The Archaeology of Climate Change in the Caribbean

Dr Jago Cooper
School of Archaeology and Ancient History
University of Leicester

Dr Matthew Peros
Department of Geography
University of Ottawa

Abstract:
This paper emerges from an attempt to more actively integrate archaeology with ongoing geographical and environmental discussions of human responses to the effects of climate change in the Caribbean. If archaeology is to contribute to the mitigation strategies currently being developed, then robust interpretations are necessary that can be practically integrated with interdisciplinary action. This paper discusses the methods needed to provide the high-resolution data and interpretations required using archaeological and paleoenvironmental research from a case study area in northern Cuba. Using data collected from an ongoing collaborative archaeological research project with the Cuban Ministry of Science, Technology and Environment, we evaluate whether it is possible to make useful interpretations of human response to past changes in sea level, precipitation and hurricane activity. Specifically, the effects of these activities on the changing nature of settlement locations, food procurement strategies and household architecture among pre-Columbian communities are evaluated. Indigenous mitigation strategies are identified and used to inform modern day preparation for the impacts of climate change in the Caribbean.

Introduction

In this paper we will present an overview of an ongoing research project entitled 'The Archaeology of Climate Change in the Caribbean'. This three year Leverhulme funded research project began in October 2008 but builds upon research conducted in the Caribbean by the authors since 1998. The overall aim of this research is to study how pre-Columbian communities in the Caribbean lived through past impacts of climate change and use this information to inform modern day mitigation strategies in the

Caribbean and build on previous research in this area (Anderson et al., 2007, Hodell et al., 1991:793, Keegan, 1995). In this paper, we use the term climate change to refer to all changes to the physical environment that could have had direct or indirect effects on climate system variability. In this paper, we focus on three impacts of climate change:

1. Relative sea level rise
2. Variation in precipitation
3. Variation in the frequency and intensity of hurricane activity

Archaeologically, three areas of human lifeways are investigated:

1. Settlement Location
2. Food procurement strategies
3. Household architecture

Before discussing this research in detail, it is important to highlight two related areas that this paper does not cover. Firstly, this paper is not focused on a review of the historic debates regarding human-environment relations in the Caribbean. The regions of the Caribbean and neighbouring lowland South America have witnessed an exciting century of debate on this subject among archaeologists, geographers and anthropologists. This debate has often motivated vigorous debate and inspired a wide range of theoretical perspectives through time, from the 'adaptation to environment' arguments of environmental determinists to the maximization of calorific returns by biogeographers (Keegan and Diamond, 1987, Meggers, 1954). Inevitably it is essential that any research regarding human environment relations in the past emerges from a well grounded theoretical perspective aware of past debates. However, it is not the purpose of this brief paper to review historical debates on this subject nor attempt to define a new theoretical perspective. If a theoretical perspective is to be stated for this research it would be broadly a historical ecological framework in which past human communities are seen as part of a wider network of environmental interrelations (Balle, 1998).

Secondly, it is not the primary aim of this research to search for, nor establish, cause and effect between changes in past environments as a result of climate change and changes in past human behaviour. In particular, it is not the aim of our work to match changes in paleoclimatic and archaeological datasets and infer a monocausal link for changes in past cultural practices as a form of adaptation to environmental change. Rather this research aims to use archaeological investigation to study pre-Columbian household architecture, food procurement strategies and settlement locations and contextualise these cultural practices using paleoclimatic research methods in order to identify the likely impacts of

climate change experienced by communities living during different periods of the pre-Columbian past.

Attempts to correlate paleoclimatic and archaeological datasets are methodologically challenging as the temporal and spatial scales at which the two disciplines generate data often limits the scope for direct inter-disciplinary comparisons. Therefore an important methodological aspect of this work is to compare and correlate these inter-disciplinary datasets at different temporal and spatial scales. For the simplicity of this paper three different scales of analysis will be summarized, these are Regional, National and Local.

Regional

The largest scale of analysis is the insular Caribbean, taken to include the islands contained within the Caribbean Sea between the continental landmasses of South and North America. This research is equally relevant for the continental coastlines of the region but the insular Caribbean has been used as the initial point of reference for this research project.

