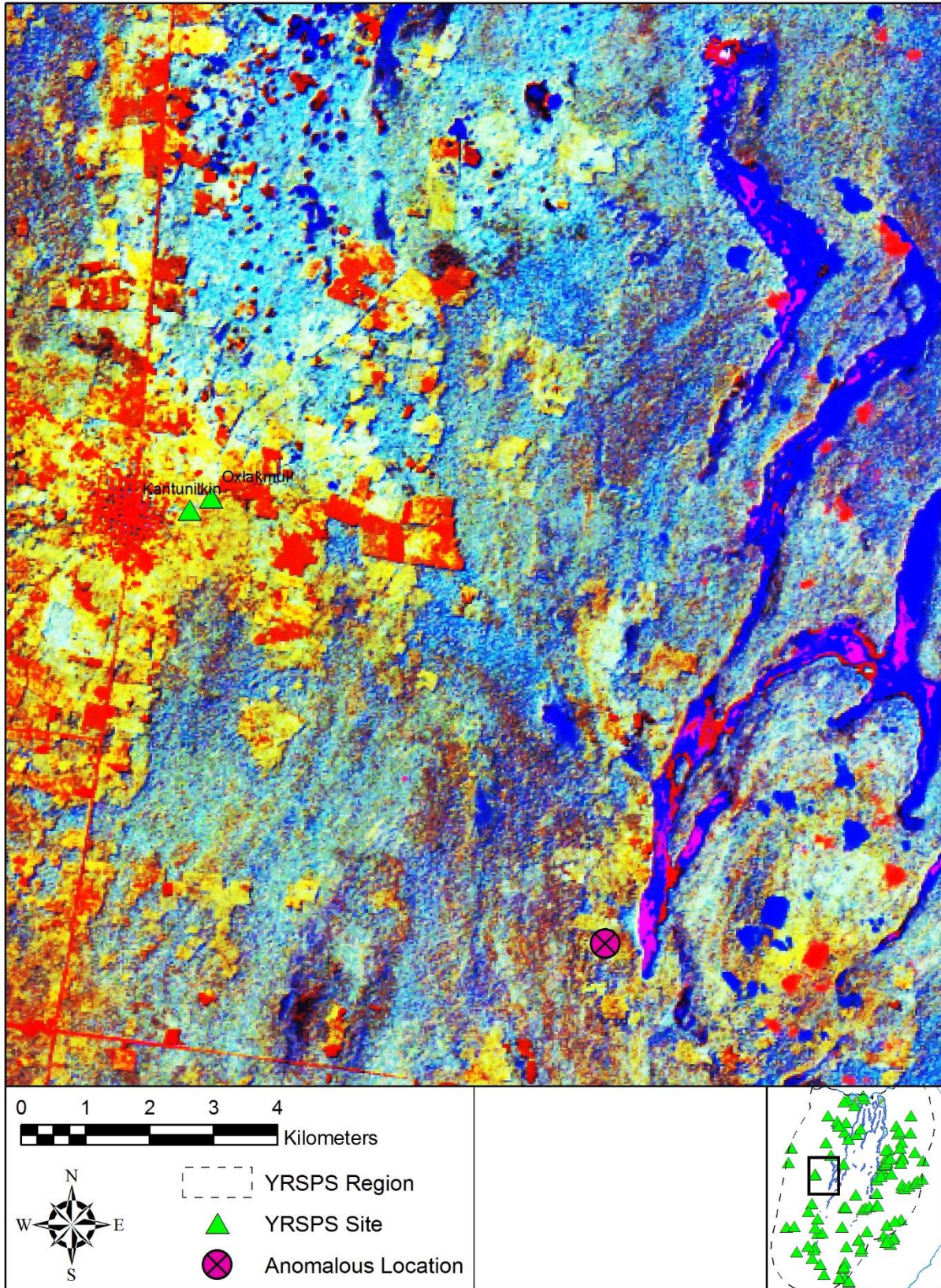


Figure 65 - Kantunilkin Area 1999 TC

identification of a signature similar in appearance to that at Anomaly 1. The abundance of active and fallow cleared areas across the zone makes it difficult to see any possible anomalies. Figure 66 from 2014 shows a signature which looks similar to those found over the site just to the north, around San Ramon, however the 1984 image does show what appears to be cleared fields in that general area. Between these two images, it is challenging to present a definitive answer. Given the general lack of anomalous signatures in the zone however, it is unlikely there is another center between Kantunilkin and the wetlands, though there may be some isolated structures throughout the zone.

6.2 Eastern Elevation Anomaly

Another observation made by Glover (2006) was the apparent low area extending north of Kimin Yuk and to east of Nohoch Pich as seen in Figure 67 and discussed above. The terreno LiDAR DEM does not show any large depression like the one visible in SRTM Data. Glover identifies this area as being mostly devoid of sites according to the local informants he was working with. The low elevation was the proposed explanation for the lack of sites in the region, and given that this explanation conflicts with the available LiDAR DEM, can remotely sensed data help confirm the absence of sites in this zone? Landsat images of the area present an intriguing possibility. Figure 67, a TC image from 1984 shows the area with no spectral signature over the low elevation zone from the SRTM data. In Figure 68, a seeming palimpsest of anomalous signatures is apparently coincident with the SRTM low zone. The SRTM mission was flown on the Space Shuttle Endeavour in the year 2000 (Bamler 1999). It's possible what is reflected in the SRTM elevation data is actually whatever event is reflected in the 1999 TC signature, possibly showing the impact of Hurricane Mitch, which hit the region in 1998 (Landsea et al. 2014; Whigham et al. 2003).