Relative Sea Level Rise

From a global perspective, the Caribbean is a particularly interesting geographical area in which to look at the impacts of relative sea level rise. This is because, from a regional perspective, there is strong evidence for a long-term trend of relative sea-level rise throughout the Holocene (Toscano and Macintyre, 2003, Peros, 2005). Relative sea level rise in the Caribbean during the early Holocene was primarily driven by eustatic forcing before being replaced by isostatic forcing during the mid to late Holocene as the lithosphere underlying the Caribbean Sea subsided as it readjusted to the effects of the melting of the Laurentide Ice Sheet (Milne et al., 2004:1184). Therefore if we broadly take human colonization of the Caribbean to have begun c.7000 BP past human communities in the Caribbean lived through at least a 5m rise in sea level before the arrival of Columbus in AD 1492 then (Kozlowski, 1974). A regional picture of relative sea level rise has been reconstructed from a wide range of paleoenvironmental data. Whilst this regional perspective highlights what an interesting area the Caribbean might be for investigating past human responses to sea level rise, it must be noted that this regional perspective misses the nuanced picture of individual coastlines where local factors such as changing coastal vegetation, coastal erosion, local bathymetry and tectonic activity come into play (Ramcharan, 2004:146, Keegan, 1991:5). Therefore, this regional view of relative sea level rise shows that it is likely to have had a major impact on pre-Columbian communities. However, this regional dataset needs to be refined

using local case studies that reveal how long term regional relative sea level rise might actually have short term impacts on local coastal communities.

Precipitation

The reconstruction and modeling of paleoprecipitation is currently a topical area of research for climate change scientists. Recent work by Broecker (2009) and others has highlighted large changes in past precipitation and the impacts of this on human settlements. However, there has been only limited research on paleoprecipitation from the Caribbean region. Among the earliest research comes from Lake Miragoane, Haiti, where Hodell et al. (1991) showed that large change in precipitation occurred over the last 10,500 years. More recent research has focused on geochemical and sedimentological data from marine sediments. Nyberg et al. (2001) generated a 2000-year record of past precipitation from the northeast Caribbean, whereas Haug et al. (2001) documented a southward migration of the Inter-Tropical Convergence Zone (ITCZ) during the Holocene in the varved-sediment record obtained from the Cariaco Basin, offshore Venezuela. Part of the reason for the lack of data from the Caribbean may be related to the low numbers of lakes suitable for obtaining paleoprecipitation records, although some closed-basin lakes are present on the islands of the Lesser Antilles, such as Lake Antoine on Grenada (McAndrews and Ramcharan, 2003). Increasing the density of sites that record paleoprecipitation events in the Caribbean may also be possible through the geochemical analysis of precipitation-sensitive speleothem deposits and this collection of primary paleoprecipitation data will be a focus for our ongoing research.

Hurricanes

Studies of historical records from the region have indicated that there have long been fluctuations in the frequency and intensity of hurricane landfalls in the Caribbean (Nyberg et al., 2007, Saunders and Lea, 2008). Prehistorically these data are harder to ascertain. Work by Donnelly and Woodruff (2007) has indicated hurricane impacts at site-specific locations in the Caribbean. Their work on coastal lagoons in Puerto Rico has shown good potential for reconstructing the prehistoric landfall of hurricanes and contains methods that can be more widely applied at sites in the Caribbean region, as has been done in coastal Belize (McCloskey and Keller, 2009). However, existing data-sets for regional variation in the frequency and intensity of hurricanes in the pre-Columbian past is limited. Ongoing research into the affects of changes in sea surface temperatures, movement of the ITCZ and African monsoon winds, which are all critical controls on hurricane activity in the Caribbean, provide a potential alternative method for modeling

how these environmental forces influenced the intensity and frequency of hurricane activity (MacKenzie, 2003, Nyberg et al., 2001:98, Hetzinger et al., 2008, Scheffers et al., 2009). Therefore by gathering data on these forcing factors in the past it should be possible to support and improve existing data for prehistoric hurricane activity through paleoclimatic modeling (Beck et al., 1997:705, Nyberg et al., 2007:701, Saunders and Lea, 2008:559). An example of these proxy data for past forcing factors comes from existing coral data that provide evidence for changing sea surface temperatures in the past (Hoegh-Guldberg et al., 2007:1737, Elsner, 2007). Therefore existing paleoenvironmental data combined with proxy data could provide improved regional evidence for the occurrence of hurricanes in the prehistoric Caribbean.