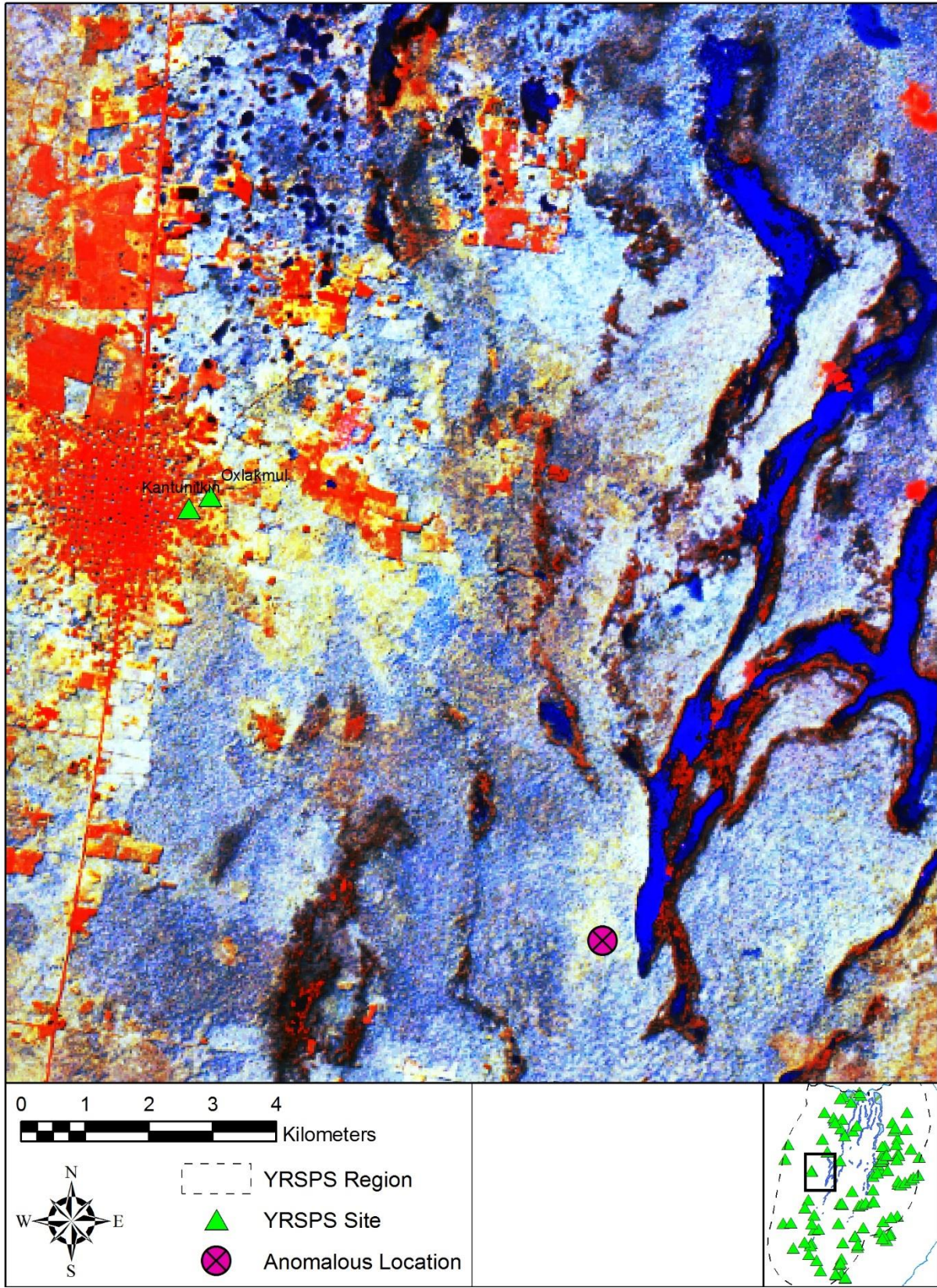


Figure 66 - Kantunilkin Area, 2014 TC

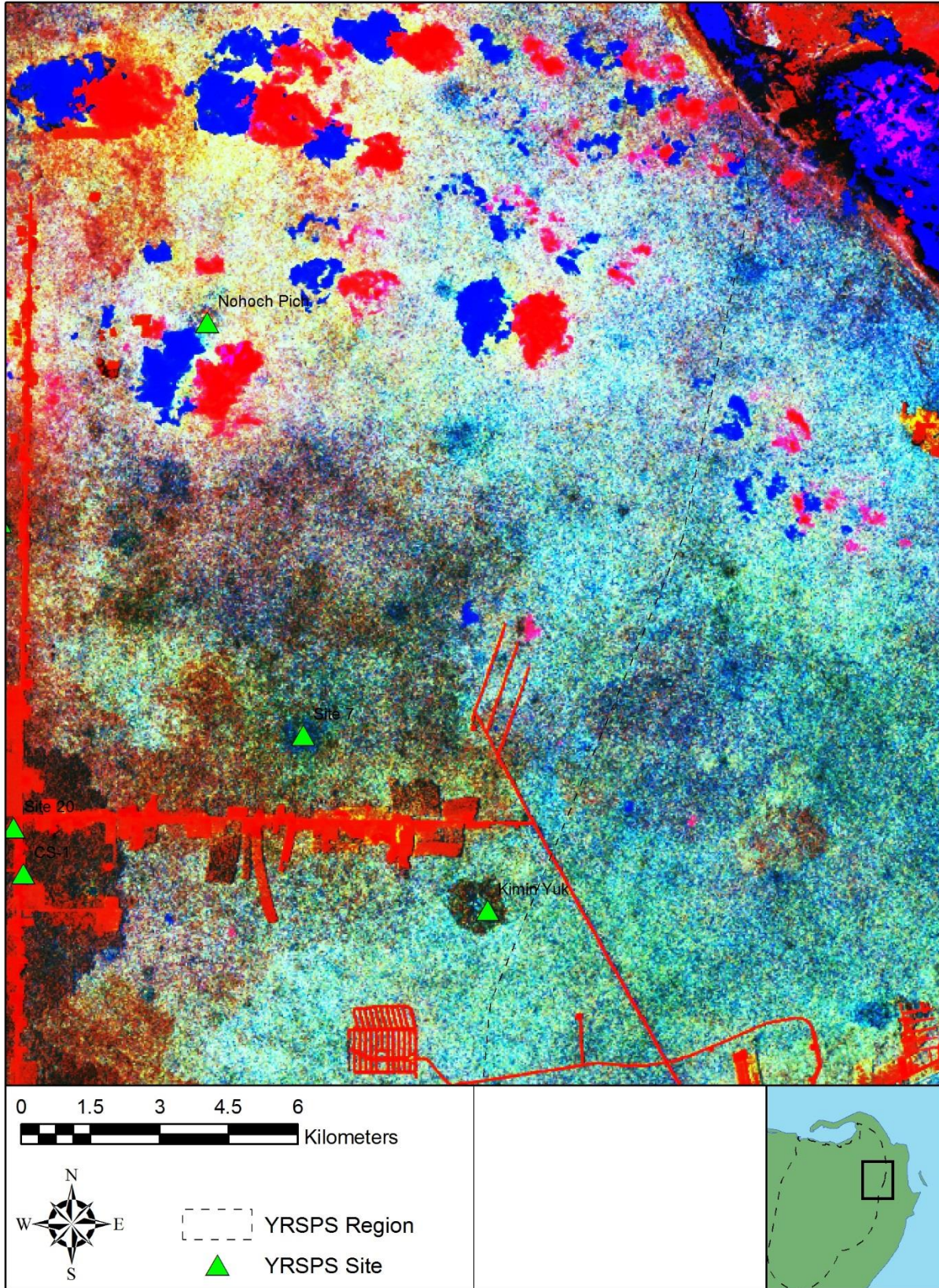


Figure 67 - YRSPS Eastern Depression, 1984 TC

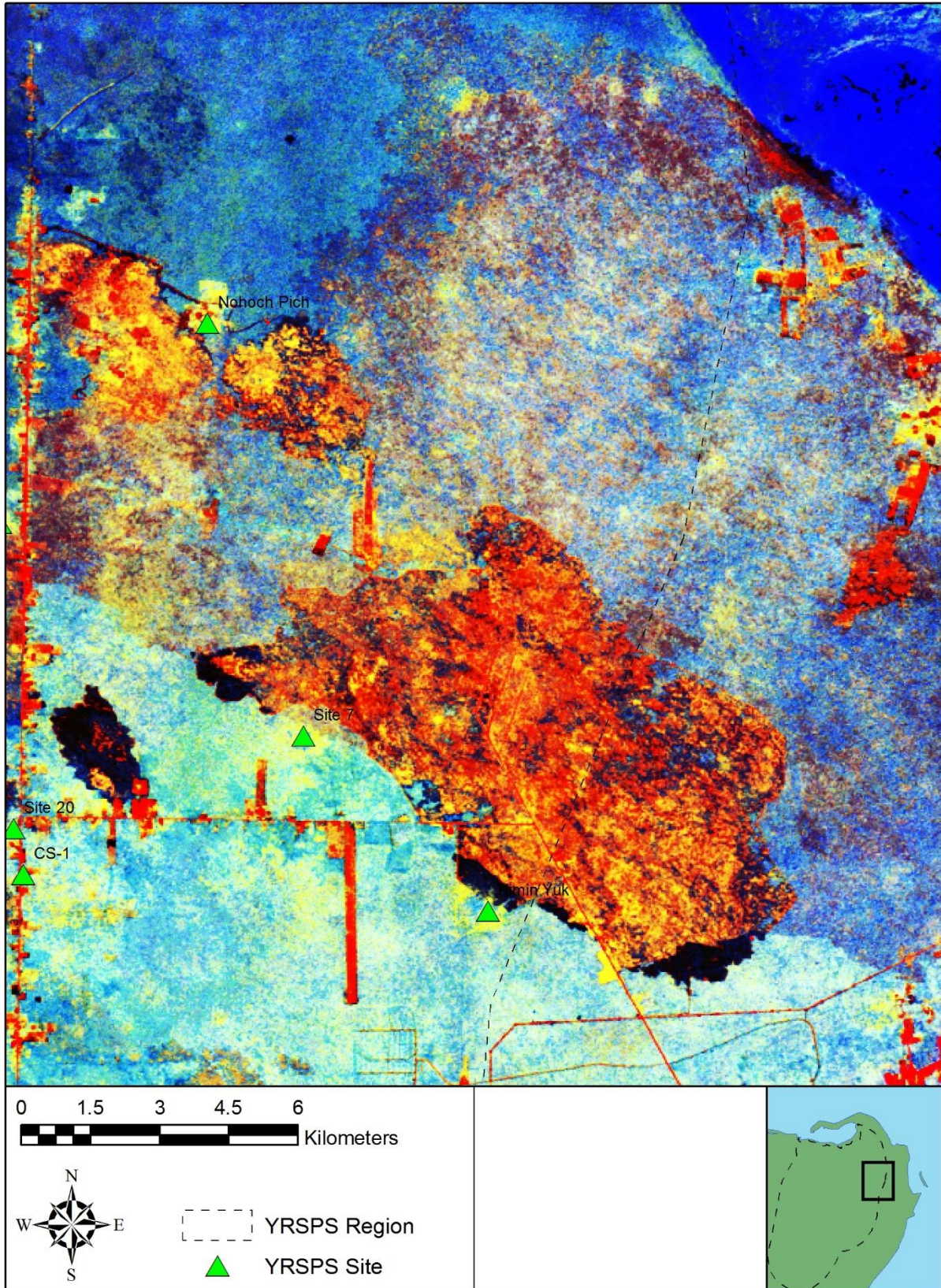


Figure 68 - YRSPS Eastern Depression, 1999 TC).

The second facet of this zone still up for debate, like the area around Kantunilkin, was whether the apparent lack of sites within the zone was due to an actual lack of sites or a sampling error due to the informant based methodology. Examining the area around Kimin Yuk and Site 7, it is apparent that there was some signature present in this area over Maya sites, as Figure 69 illustrates. This signature was different, however, than those seen just to the north, near Anomaly 1 and Site 18, though the images are nearly 15 years separated. They were also taken with different satellites, under different seasonal conditions. The TC image from 2015 (Figure 70) shows different signatures for the same sites, however the apparent signature over Site 7 in Figure 69 has been lost, yet the signature over the site of Kimin Yuk is now much more typical of the Brighter and Greener signature documented elsewhere. Examining the site of Kimin Yuk in detail (Figure 71), it is possible to see that the constraint of the boundary of the signature over the site does not appear to be directly related to the presence of documented architecture, however an intriguing alternative explanation for this correlation is the presence of hidden or invisible (after Johnston 2002) anthropogenic modification to the landscape. Testing this hypothesis would require excavations, which were not within the scope of this project. The anomaly around Site 7 is different and much bluer than the anomaly over Kimin Yuk, except for the areas of directly above architecture, the significance of which I discuss below.

I cannot understate the role that the previous data available in the region (Glover 2006, Leonard 2013) has had in allowing these sorts of interpretations. Without baseline data to reference and a wealth of experience in the various micro-biomes within the Yalahau, ascertaining signal from noise in the symphony of multi- and hyper-spectral data would have been an impossible task. At the same time, picking signal from noise in this data can greatly enhance the interpretive power of local informant knowledge about a region.

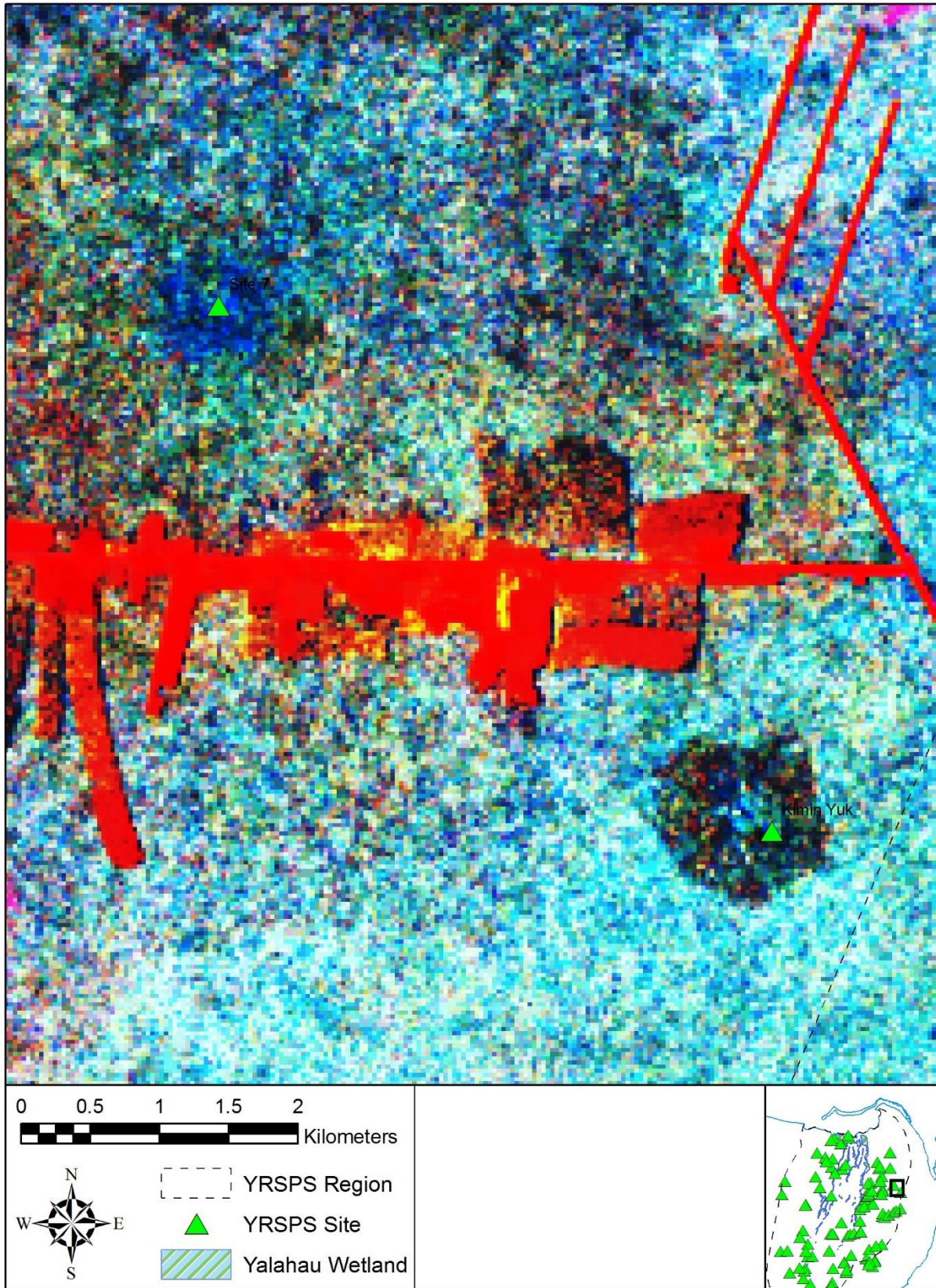


Figure 69 - Kimin Yuk, 1984 TC

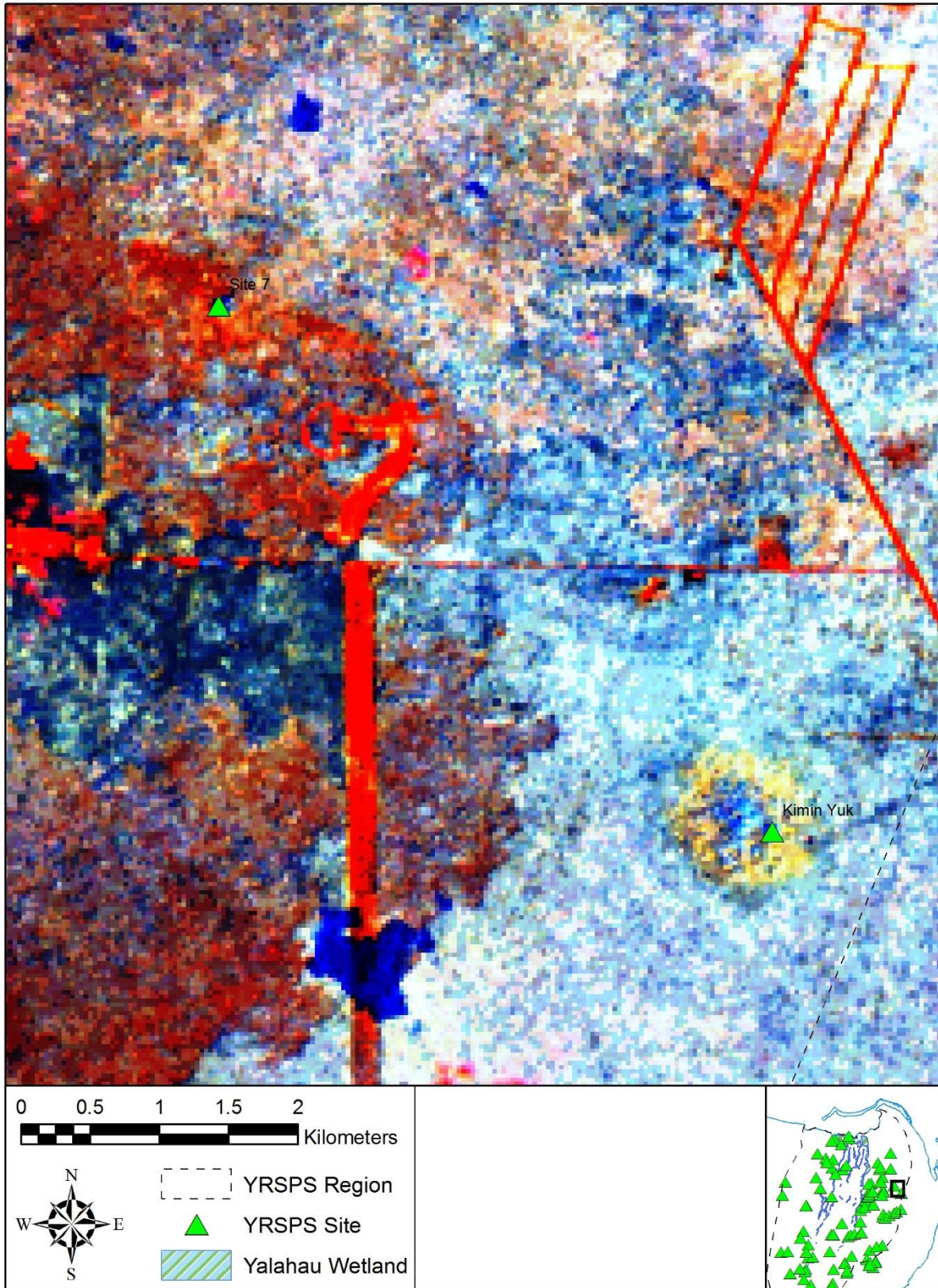


Figure 70 - Kimin Yuk, 2015 TC

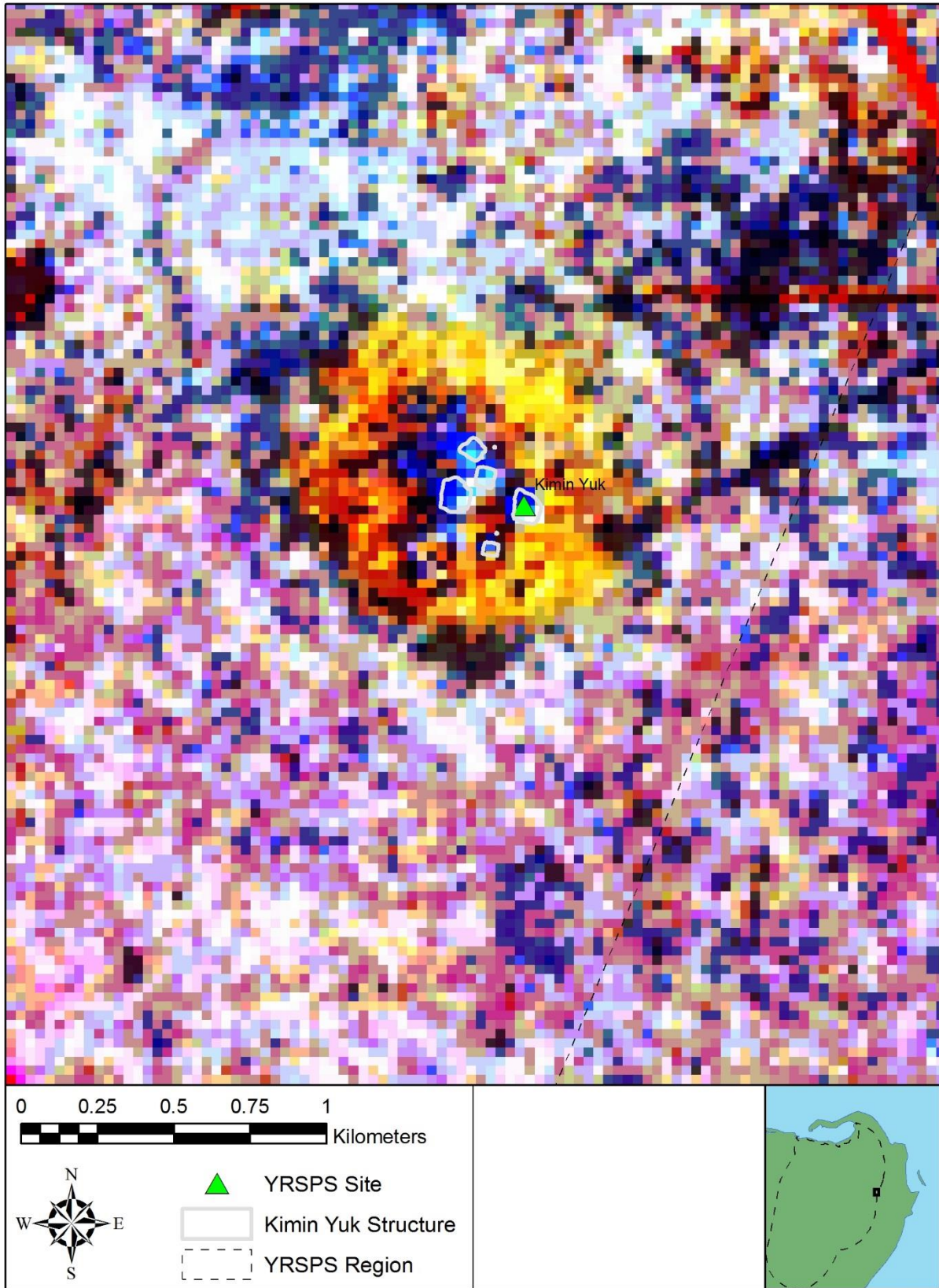


Figure 71 - Kimin Yuk Detail, 2015 TC

6.3 Methodological Synthesis

While remote sensing focused research may be able to contribute knowledge to archaeology, the utility of these data in archaeology depends on the creativity of the researcher in linking variations in data to variation in human activity in the past. Though I was able to identify a number of the previously identified YRSPS sites in the remotely sensed data, my ability to do so was greatly enhanced by the previous research in the area. The high number of YRSPS sites located within zones too recently disturbed for reliable remote sensing assessment cements the utility of informant based and other physical survey for assessing prehistoric settlement. Likewise, remote sensing allows the research to build on past experiences and to explore when no local guide may be available. The availability of free Google Earth imagery has allowed for virtual flyover surveys of the region (Fedick 2014). The compatibility of these methods is significant – both remote sensing and physical survey can, and should, be used together, one to improve the other. Each method has strengths and weaknesses, however together the complementary methods produce a picture that is more complete than either would be alone.

Post-structural interpretation of the archaeological record acknowledges that the links researchers make within data are their own and not necessarily representative of any inherent truth about the past. Acknowledging this fact, I submit that interpretations of remotely sensed data that incorporate multiple lines of evidence beyond remote sensing – including local knowledge, personal observation and human (as opposed to machine) based pattern recognition are preferable to rote application of software defined methods of data analysis, such as the uncritical use of viewsheds, least cost path analyses or probability modeling. In my view best practices for remote sensing and archaeological research revolve around dialogue between disciplines (prehistoric and historic archaeologists both local and from abroad, biologists, cultural anthropologist, historians, hydrogeologists) and with local stakeholders (land owners, local residents, local informants, regional

and national political leaders, local regional and national archaeological permitting authorities).

Remote sensing cannot and should not replace physical verification of archaeological sites. Likewise, an informant-based survey of archaeological remains should not neglect to attempt remote detection of archaeological sites, as the presence or absence of informants is not in any way related to the presence or absence of archaeological remains.

I return here to more thoroughly discuss the work of Marcos Llobera (2005), previously addressed in Chapter 2, in the context of my own concept of using quantitative methods in a more post-structural manner. Llobera utilized GIS tools in a post-structural, post-processual and creative manner. By restricting the parameters of the software tool used to derive viewshed based on subjective observations about viewing distance and perception with regards to the specific biomechanics of human sight, Llobera created a series of concentric viewsheds representing the near, mid and far fields of vision. Viewshed analysis has been particularly problematic for archaeologists. Because of the name of the tool - “view” shed - the implication of bringing the human being into software has appeal that is difficult to ignore. However, the default bounds of a viewshed in most software packages are arbitrarily large compared to human perception. One of the primary use cases for viewshed type processed data products in industry is for antenna inter-visibility. Thus Llobera, seeing the possibilities and limits created by the software tool, creatively integrated the tool into the program of research he was conducting. By measuring the changes in perception and combining personal insight and observation with software tools Llobera (2005) was able to use GIS and remote sensing (Digital Elevation Models) to generate and evaluate interpretations of the landscape.

Though this research did not utilize viewshed analysis, the tool has been well debated generally in the context of GIS in Archaeology, and I view this debate as a microcosm of the debate occurring more generally. Many other researchers sustain the critique on GIS methods (e.g., Frieman