Summary

Discussion of this paleoenvironmental evidence for the impacts of climate change at a regional scale highlights how this research often operates at a spatial and temporal scale that is difficult to correlate with archaeological evidence for changes in past cultural behaviour. It has often been a common temptation to compare large-scale regional paleoenvironmental change with large scale changes in human behaviour but it is methodologically difficult to do so (Richerson et al., 2001). Regional, large scale changes in past human behaviour are still only broadly understood in the Caribbean. For example, the spatial and temporal resolution for the colonization of the Caribbean, between 8k and 6k is too broad to start to correlate with known events such as the collapse of the Laurentide Ice Sheet, dramatic eustatic relative sea level rise and contemporaneous increased levels of precipitation in the region (Higuera-Gundy et al., 1999:159, Milne et al., 2004:1183, Overpeck et al., 1989:556). Furthermore, the spatial and temporal resolution for changes in human behavior, like the development of intensive agricultural production and large scale sedentary populations, are not sufficiently understood on a regional scale to correlate with changes in precipitation. Such changes as sustained drying events that create potential food insecurity issues are themes that have been well explored elsewhere in the world (Brooks, 2006). Therefore we need to consider at what scale Caribbean archaeology can produce a dataset of sufficient resolution to correlate effectively with existing paleoenvironmental data.

National

Cuba makes up over 47% of the landmass of the insular Caribbean and provides the largest sovereign state in the region. Recent attempts to create a national archaeological database provide an opportunity to explore archaeological data at a broad scale of

analysis (Cooper, In Press, Cooper, 2007b, Departamento de Arqueología de Centro de Antropología, 2003, Febles Duenas et al., 1987, Febles Duenas and Martínez, 1995). The archaeological data within this Cuban sites and monuments record have been integrated with a GIS platform to facilitate spatial analysis (Figure 1). By combining national paleoenvironmental data with this national archaeology database within this GIS platform it is possible to facilitate interpretive modeling. The archaeological database includes a wide range of site information including site location, cultural classification, artefact categories, subsistence categories and can enable discussion of settlement location and food procurement strategies in relation to the impacts of climate change over time.

Settlement Location

At a national scale it is possible to see how changing relative sea levels might have affected settlement patterns over time. By modeling past relative sea level rise with national bathymetric data it is possible to indicate areas where pre-Columbian coastal communities would have been most vulnerable to the impacts of relative sea level rise. This analysis also highlights problems with the existing archaeological sample of sites, as a large percentage of previously occupied pre-Columbian territory is currently submerged underwater. This modeling of national site locations also provides a way of testing long-standing hypotheses that pre-Columbian demographic distribution was related to patterns of paleoprecipitation (Tabio, 1995), with densely populated areas in parts of the country with least variable rates of precipitation (Valcárcel Rojas, 2002). Another long-standing hypothesis that can be tested by these models is that pre-Columbian settlements were located in places resistant to the impacts of hurricanes. First of all by being concentrated in areas where hurricanes have less frequent return rates, secondly by being located in close proximity to cave systems that could be used as hurricane shelters and thirdly being located in areas that were resistant to flooding from coastal storm surge and post-precipitation flooding. The evidence for this resilience of pre-Columbian settlement location is examined in more detail below.

Food Procurement strategies

Related to the themes of settlement location are the ways in which past food procurement strategies might have changed over time in relation to environmental change. Of particular focus in this research is how past impacts of climate change might have affected food security for pre-Columbian populations. Relative sea level rise would have changed the availability of freshwater aquifers and increased the salinity of coastal

soils (Higuera-Gundy et al., 1999:159). Storm surge events and coastal flooding would have impacted upon littoral and marine ecosystems. Archaeological research has shown that food resources from littoral and marine environments were an important component of pre-Colombian diet (Dacal Moure, 1978). Therefore modeling the way in which relative sea level rise potentially increases food insecurity enables discussion of the ways in which past communities might have developed mitigation strategies to cope with these events.