and Gillings 2007; Gillings 2012; Loebel 2012; Rennell 2012). These methods are inherently statistical (a DEM, is extrapolated using statistical methods) and thus subject to statistical errors. This is in addition to taphonomic issues, like erosion, and before a schema (after Johnston 2002) of visible, hidden or invisible is even applied to help understand the results. These aspects are the same for Landsat data, though there are more bands and so more than one value for a given area. And as discussed in Section 4.2, each set of these values represents an area 30 meters by 30 meters, coincidentally the same size as the first structure located in this thesis at Anomaly 1.

Any method utilized must be situated within the program of research for which it was performed explicitly with these limitations acknowledged. The purpose of this is to generate a dialogue between results, method and theory to produce and document the production of a well-supported interpretation. It is in this dialectic generation and evaluation of interpretation that I have found the most utility in engaging with remotely sensed data. By helping to visualize the environment and assist in detecting subtle variation remote sensing data can help to locate undocumented sites and uncover cenotes.

Conversations with “Men of the Monte”, my guides in Yalahau, reveal a wealth of knowledge about all aspects of the forest – observations range from the type and age of the forest growth to the intentional removal or protection of various species of tree. Genus *Manilkara* (Chicle) and genus *Ceiba* are protected generally, even during the clearing of Milpa or the cutting of boundaries or paths, (known locally as mensuras and brechas, respectively), according to multiple guides in multiple towns across the region. These people are present day Yalahau residents, many of whom had never met each other and yet they recognized common interest in preserving certain resources within the area.

Those who regularly hunt, gather, farm, work and live in the uplands and lowlands that make up the Yalahau region – those who I hired as guides, like my friend Don Ignacio (who led me to the

first anomaly I identified as a site) see and perceive a lot more of the forest while walking through it than I am able to. Incredibly and perhaps fortuitously, the remotely sensed data I had at my fingertips allowed me to visualize variation that I initially missed on the ground – variation which Don Ignacio and others with more local knowledge of the landscape are able to see. Take, as an example, the following narrative description of the journey through the forest to Anomaly S1.

6.4 A Walk in the Woods with Don Ignacio

In preparation for my planned visit to the anomaly, I traced an outline around the anomaly as I saw it in the GIS software. I loaded this outline, along with some natural color satellite imagery for navigation and orientation onto the GIS equipped tablet that I use as a GPS and data recorder for fieldwork. Thanks to the satellite imagery, I could see the presence of a break in the foliage indicative of some level of cleared path leading north a number of meters into the forest, and then west directly towards the center of the anomaly. Along the way, in my broken Spanish, I explained as best I could the purpose and methods of my research to Don Ignacio, who had graciously agreed to accompany me as guide. Understanding my interest in both the nature of changes within the forest and the archaeology broadened the spectrum of observations from my companion greatly. Slight changes in the prevailing vegetation would prompt a brief explanation of the various beneficial and detrimental plants. As a former boy scout with a strong allergy to poison ivy, I had a very strong interest in the identification of *Metopium brownei* (chechem or poisonwood). When I explained my concern to Don Ignacio, this prompted a careful and deliberate explanation of how to identify the plant at all stages of growth from seedling to tree, including an impromptu quiz when confronted with a small patch of chechem seedlings.

Upon arrival at the boundary of the outline, delineated sight unseen the night before the trip, Don Ignacio pointed out what was the most striking shift in vegetative coverage thus far. The forest behind and to either side of us seemingly ended in what appeared to be a wall of greenery, denser

and more intimidating than any of the forest we had traversed previously. Looking back, the forest behind us was positively open compared to what lay ahead (Figures 72-76). According to Don Ignacio, the brecha we were on was cut in one session, the same width along its entire length, a few years previously – yet the path forward was noticeably smaller. Walking forward and looking at my GPS, I saw that the outline I made based on the anomaly directly correlated with the visible change in the vegetation. Moving forward into the anomaly, many more stones were present on the ground surface, eventually giving way to at least two low platforms, which is the site documented in section 5.3.3.