Summary

The reality is that this national scale of analysis provides some very interesting general patterns but with only 140 radiocarbon dates from archaeological sites in Cuba, the temporal resolution of the sites prevents reliable data for interpretation. However, what this analysis does provide is observed patterns of potential correlation that can be tested using higher resolution data at a smaller spatial scale. Therefore research questions identified in the national datasets can be investigated further by using data produced from targeted fieldwork in a case study area.

Local and Site Specific

We have been conducting fieldwork in north central Cuba since 2002. Fieldwork has focused on a case study area that includes a 2000 sq. km. area of Ciego de Avila province, Santa Clara province and the Sabana Camaguey archipelago (Figure 2). Archaeological surveys, excavations and artefact analyses have provided a detailed picture of past human activity within this case study area spanning a time period of 2755 BC to AD 1670 (Cooper, 2004, Cooper, 2008, Cooper and Valcárcel Rojas, 2004, Cooper et al., 2006, Calvera Rosés et al., 2006, Calvera Rosés et al., 2005, Valcárcel Rojas et al., 2006). Artefact analyses of material from recently excavated sites in the case study area provide some interesting patterns in changing food procurement strategies and settlement locations over time. Targeted local paleoenvironmental research has also been conducted with transects of multiple sediment cores through the same geographical case study area (Peros et al., 2007a) (Figure 2). Geomorphological and archaeobotanical analysis of these cores provides a clearer understanding of the local impacts of relative sea level rise in the case study area by documenting how hydrological changes associated with relative sea level rise transformed local mangrove and cattail communities and coastal configuration and drainage (Peros et al., 2007b). In addition there is initial evidence from some of these cores for past hurricanes and precipitation changes and targeted cores to investigate this further are planned in forthcoming fieldwork.

It is not possible to discuss the evidence for the potential impacts of climate change on each archaeological site in the case study area in this paper but the one site of Los Buchillones, which has been studied in detail over recent years, deserves closer attention. This pre-Columbian site has evidence of human occupation from AD 1265 to 1670. There is very little evidence of European contact with this indigenous community, with just one majolica sherd found without archaeological context on the shoreline in 1998. The site includes a number of wooden structures built on stilts along the coastline between the two modern day towns of Punta Alegre and Maximo Gomez. Stretching some 2.2 km along the coast (Cooper and Valcárcel Rojas, 2004) there appear to be both dry and wetland areas of the site. The wetland areas of the site have exceptional levels of preservation (Calvera Rosés et al., 2006) and excavations have uncovered a series of wooden stilted houses at the site (Figure 3) (Valcárcel Rojas et al., 2006). Multiple transects of sediment cores through the site indicate that these structures were built over wetland conditions following a period of relative sea level rise (Peros et al., 2006). Research questions raised during consideration of broader regional and national scales of analysis can be investigated using archaeological and paleoenvironmental datasets from this local case study area.

Settlement Patterns

The nature of early hunter forager sites in Cuba makes settlements or areas of temporary residence difficult to identify. We have found and excavated a number of sites from early periods of Cuban prehistory on the offshore islands of the Sabana Camaguey archipelago in the case study area. However, during later periods we find no evidence for permanent settlements on these offshore islands in the case study area. An important factor to consider is fresh water supplies, as most of the islands currently have no freshwater sources available. Therefore, the way in which rising relative sea levels would have affected natural aquifers along paleocoastlines and offshore islands is clearly a key impact that would have affected the ability of past human communities to live on the offshore islands. The established residential settlements we have identified in the case study area are predominantly from later periods following the introduction agriculture. All of these permanent residential settlements are on the Cuban mainland. Each of these sites is located on relatively flat ground, with good agricultural potential but they are also all located within close proximity of upland areas. Ethnohistorical accounts suggest that indigenous settlements were located close to cave systems that would act as shelters when hurricanes approached (Pané, 1498 (1990)). This argument is supported by the

evidence in the case study area with pre-Columbian sites all located in close proximity of cave systems in nearby hills (Figure 2).