6.5 Integrating Interpretation

While at larger regional sites ceramic data can span from the Middle Preclassic to the Early Classic and Postclassic, establishing a clear chronology of use and abandonment is extremely problematic for smaller sites distributed throughout the landscape. Infrequent storms in the region will often result in communities moving a few kilometers from their previous location after the storms pass from modern examples (Glover 2006:645). Would this not have occurred in the more distant past as well? Low lying terrain can be extremely susceptible to flooding, and slight changes in topography can vastly alter the direction of water flow and severity of flooding. In assessing this sort of question, the utility of remote sensing is perhaps less in the quantifiable data. The utility lies instead in the subjective quality of interpretations based on multi-system remote sensing. These more nuanced interpretations certainly have the power to enhance future archaeological research in the Yalahau region.

6.6 Recommendations and Conclusions

There are a number of possible explanations for the anomalous spectral signatures present in the Landsat TC



Figure 72 - Don Ignacio



Figure 73 - Bogle and Vaughan



Figure 74 - Managed Resource – Chicozapote Tree with marks of the harvest



Figure 75 - Don Ignacio, on his Brecha



Figure 76 - The Jungle Closes in as we approach Anomaly

images. There is a corollary to the quote from *How to Lie with Maps* (Monmonier and Blij 1996:2) when it comes to mapped data and archaeology. If “[a] single map is but one of an infinitely large number of maps that might be produced for the same situation or from the same data” then it follows that one map can have any number of interpretations by an audience as to the nature of the data underlying the map. It’s clear from both the anomalies identified as archaeological sites for this thesis as well as from the already available YRSPS data that structures do not appear to be the source or the sole source of much of the spectral signatures. Other possible explanations include differential speciation at the location of some sites as a result of legacy effects of the “Managed Mosaic” (Fedick 1996) of Maya agriculture. Structures could be impacting access to water for trees rooted high above the water table on architecture (Fedick 2014). Alternatively, architecture (in particular eroding limestone (Fedick 2014)) may hold water, aiding trees rooted on structures. Future research can address these questions as well as further utilize the methods outlined in this thesis for site detection in Landsat 8 imagery, which has yet to be acquired.

6.6.1 Directions for Future Research

There are two primary avenues for future research following this thesis. First, continued acquisition, processing and analysis of remotely sensed data should remain a facet of research in the Yalahau region. This will involve the continued request and retrieval of updated commercial and publicly available satellite imagery utilizing the methods outlined in Chapter 4 as well as the acquisition of new data through the use of unmanned aerial systems. The second general category of continued research is in the further verification and fieldwork with regards to the anomalies. This research has two primary branches, the first is in visiting and verifying the presence or absence of prehistoric materials at the anomalous locations proposed in Chapter 5. The second is in assessing what exactly is causing the anomalous signatures in the first place. This work can take the form of

soil chemistry analysis or ecological analysis, or preferably both. These assessments would help to elucidate what impacts are causing the visible spectral signatures, which have been using in this thesis to identify undocumented Maya sites.

6.6.1.1 Ecological and Geochemical Survey

Almost in contrast to the aerial angle for further research is a program of exploratory ecological and geochemical ground-based survey in order better evaluate what potential effects are present within the anomalies that may help to further inform the use of remote sensing in the Yalahau region. Ecological transects, like those conducted at Vista Alegre, which span some of the anomalies already identified may help with the identification of differential distribution of species as a possible mechanism to explain the anomalous signature observed. Geochemical survey would accomplish the same goal, but from the perspective of how geochemistry may impact remotely sensed data. Either of these two factors has the potential to impact vegetation and help to produce a spectral signature. Observations about the seasonality of the differences between site and non-site (Garrison et al. 2008; Hixson 2013) could inform this research, with ecological survey designed temporally to test what effects are present when, with relation to the rainy and dry seasons.

6.6.1.2 Continued Satellite and UAS Remote Sensing

There is a clear improvement that can be made upon this type (remote sensing site prospection) of research moving forward – Unmanned Aerial Systems (UAS) can greatly enhance the capabilities provided by remote sensing discussed throughout this thesis. The primary benefit of Unmanned Systems is in the ability to tailor the selection of data to the research questions at hand. A primary example would be the capability to customize the capture of Near Infrared Imagery, as discussed in Chapter 3, capable of sensing subtle variation in vegetation to rainfall events. As rainfall has been seen to correlate to the detectability of signs of human impacts on the environment in

remotely sensed data (Hixson 2013), this represents a significant opportunity to increase the effectiveness of remote sensing in archaeology. Natural color imagery is also greatly enhanced by this sort of tailored data collection. Satellites cannot change course or hold for a day to avoid weather that impacts the quality of collected imagery.

Despite this limitation, the addition of Landsat 8 to the remote sensing toolkit for Archaeology was a tremendous boon to this thesis, and I suspect that the data from this freely available platform will continue to benefit archaeologists in diverse environments the world over including Mesoamerica, even if the path to true utility is not as a cleared thoroughfare but a narrow and winding walkway. As newer satellites are launched and new imagery becomes available it will be necessary to revisit this topic, and reassess what is possible with the remotely sensed data, however this thesis is an example of what can be done with freely available data at this time. Remote sensing is not a single tool that can be implemented in a rote fashion. Instead, remote sensing consists of many tools, which, together, both make possible and constrain investigation in many disciplines. Tools do not themselves cause paradigm shifts in investigatory methods. Remote sensing methods present similar yet definitively different possibilities and constraints for the conduct of archaeological research. The toolbox problem discussed in chapter 2 exists for all archaeological methods and is not unique to remote sensing. Remote sensing and more traditional types of archaeological investigation must be implemented in parallel, and together provide a more complete picture of the human past than either method is able to alone. I look forward to continuing to work at the intersection of remote sensing, GIS, Archaeology and Environmental science as I undertake future archaeological investigations.

REFERENCES CITED

- Amador, Fabio Esteban
2010 *Ancient Pottery in the Yalabau Region: A Study of Ceramics and Chronology in Northern Quintana Roo, Mexico*. LAP Lambert Academic Publishing, Saarbrücken.
- Andrews, Anthony P.
1984 The Political Geography of the Sixteenth Century Yucatan Maya: Comments and Revisions. *Journal of Anthropological Research* 40(4): 589–596.
- Ashmore, Wendy
1984 Classic Maya Wells at Quirigua, Guatemala: Household Facilities in a Water-Rich Setting. *American Antiquity* 49(1): 147–153.
- 2002 “Decisions and Dispositions”: Socializing Spatial Archaeology: Archeology Division Distinguished Lecture 99th AAA Annual Meeting, San Francisco, CA, and November 2000. *American Anthropologist* 104(4): 1172–1183.
- Baig, Muhammad Hasan Ali, Lifu Zhang, Tong Shuai, and Qingxi Tong
2014 Derivation of a Tasseled Cap Transformation Based on Landsat 8 at-Satellite Reflectance. *Remote Sensing Letters* 5(5): 423–431.
- Bamler, Richard
1999 *The SRTM Mission - A World-Wide 30 m Resolution DEM from SAR Interferometry in 11 Days*: 145–154.
- Barber, Martyn
2009 *The History of Aerial Photography: Mata Hari's Glass Eye and Other Stories*. English Heritage, London.
- Beach, Tim, Sheryl Luzzadder-Beach, Nicholas Dunning, John Jones, Jon Lohse, Tom Guderjan, Steve Bozarth, Sarah Millsaugh, and Tripti Bhattacharya
2009 A review of human and natural changes in Maya Lowland wetlands over the Holocene. *Quaternary Science Reviews* 28(17–18). *Quaternary Ice Sheet-Ocean Interactions and Landscape Responses*: 1710–1724
- Beddows, Patricia A.
2003 *Cave hydrology of the Caribbean Yucatan coast*. AMCS, Austin, TX.
- Bevan, Andrew, and James Conolly
2002 GIS, Archaeological Survey, and Landscape Archaeology on the Island of Kythera, Greece. *Journal of Field Archaeology* 29(1/2): 123–138.

- Brady, James E.
1997 Settlement Configuration and Cosmology: The Role of Caves at Dos Pilas. *American Anthropologist, New Series* 99(3):602-618.
- Brady, James E., and Keith M. Prufer (editors).
2010 *In the Maw of the Earth Monster: Mesoamerican Ritual Cave Use*. University of Texas Press, Austin.
- Brady, James E., and Dominique Rissolo
2006 A Reappraisal of Ancient Maya Cave Mining. *Journal of Anthropological Research* 62(4): 471–490.
- Brainerd, George W.
1956 Changing Living Patterns of the Yucatan Maya. *American Antiquity* 22(2): 162–164.
- Butler, Mary
1934 A Note on Maya Cave Burials. *American Anthropologist* 36(2):223-225.
- Castañeda, Quetzil E.
2004 “We Are Not Indigenous!” An Introduction to Maya Identity of Yucatan. *The Journal of Latin American Anthropology* 9(1): 35–63.
- Chase, Arlen F., Diane Z. Chase, Christopher T. Fisher, Stephen J. Leisz, and John F. Weishampel
2012 Geospatial revolution and remote sensing LiDAR in Mesoamerican archaeology. *Proceedings of the National Academy of Sciences of the United States of America* 109(32): 12916–12921.
- Chase, Arlen F., Diane Z. Chase, Jaime J. Awe, John F. Weishampel, Gyles Iannone, Holley Moyes, Jason Yaeger, Kathryn Brown, Ramesh L. Shrestha, William E. Carter, and Juan Fernandez Diaz
2014 Ancient Maya Regional Settlement and Inter-Site Analysis: The 2013 West-Central Belize LiDAR Survey. *Remote Sensing* 6(9): 8671–8695.
- Chase, Arlen F., Diane Z. Chase, John F. Weishampel, Jason B. Drake, Ramesh L. Shrestha, K. Clint Slatton, Jaime J. Awe, and William E. Carter
2011 Airborne LiDAR, archaeology, and the ancient Maya landscape at Caracol, Belize. *Journal of Archaeological Science* 38(2): 387–398.
- Chase, Arlen F., Lisa J. Lucero, Vernon L. Scarborough, Diane Z. Chase, Rafael Cobos, Nicholas P. Dunning, Scott L. Fedick, Vilma Fialko, Joel D. Gunn, Michelle Hegmon, Gyles Iannone, David L. Lentz, Rodrigo Liendo, Keith Prufer, Jeremy A. Sabloff, Joseph A. Tainter, Fred Valdez, and Sander E. Leeuw
2014 2 Tropical Landscapes and the Ancient Maya: Diversity in Time and Space. *Archeological Papers of the American Anthropological Association* 24(1): 11–29.
- Chase, Arlen F., and Vernon L. Scarborough, editors
2014. The Resilience and Vulnerability of Ancient Landscapes: Transforming Maya Archaeology through IHOPE. *Archeological Papers of the American Anthropological Association*, no. 24. Wiley, Hoboken, NJ

Chatters, James C., Douglas J. Kennett, Yemane Asmerom, Brian M. Kemp, Victor Polyak, Alberto Nava Blank, Patricia A. Beddows, Eduard Reinhardt, Joaquin Arroyo-Cabrales, Deborah A. Bolnick, Ripan S. Malhi, Brendan J. Culleton, Pilar Luna Erreguerena, Dominique Rissolo, Shanti Morell-Hart, and Thomas W. Stafford Jr.

2014 Late Pleistocene Human Skeleton and mtDNA Link Paleoamericans and Modern Native Americans. *Science* 344(6185): 750.

Cohen, Jacob

1994 The earth is round ($p < .05$). *American psychologist* 49(12): 997–1003.

Comer, Douglas C., and Michael J. Harrower

2013 *Mapping Archaeological Landscapes from Space*. Springer, New York, NY.

Crampton, Jeremy W., and John Krygier

2005 An introduction to critical cartography. *ACME: an International E-journal for Critical Geographies* 4(1): 11–33.

Crist, Eric P.

1985 A TM tasseled cap equivalent transformation for reflectance factor data. *Remote Sensing of Environment* 17(3): 301–306.

Crist, Eric P., and Richard C. Cicone

1984 A physically-based transformation of Thematic Mapper data—The TM Tasseled Cap. *Geoscience and Remote Sensing, IEEE Transactions on* (3): 256–263.

Crumley, Carole L.

1994 *Historical ecology: cultural knowledge and changing landscapes*. Edited by Carole L. Crumley. School of American Research advanced seminar series. Santa Fe, N.M.: School of American Research Press, Seattle.

Custer, Jay F., Timothy Eveleigh, Vytautas Klemas, and Ian Wells

1986 Application of LANDSAT Data and Synoptic Remote Sensing to Predictive Models for Prehistoric Archaeological Sites: An Example from the Delaware Coastal Plain. *American Antiquity* 51(3): 572–588.

Deuel, Leo

1969 *Flights into Yesterday: The Story of Aerial Archaeology*. St. Martin's Press.

Doneus, Michael, Christian Briese, Martin Fera, and Martin Janner

2008 Archaeological prospection of forested areas using full-waveform airborne laser scanning. *Journal of Archaeological Science* 35(4): 882–893.

Doneus, Michael, and Thomas Kuhteiber

2013 Airborne Laser Scanning and Archaeological Interpretation - bringing back the people. In *Interpreting Archaeological Topography: 3D Data, Visualization and Observation*. Oxbow Books, Oxford, UK ; Oakville, CT.

- Doyle, James A.
2012 Regroup on “E-Groups”: Monumentality and Early Centers in the Middle Preclassic Maya Lowlands. *Latin American Antiquity* 23(4): 355–379.
- Doyle, James A., Thomas G. Garrison, Stephen D. Houston, and Martin Carver
2012 Watchful Realms: Integrating GIS Analysis and Political History in the Southern Maya Lowlands. *Antiquity* 86(333): 792–807.
- Drennan, Robert D.
1984 Long-Distance Movement of Goods in the Mesoamerican Formative and Classic. *American Antiquity* 49(1): 27–43.
- Dunning, Nicholas, Timothy Beach, Pat Farrell, and Sheryl Luzzadder-Beach
1998 Prehispanic Agrosystems and Adaptive Regions in the Maya Lowlands. *Culture & Agriculture* 20(2-3): 87–101.
- Dunning, Nicholas P., Sheryl Luzzadder-Beach, Timothy Beach, John G. Jones, Vernon Scarborough, and T. Patrick Culbert
2002 Arising from the Bajos: The Evolution of a Neotropical Landscape and the Rise of Maya Civilization. *Annals of the Association of American Geographers* 92(2): 267–283.
- Ebert, David
2004 Applications of Archaeological GIS. *Canadian Journal of Archaeology* 28(2): 319–341.
- Ebert, James I.
1984 Remote Sensing Applications in Archaeology. *Advances in Archaeological Method and Theory*: 293–362.
- Eckardt, Hella, Peter Brewer, Sophie Hay, and Sarah Poppy
2009 Roman Barrows and their Landscape Context: a GIS Case Study at Bartlow, Cambridgeshire. *Britannia* 40: iv–98.
- Escalona Ramos, Alberto
1946 Algunas ruinas prehispanicas en Quintana Roo. *Boletín de la Sociedad Mexicana de Geografía y Estadística* 61: 513–628.
- Fairén-Jiménez, Sara
2007 British Neolithic Rock Art in Its Landscape. *Journal of Field Archaeology* 32(3): 283–295.
- Fedick, Scott L. (editor).
1996 *The Managed Mosaic: Ancient Maya Agriculture and Resource Use*. University of Utah Press.
2014 6 A Reassessment of Water and Soil Resources in the Flatlands of the Northern Maya Lowlands. *Archeological Papers of the American Anthropological Association* 24(1): 72–83.
- Fedick, Scott L., and Jennifer P. Mathews
2005 The Yalahau Regional Human Ecology Project: An Introduction and Summary of Recent Research. In *Quintana Roo Archaeology*. University of Arizona Press, Tucson, AZ.

Fedick, Scott L., Bethany A. Morrison, Bente Juhl Andersen, Sylviane Boucher, Jorge Ceja Acosta, and Jennifer P. Mathews

2000 Wetland Manipulation in the Yalahau Region of the Northern Maya Lowlands. *Journal of Field Archaeology* 27(2): 131–152.

Fedick, Scott L., and Karl A Taube

1995 The Yalahau Regional Human Ecology Project: Research Orientation and Overview of the 1993 Investigations. In *The view from Yalahau: 1993 archaeological investigations in northern Quintana Roo, Mexico*. Latin American Studies Program, University of California, Riverside, Riverside, CA.

Fernández-Hernandez, J., D. González-Aguilera, P. Rodríguez-González, and J. Mancera-Taboada

2015 Image-Based Modelling from Unmanned Aerial Vehicle (UAV) Photogrammetry: An Effective, Low-Cost Tool for Archaeological Applications. *Archaeometry* 57(1): 128–145.

Fitzjohn, Matthew

2007 Viewing Places: GIS Applications for Examining the Perception of Space in the Mountains of Sicily. *World Archaeology* 39(1): 36–50.

Fletcher, Richard, and Rona Winter

2008 Prospects and Problems in Applying GIS to the Study of Chalcolithic Archaeology in Southern Israel. *Bulletin of the American Schools of Oriental Research* (352): 1–28.

Folan, William J., Joel Gunn, Jack D. Eaton, and Robert W. Patch

1983 Paleoclimatological Patterning in Southern Mesoamerica. *Journal of Field Archaeology* 10(4): 453–468.

Ford, Anabel, and Scott Fedick

1992 Prehistoric Maya Settlement Patterns in the Upper Belize River Area: Initial Results of the Belize River Archaeological Settlement Survey. *Journal of Field Archaeology* 19(1): 35–49.

Freter, AnnCorinne

2004 Multiscalar Model of Rural Households and Communities in Late Classic Copan Maya Society. *Ancient Mesoamerica* 15(01): 93–106.

Frieman, Catherine, and Mark Gillings

2007 Seeing Is Perceiving? *World Archaeology* 39(1): 4–16.

Gabbert, Wolfgang

2001 Social Categories, Ethnicity and the State in Yucatán, Mexico. *Journal of Latin American Studies* 33(3): 459–484.

Gallareta Negron, Tomas, and Karl A Taube

2006 Late Postclassic Occupation in the Ruinas de San Angel Region. In *Lifeways in the Northern Maya Lowlands: New Approaches to Archaeology in the Yucatán Peninsula*. University of Arizona Press, Tucson, AZ.