The location of pre-Columbian settlements in flood resistant areas can also be tested using data from the case study area. GIS led spatial analysis of potential flooding can be modeled using current topographic and hydrographic data. This analysis appears to indicate that pre-Columbian sites are predominantly in areas that are resistant to flood risk. A closer inspection of sites that appear to be in flood risk areas, such as Los Buchillones, also provides interesting results and will be discussed in further detail later in this paper.

Food procurement Strategies

The impacts of climate change, namely relative sea level rise, changes in precipitation patterns and hurricane activity, inevitably affected available food resources in the past. However, as is well established, there are numerous factors not related to these climate induced environmental pressures that are also going to impact upon past food procurement strategies (Carlson and Keegan, 2004). Therefore, as previously stated this research is not aiming to identify a causal link between changing food procurement strategies and the impacts of climate change. A further taphanomic caveat should also be noted as there is a bias in the preserved faunal remains from different sites and this is another reason to be cautious with interpretations of the available evidence. However, what this research does attempt to do is analyse the substantive faunal collections from the case study area and identify how food procurement strategies changed over time (Cooper, 2007a). This analysis shows in what ways these changes might have been advantageous given the identified impacts of climate change in the case study area.

The earliest evidence for past food procurement strategies from Midden 1 on Cayo Caiman Mata de Coco, 2755 BC , and the older stratigraphic levels of excavations from Midden 1, Punta Morra, Caves 1 and 3 Cayo Guillermo Hijo de Este up to 1035 BC, is that initial food procurement strategies focused on targeted species from single environmental zones. Predominantly littoral and shallow sandy bottomed coastal waters. Overtime this focus on single environmental zones changes and we see a much wider diversity of marine ecosystem exploitation. The more recent stratigraphic contexts of Caves 1 and 3 Cayo Hijo de Guillermo Este, Midden 1, Punta Morra and Los Buchillones show a wide range of different marine environments being exploited including offshore reef and pelagic waters. We also see much greater distances being travelled from settlement sites for resource and subsistence purposes, including over

32km from Los Buchillones to Cayo Hijo de Guillermo Este. Changing demographic pressures and overexploitation of available resources are likely to be important factors during this time but the rising relative sea levels identified in the case study area during this period would have impacted upon the availability of food resources from different environmental zones. Therefore diversifying the range of environmental zones being exploited provides resilience against food insecurity created by changes in marine and coastal ecosystems as a result of the impacts of climate change. Another clear picture that emerges from the case study area is the increasing distance at which food resources are being moved and the increasing complexity with which trade and exchange networks are developed. Detailed analysis of these networks of interaction can be found elsewhere but it appears that resource and subsistence materials were regularly moving distances of up to 100km between offshore reef environments, coastal zones and upland areas in the interior of the Cuban mainland (Cooper, 2007a). These elaborate networks for the redistribution of food resources between different environmental zones have important consequences for food security. Inevitably, short-term impacts of climate change such as flooding, drought or hurricane wind shear can create catastrophic impacts for communities living in the affected area. However, evidence for the impacts of these events and in particular hurricane damage suggests that these impacts can often be quite local. The destructive path of a hurricane maintains a limited major impact zone, therefore having a food procurement network in place that can provide food resources beyond the directly impacted area can provide resilience to these impacts on food security. Further analysis of these topics is ongoing and is particularly focused on how social relationships are formed around these trade and exchange networks (Rosen, 2007). An initial hypothesis is that this practical resilience of food procurement strategies against climate induced local environmental disasters is reinforced by social bonds between interrelated communities living in different geographical areas that create an intergenerational system of social storage.

Household Architecture

There have been a number of studies of pre-Columbian household architecture in the Caribbean (Curet, 1992, Drewett, 2003). These studies indicate a widespread use of wooden house structures using substantive wooden posts embedded in the ground with a lighter superstructure of wooden rafters and thatched roofs. The excavation of preserved household structures at Los Buchillones provides an illuminating picture of household architecture with preserved wooden timbers (Figure 3). For details of these

excavations see Valcàrcel Rojas et al. (2006). Initially these wooden structures with thatched roofs might appear to be poor designs to withstand the impacts of coastal flooding and hurricane wind shear. However, with further consideration this choice of household architecture has a number of important advantages in stark contrast with more popular household structures used in the Caribbean today. The use of stilted structures suspended over coastal wetland areas at Los Buchillones meant that these buildings were not affected by post-precipitation flooding. Flood waters at Los Buchillones running down the nearby upland areas of the Lomas de Punta Alegre, ran under the house floors and directly into the sea not affecting residents. The impact of storm surge coastal flooding at Los Buchillones is mitigated by the location of the site behind the Sabana Camaguey archipelago. A series of low-lying mangrove islands form a natural sea defence preventing tidal surges by restricting the flow of water in and out of the Bahia de Buena Vista. Therefore this household design and settlement location actually provide some resilience to the threat of coastal and rainwater flooding. Disaster management of the threat from hurricanes shows clearly that the initial impact of wind shear is only one part of the impact on a community living in the Caribbean. One of the most important aspects of a successful disaster management plan is the planning for post-hurricane reconstruction and the speed with which communities can return to 'life as before'. Based on the assumption that pre-Columbian communities used nearby cave systems as refuges during the actual hurricane impact, the household architecture used by these communities has a number of advantages in this regard. The substantive house posts, embedded up to 1.7m into the ground are resistant to wind shear, and radiocarbon dates from Los Buchillones indicate they have remained in place, and in use, for hundreds of years (Valcárcel Rojas et al., 2006). Consequently it is only the lightweight superstructure of wooden rafters and thatched roof that will lift off during a hurricane. Therefore, when returning to rebuild the settlement following a hurricane, all that is required is the redressing of the surviving post skeleton using locally available and abundant resources.

Conclusions

Archaeological research can provide important data to inform modern day communities living in the Caribbean. Current Caribbean populations are facing similar impacts of climate change as people have done in the past, albeit with an unprecedented rate of change predicted (IPCC, 2007, Jansen et al., 2007). There are lessons to be learnt from pre-Columbian settlement locations in areas resilient to post-precipitation and coastal

flooding, in locations close to cave systems that can be used as refuges during hurricanes. In addition the impact of rising relative sea levels on coastal aquifers and the availability of freshwater need to be further investigated. The changing nature of food procurement strategies overtime are an interesting area for research. The increased range of environmental zones being exploited provides resilience against local environmental impacts for individual settlements. The development of long distance trade and exchange networks between settlements in different geographical areas provides a support mechanism for more dramatic local impacts such as hurricanes. Although the existence of these long distance trade and exchange networks has been established, the nature of social relations supporting them requires further study. The use of stilted wooden house structures in the case study area provides interesting evidence for discussion. The resilience of pre-Columbian houses, stilted over coastal wetlands, to coastal and rainfall flooding is an interesting observation. Another observation for further consideration is the low reconstruction costs following storm damage in contrast to the modern day high costs of clearing away unusable concrete debris and waiting for the importation of non-local building materials.

This research has focused on correlating archaeological and paleoenvironmental datasets at varying spatial and temporal scales. This approach helps to develop a clearer picture of how pre-Columbian populations living in the Caribbean lived through over 7000 years of climate induced impacts on their environment. This paper suggests that by analyzing the ways in which pre-Columbian communities developed settlement patterns, food procurement strategies and household architecture over time it is possible for archaeologists and paleoclimatologists to inform debates on modern day mitigation strategies for the impacts of climate change in the Caribbean.

List of Figures

Figure 1: Map of Cuba showing location of pre-Columbian archaeological sites and the outline of the Local Case Study Area.

Figure 2: Map of Local Case Study Area showing palaeoenvironmental core sites and the location of pre-Colombian sites next to upland areas where cave systems can be found.

Figure 3: Photographs of the excavation of preserved pre-Columbian house structure at Los Buchillones and a pre-Columbian house reconstruction built in a nearby cultural heritage centre.

References

ANDERSON, D. G., MAASCH, K. A., SANDWEISS, D. H. & MAYEWSKI, P. A. (2007) Climate and culture change: exploring Holocene transitions. IN ANDERSON, D. G., MAASCH, K. A. & SANDWEISS, D. H. (Eds.) *Climate Change & Cultural Dynamics: A Global Perspective on Mid-Holocene Transitions.* London, Academic Press.