- Garrison, T. G.
2010 Remote sensing ancient Maya rural populations using QuickBird satellite imagery. *International Journal of Remote Sensing* 31(1): 213–231.
- Garrison, Thomas Gardner
2007 *Ancient Maya territories, adaptive regions, and alliances: Contextualizing the San Bartolo -Xultun intersite survey*. Unpublished PhD Dissertation, Department of Anthropology, Harvard University, Cambridge, MA.
- Garrison, Thomas G., Bruce Chapman, Stephen Houston, Edwin Román, and Jose Luis Garrido López
2011 Discovering ancient Maya settlements using airborne radar elevation data. *Journal of Archaeological Science* 38(7): 1655–1662.
- Garrison, Thomas G., Stephen D. Houston, Charles Golden, Takeshi Inomata, Zachary Nelson, and Jessica Munson
2008 Evaluating the use of IKONOS satellite imagery in lowland Maya settlement archaeology. *Journal of Archaeological Science* 35(10): 2770–2777.
- Giordano, Marco, and Bryan S. Haley
2006 Airborne remote sensing and geospatial analysis. *Remote sensing in archaeology: an explicitly North American perspective*. University of Alabama Press, Tuscaloosa: 47–77.
- Giardino, Marco J.
2011 A history of NASA remote sensing contributions to archaeology. *Journal of Archaeological Science* 38(9). Satellite remote sensing in archaeology: past, present and future perspectives: 2003–2009.
- Gillespie, Susan D.
2011 Archaeological Drawing as Re-Presentations: the Maps of Complex A, La Venta, Mexico. *Latin American Antiquity* 22(1): 3–36.
- Gillings, Mark
2012 Landscape Phenomenology, GIS and the Role of Affordance. *Journal of Archaeological Method and Theory* 19(4): 601–611.
- Glover, Jeffrey B.
2006 *The Yalahau Regional Settlement Pattern Survey: A Study of Ancient Maya Social Organization in Northern Quintana Roo, Mexico*. Unpublished PhD Dissertation, Department of Anthropology, University of California, Riverside.
2012 The Yalahau Region: A Study of Ancient Maya Sociopolitical Organization. *Ancient Mesoamerica* 23(02): 271–295.

- Glover, Jeffrey B., and Dominique Rissolo
 2010 *La Costa Escondida: Una Investigacion Arqueologica Del Puerto Maya Vista Alegre, Quintana Roo, Mexico* Temporada de Campo 2008 y Análisis 2009. Informe Técnico Anual al Consejo de Arqueología Del Instituto Nacional de Antropología e Historia.
- Glover, Jeffrey B., Dominique Rissolo, Joseph W. Ball, and Fabio E. Amador
 2011 Who were the Middle Preclassic Settlers of Quintana Roo's North Coast? New Evidence from Vista Alegre. *Mexicon*: 69–73.
- Glover, Jeffrey B., Dominique Rissolo, and Jennifer P. Mathews
 2011 The hidden world of the maritime Maya: Lost landscapes along the north coast of Quintana Roo, Mexico. In *The Archaeology of Maritime Landscapes*, 195–216. Springer, New York, NY
- Gordon, George B.
 1897 Caverns of Copan, Honduras. *Memoirs of the Peabody Museum of American Archaeology and Ethnology* 1
- Glover, Jeffrey B., Dominique Rissolo, Jennifer P. Mathews, and Carrie A. Furman
 2012 El Proyecto Costa Escondida: Arqueología y Compromiso Comunitario a lo Largo de la Costa Norte de Quintana Roo, Mexico. *Chungará* 44(3): 511–522.
- Halperin, Christina T., Sergio Garza, Keith M. Prufer and James E. Brady
 2003 Caves and the Ancient Maya Ritual Use of Jute. *Latin American Antiquity* 14(2):207-219.
- Hendon, Julia A.
 2010 *Houses in a Landscape: Memory and Everyday Life in Mesoamerica*. Duke University Press Books, Durham, NC.
- Hightower, Jessica N., A. Christine Butterfield, and John F. Weishampel
 2014 Quantifying Ancient Maya Land Use Legacy Effects on Contemporary Rainforest Canopy Structure. *Remote Sensing* 6(11): 10716–10732.
- Hixson, David R.
 2013 The Use of Multispectral Satellite Imagery and Airborne Synthetic Aperture Radar for the Detection of Archaeological Sites and Features in the Western Maya Wetlands of Chunchucmil, Yucatan, Mexico. In *Mapping Archaeological Landscapes from Space*. Springer, New York, NY.
- Huang, Chengquan, Bruce Wylie, Limin Yang, Collin Homer, and Gregory Zylstra
 2002 Derivation of a tasseled cap transformation based on Landsat 7 at-satellite reflectance. *International Journal of Remote Sensing* 23(8): 1741–1748.
- Hutson, Scott R., David R. Hixson, Aline Magnoni, Daniel Mazeau, and Bruce Dahlin
 2008 Site and Community at Chunchucmil and Ancient Maya Urban Centers. *Journal of Field Archaeology* 33(1): 19–40.

- Hutson, Scott R., Travis W. Stanton, Aline Magnoni, Richard Terry, and Jason Craner
2007 Beyond the buildings: Formation processes of ancient Maya houselots and methods for the study of non-architectural space. *Journal of Anthropological Archaeology* 26: 442–473.
- Iannone, Gyles, Keith Prufer, and Diane Z. Chase
2014 11 Resilience and Vulnerability in the Maya Hinterlands. *Archeological Papers of the American Anthropological Association* 24(1): 155–170.
- Johnston, Kevin J.
2002 Protrusion, Bioturbation, and Settlement Detection during Surface Survey: The Lowland Maya Case. *Journal of Archaeological Method & Theory* 9(1): 1–67.
- Jones, Eric E.
2006 Using Viewshed Analysis to Explore Settlement Choice: A Case Study of the Onondaga Iroquois. *American Antiquity* 71(3): 523–538.
- Kauth, R., and G. Thomas
1976 The Tasseled Cap -- A Graphic Description of the Spectral-Temporal Development of Agricultural Crops as Seen by LANDSAT. *LARS Symposia*.
- Kobal, Milan, Irena Bertoneclj, Francesco Pirotti, Igor Dakskobler, and Lado Kutnar
2015 Using Lidar Data to Analyse Sinkhole Characteristics Relevant for Understorey Vegetation under Forest Cover-Case Study of a High Karst Area in the Dinaric Mountains. *PLoS one* 10(3): e0122070.
- Koch, A., and C. Heipke
2001 Quality Assessment of Digital Surface Models derived from the Shuttle Radar Topography Mission (SRTM).
- Koch, A., C. Heipke, and P. Lohmann
2002 Analysis of SRTM DTM – Methodology and practical results. In *International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences*, Com. IV, 470–475.
- Kosiba, Steve, and Andrew M. Bauer
2013 Mapping the Political Landscape: Toward a GIS Analysis of Environmental and Social Difference. *Journal of Archaeological Method and Theory* 20(1): 61–101.
- Landsea, C., J. Franklin, and J. Beven
2014 The revised Atlantic hurricane database (HURDAT2).
- Lasaponara, Rosa, and Nicola Masini
2011 Satellite remote sensing in archaeology: past, present and future perspectives. *Journal of Archaeological Science* 38(9): 1995–2002.
- Laughlin, Robert M.
1975 The Great Tzotzil Dictionary of San Lorenzo Zinacantan. *Smithsonian Contributions to Anthropology* 19.

Leonard, Daniel Ian

2013 *The Yalahau Regional Wetland Survey: Ancient Maya Land Use in Northern Quintana Roo, Mexico*. Unpublished PhD Dissertation, Department of Anthropology, University of California, Riverside.

Lesser, J. M., and A. E. Weidie

1988 *Region 25, Yucatan Peninsula. Hydrogeology*. The Geological Society of North America, Boulder Colorado. 1988. P. 237-241.

Llobera, Marcos

2007 Reconstructing Visual Landscapes. *World Archaeology* 39(1): 51–69.

2012 Life on a Pixel: Challenges in the Development of Digital Methods within an “Interpretive” Landscape Archaeology Framework. *Journal of Archaeological Method & Theory* 19(4): 495–509.

Loebel, Thomas J.

2012 Pattern or bias? A critical evaluation of Midwestern fluted point distributions using raster based GIS. *Journal of Archaeological Science* 39: 1205–1217.

Lucero, Lisa J., Scott L. Fedick, Nicholas P. Dunning, David L. Lentz, and Vernon L. Scarborough

2014 3 Water and Landscape: Ancient Maya Settlement Decisions. *Archeological Papers of the American Anthropological Association* 24(1): 30–42.

Lucero, Lisa J., Joel D. Gunn, and Vernon L. Scarborough

2011 Climate Change and Classic Maya Water Management. *Water* (20734441) 3(2): 479–494.

Mack, Alexandra

2004 One Landscape, Many Experiences: Differing Perspectives of the Temple Districts of Vijayanagara. *Journal of Archaeological Method and Theory* 11(1): 59–81.

Mathews, Jennifer P.

2001 Radiocarbon Dating of Architectural Mortar: A Case Study in the Maya Region, Quintana Roo, Mexico. *Journal of Field Archaeology* 28(3/4): 395–400.

McEwan, Dorothy Graves

2012 Qualitative Landscape Theories and Archaeological Predictive Modelling—A Journey through No Man’s Land? *Journal of Archaeological Method and Theory* 19(4): 526–547.

McEwan, Dorothy Graves, and Kirsty Millican

2012 In Search of the Middle Ground: Quantitative Spatial Techniques and Experiential Theory in Archaeology. *Journal of Archaeological Method and Theory* 19(4): 491–494.