BALLE, W. (1998) Historical Ecology: Premises and Postulates. IN BALLE, W. (Ed.) *Advances in Historical Ecology.* New York, Columbia University Press.

BECK, W. J., RÉCY, J., TAYLOR, F., EDWARDS, L. R. & CABLOCH, G. (1997) Abrupt changes in early Holocene tropical sea surface temperature derived from coral records. *Nature,* 385.

BROECKER, W. S. (2009) The impact of global warming on precipitation patterns. *Climate Change: Global Risks, Challenges and Decisions.* Copenhagen, IOP Conference Series: Earth and Environmental Science 6.

BROOKS, N. (2006) Cultural responses to aridity in the Middle Holocene and increased social complexity. *Quaternary International,* 151**,** 29-49.

CALVERA ROSÉS, J., VALCÁRCEL ROJAS, R. & COOPER, J. (2006) Los Buchillones: Universo de Madera. *Revista de la Academia de Ciencias de la Republica Dominicana,* 3**,** 9-16.

CALVERA ROSÉS, J., VALCÁRCEL ROJAS, R., COOPER, J. & BRITO MARTINEZ, O. (2005) Exploraciones arqueológicas en el Jardines del Rey, Cuba. *Revista del Gabinete de Arqueología,* 4**,** 203.

CARLSON, L. A. & KEEGAN, W. F. (2004) Resource Depletion in the Prehistoric Northern West Indies. IN FITZPATRICK, S. (Ed.) *Voyages of Discovery: The Archaeology of Islands.* Westport, Praeger.

COOPER, J. (2004) Islas y Isleños en el Caribe: Interacción a través del paisaje. *El Caribe Arqueológico,* 8**,** 91-96.

COOPER, J. (2007a) Island Interaction in the Prehistoric Caribbean: an archaeological case study from Northern Cuba. *PhD Thesis: Institute of Archaeology.* University College London.

COOPER, J. (2007b) Registro Nacional de Arqueologia Aborígen de Cuba: una discusión de metodos y prácticas. *El Caribe Arqueológico,* 10**,** 132-150.

COOPER, J. (2008) Creating Connections between Caribbean Islands: an archaeological perspective from northern Cuba. IN CONOLLY, J. & CAMPBELL, M. (Eds.) *Comparative Island Archaeologies.* British Archaeological Reports.

COOPER, J. (In Press) Pre-Columbian Archaeology of Cuba: a study of national site distribution patterns and radiocarbon chronologies. IN FITZPATRICK, S. M. & ROSS, A. H. (Eds.) *Island Shores, Distant Pasts: Archaeological and Biological Approaches to the Pre-Columbian Settlement of the Caribbean.* Gainesville, University of Florida Press.

COOPER, J. & VALCÁRCEL ROJAS, R. (2004) Pre-Hispanic Settlements along the North Coast of Cuba: A pilot survey report from Los Buchillones. *Papers from the Institute of Archaeology,* 15**,** 77-81.

COOPER, J., VALCÁRCEL ROJAS, R. & CRUZ RAMÍREZ, P. (2006) Gente en los cayos. Los Buchillones y sus vínculos marítimos. *El Caribe Arqueológico,* 9**,** 66-75.

CURET, L. A. (1992) House Structure and Cultural Change in the Caribbean: Three Case Studies from Puerto Rico. *Latin American Antiquity,* 3**,** 160-174.

DACAL MOURE, R. (1978) *Artefactos de Concha en Las Communidades Aborigenes Cubanas,* Ciudad de la Habana, Museo Anthropológico Montané.

DEPARTAMENTO DE ARQUEOLOGÍA DE CENTRO DE ANTROPOLOGÍA (2003) Atlas Arqueológico de Cuba: una estrategia científica para la investigación y la conservación del patrimonio histórico aborigen. *Catauro: Revista Cubana de Antropologia,* 5**,** 199-202.

DONNELLY, J. P. & WOODRUFF, J. D. (2007) Intense hurricane activity over the past 5000 years controlled by El Nino and the West African Monsoon. *Nature,* 447**,** 465-468.