- Means, Philip Ainsworth, Andrés de Avendaño y Loyola, Alonso Cano, Earnest Albert Hooton, Samuel James Guernsey, and Charles Clark Willoughby
1974 *History of the Spanish conquest of Yucatan and of the Itzas / By Philip Ainsworth Means*. Papers of the Peabody Museum of American Archaeology and Ethnology, Harvard University: vol. VII. New York : Kraus Reprint, 1974.
- Millon, Rene
1964 The Teotihuacan Mapping Project. *American Antiquity* 29(3): 345–352.
1970 Teotihuacán: Completion of Map of Giant Ancient City in the Valley of Mexico. *Science* 170(3962): 1077–1082.
- Monmonier, Mark, and H. J. de Blij
1996 *How to Lie with Maps*. 2nd ed. University Of Chicago Press, Chicago, IL.
- Montmollin, Olivier de
1988 Scales of Settlement Study for Complex Societies: Analytical Issues from the Classic Maya Area. *Journal of Field Archaeology* 15(2): 151–168.
- Moyes, Holley
2005 The Sweatbath in the Cave: A Modified Passage in Chechem Ha Cave, Belize in *Stone Houses and Earth Lords* edited by K. M. Prufer and J. E. Brady. 187-212. University of Colorado Press. Boulder, CO.
- Parcak, Sarah H.
2009 *Satellite Remote Sensing for Archaeology*. 1st ed. Routledge, New York, NY
- Peck, Douglas T.
2005 Re-Examination of Spanish Colonial Period Documents Related to Prehistoric Maya History and Mythology. *Revista de Historia de América* (136): 21–35.
- Perry, Eugene, Guadalupe Velazquez-Oliman, and Luis Marin
2002 The Hydrogeochemistry of the Karst Aquifer System of the Northern Yucatan Peninsula, Mexico. *International Geology Review* 44(3): 191–221
- Pope, Kevin O., and Bruce H. Dahlin
1989 Ancient Maya Wetland Agriculture: New Insights from Ecological and Remote Sensing Research. *Journal of Field Archaeology* 16(1): 87–106
- Prufer, Keith M., and James E. Brady (editors).
2005 *Stone Houses and Earth Lords: Maya Religion in the Cave Context*. University Press of Colorado, Boulder, CO.
- Prufer, Keith M. and Peter S. Dunham
2009 A Shaman's Burial from an Early Classic Cave in the Maya Mountains of Belize, Central America. *World Archaeology* 41(2):295-320

- Prufer, Keith M. and W. Jeffery Hurst
2007 Chocolate in the Underworld Space of Death: Cacao Seeds from an Early Classic Mortuary Cave. *Ethnohistory* 54(2):273-301
- Prufer, Keith M., Amy E. Thompson, and Douglas J. Kennett
2015 Evaluating airborne LiDAR for detecting settlements and modified landscapes in disturbed tropical environments at Uxbenká, Belize. *Journal of Archaeological Science* 57: 1–13.
- Raab, L. Mark, and Albert C. Goodyear
1984 Middle-Range Theory in Archaeology: A Critical Review of Origins and Applications. *American Antiquity* 49(2): 255–268.
- Redman, Charles L.
1999 *Human Impact on Ancient Environments*. Reprint edition. University of Arizona Press, Tucson, AZ
- Reeder, Leslie, Torben Rick, and Jon Erlandson
2012 Our disappearing past: a GIS analysis of the vulnerability of coastal archaeological resources in California's Santa Barbara Channel region. *Journal of Coastal Conservation (Springer Science & Business Media B.V.)* 16(2): 187–197.
- Rennell, Rebecca
2012 Landscape, Experience and GIS: Exploring the Potential for Methodological Dialogue. *Journal of Archaeological Method and Theory* 19(4): 510–525.
- Restall, Matthew, and John F. Chuchiak
2002 A Reevaluation of the Authenticity of Fray Diego de Landa's Relación de las cosas de Yucatán. *Ethnohistory* 49(3): 651–669.
- De Reu, Jeroen, Jean Bourgeois, Machteld Bats, Ann Zwertvaegher, Vanessa Gelorini, Philippe De Smedt, Wei Chu, Marc Antrop, Philippe De Maeyer, Peter Finke, Marc Van Meirvenne, Jacques Verniers, and Philippe Crombé
2013 Application of the topographic position index to heterogeneous landscapes. *Geomorphology* 186: 39–49.
- Rissolo, Dominique
2003 *Ancient Maya Cave Use in the Yalahau Region, Northern Quintana Roo, Mexico*. Association for Mexican Cave Studies Bulletin 12. Austin, TX.
- Rissolo, Dominique, José Manuel Ochoa Rodríguez, and Joseph W. Ball
2005 A Reassessment of the Middle Preclassic in Northern Quintana Roo. *Quintana Roo Archaeology*: 66–76.
- Roberts, Jennifer L.
2000 Landscapes of Indifference: Robert Smithson and John Lloyd Stephens in Yucatán. *The Art Bulletin* 82(3): 544–567.

- Roys, Ralph Loveland
1957 *The political geography of the Yucatan Maya*. Vol. 613. Carnegie Institution of Washington.
- Sandweiss, Daniel H., and Alice R. Kelley
2012 Archaeological Contributions to Climate Change Research: The Archaeological Record as a Paleoclimatic and Paleoenvironmental Archive. *Annual Review of Anthropology* 41(1): 371–391.
- Saturno, William, Thomas L. Sever, Daniel E. Irwin, Burgess F. Howell, and Thomas G. Garrison
2007 Putting Us on the Map: Remote Sensing Investigation of the Ancient Maya Landscape. In *Remote Sensing in Archaeology*, edited by James Wiseman and Farouk El-Baz, 137–160. Interdisciplinary Contributions to Archaeology. Springer New York.
- Sayer, Duncan, and Michelle Wienhold
2013 A GIS-Investigation of Four Early Anglo-Saxon Cemeteries: Ripley's K-function Analysis of Spatial Groupings Amongst Graves. *Social Science Computer Review* 31(1): 71–89.
- Schliemann, Johann Ludwig Heinrich
1884 *Troja: results of the latest researches on the site of Homer's Troy*.
- Sharon, Ilan, Yehuda Dagan, and Gilah Tzionit
2004 The [awful?] truth about GIS and archaeology. *British School at Athens Studies* 11: 151–162.
- Shaw, Justine M., and Jennifer P. Mathews (editors).
2005 *Quintana Roo Archaeology*. University of Arizona Press, Tucson, AZ
- Sorensen, Kathryn Ann
2010 *Ancient Maya Site Planning Principles: A Case Study for the Preclassic/classic Transition*. UMI Dissertation Services.
- Stephens, John L.
1963 *Incidents of Travel in Yucatan*. Dover Publications, New York, June 1.
1969 *Incidents of Travel in Central America, Chiapas, and Yucatan*, Volume I. New impression edition. Dover Publications, New York, NY
- Taube, Karl
1993 Monumental Architecture of the Yalahau Region and the Megalithic Style of the Northern Maya Lowlands. *The view from Yalahau*: 23–58.
- Thomas, David Hurst
1978 The Awful Truth about Statistics in Archaeology. *American Antiquity* 43(2): 231–244.
- Trigger, Bruce G.
2006 *A History of Archaeological Thought*. 2nd ed. Cambridge University Press, September 11.
Tulaczyk, Slawomir M., Eugene C. Perry, Charles E. Duller, and Miguel Villasuso
1993 Influence of the Holbox fracture zone on the karst geomorphology and hydrogeology of northern Quintana Roo, Yucatan Peninsula, Mexico. *Applied karst geology. Balkema, Rotterdam, the Netherlands*: 181–189.

- Turner, B. L. and Jeremy A. Sabloff
2012 Classic Period collapse of the Central Maya Lowlands: Insights about human—environment relationships for sustainability. *Proceedings of the National Academy of Sciences of the United States of America* 109(35): 13908–13914.
- Verhagen, Philip, and Thomas G. Whitley
2012 Integrating Archaeological Theory and Predictive Modeling: a Live Report from the Scene. *Journal of Archaeological Method and Theory* 19(1): 49–100.
- Vogt, Evon Z. and David Stuart
2005 Some notes on Ritual Caves among the Ancient and Modern Maya in *In the Maw of the Earth Monster* edited by J. E. Brady and K. M. Prufer, 155-185. University of Texas Press, Austin.
- Ward, William Cruse, Alfred Edward Weidie, and William Back
1985 Geology and hydrogeology of the Yucatan and Quaternary geology of northeastern Yucatan Peninsula. New Orleans Geographical Society, New Orleans, LA.
- Weishampel, John F., Jessica N. Hightower, Arlen F. Chase, Diane Z. Chase, and Ryan A. Patrick
2011 Detection and morphologic analysis of potential below-canopy cave openings in the karst landscape around the Maya polity of Caracol using airborne LiDAR. *Journal of Cave and Karst Studies* 73(3): 187–196.
- Weiss, Andrew
2001 Topographic position and landforms analysis. In *Poster presentation, ESRI User Conference, San Diego, CA*.
- Whigham, D. F., I. Olmsted, E. Cabrera Cano, A. B. Curtis, A. Gómez-Pompa, M. F. Allen, S. L. Fedick, J. J. Jiménez-Osornio, and others
2003 Impacts of hurricanes on the forests of Quintana Roo, Yucatán Peninsula, Mexico. In *The Lowland Maya Area: Three Millennia at the Human-Wildland Interface*. Proceedings of the 21st Symposium of Plant Biology, University of California at Riverside, USA, January 2001. 193–213. Food Products Press.
- Wollwage, Lance, Scott Fedick, Sergey Sedov, and Elizabeth Solleiro-Rebolledo
2012 The Deposition and Chronology of Cenote T'isil: A Multiproxy Study of Human/Environment Interaction in the Northern Maya Lowlands of Southeast Mexico. *Geoarchaeology* 27(5): 441.