DREWETT, P. (2003) Feasting at the ball game: the Belmont project, Tortola, British Virgin Islands. *Archaeology International,* 6**,** 56-59.

ELSNER, J. B. (2007) Tempests in Time. *Nature,* 447**,** 647-649.

FEBLES DUENAS, J., GUARCH DELMONTE, J. M., RIVES, A., SÁNCHEZ, R. & MONTEAGUDO, M. (1987) *Censo arqueológico de Cuba por tratamiento computarizado,* La Habana, Folleto, Departamento de Arqueología, Centro de Antropología, Academia de Ciencias de Cuba.

FEBLES DUENAS, J. & MARTÍNEZ, A. R. (1995) Informacion Censal Arqueologica de Cuba. *CD ROM. Taíno: Arqueologia de Cuba.* Colima, Centro de Antropología y CEDISAC.

HAUG, G. H., HUGHEN, K. A., PETERSON, L. C., SIGMAN, D. M. & ROHL, U. (2001) Southward migration of the Intertropical Convergence Zone through the Holocene. *Science,* 293**,** 1304-1308.

HETZINGER, S., PFEIFFER, M., DULLO, W.-C., KEENLYSIDE, N., LATIF, M. & ZINKE, J. (2008) Caribbean coral tracks Atlantic Multidecadal Oscillation and past hurricane activity. *Geology,* 36**,** 11-14.

HIGUERA-GUNDY, A., BRENNER, M., HODELL, D. A., CURTIS, J. H., LEYDEN, B. W. & BINFORD, M. W. (1999) A 10,300 14C yr Record of Climate and Vegetation Change from Haiti. *Quarternary Research,* 52**,** 159-170.

HODELL, D. A., CURTIS, J. H., JONES, G. A., HIGUERA-GUNDY, A., BRENNER, M., BINFORD, M. W. & DORSEY, K. T. (1991) Reconstruction of Caribbean climate change over the past 10,500 years. *Nature,* 352**,** 790-793.

HOEGH-GULDBERG, O., MUMBY, P. J., HOOTEN, A. J., STENECK, R. S., GREENFIELD, P., GOMEZ, E., HARVELL, C. D., SALE, P. F., EDWARDS, A. J., CALDEIRA, K., KNOWLTON, N., EAKIN, C. M., IGLESIAS-PRIETO, R., MUTHIGA, N., BRADBURY, R. H., DUBI, A. & HATZIOLOS, M. E. (2007) Coral Reefs Under Rapid Climate Change and Ocean Acidification. *Science,* 318**,** 1737-1742.

IPCC (2007) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IN SOLOMON, S., QIN, D., MANNING, M., CHEN, Z., MARQUIS, M., AVERYT, K. B., TIGNOR, M. & MILLER, H. L. (Eds.). Cambridge, Cambridge University Press.

JANSEN, E., OVERPECK, J., BRIFFA, K. R., DUPLESSY, J.-C., JOOS, F., MASSON-DELMOTTE, V., OLAGO, D., OTTO-BLIESNER, B., PELTIER, W. R., RAHMSTORF, S., RAMESH, R., RAYNAUD, D., RIND, D., SOLOMINA, O., VILLALBA, R. & ZHANG, D. (2007) Paleoclimate. IN SOLOMON, S., QIN, D.,

MANNING, M., CHEN, Z., MARQUIS, M., AVERYT, K. B., TIGNOR, M. & MILLER, H. L. (Eds.) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, Cambridge University Press.

KEEGAN, F. W. (1991) Lucayan Settlement Patterns and Recent Coastal Changes in the Bahamas. IN JOHNSON, L. L. (Ed.) *Paleoshorelines and Prehistory: An Investigation of Method.* London, CRC Press.

KEEGAN, W. (1995) Recent Climatic and Sea Level Fluctuations in Relation to West Indian Prehistory. *Proceedings of the XVIth International Congress for Caribbean Archaeology,* Vol. XVI**,** 95-104.

KEEGAN, W. F. & DIAMOND, J. M. (1987) Colonization of Islands by Humans: A biogeographical perspective. *Advances in Archaeological Method and Theory,* 10**,** 49-91.

KOZLOWSKI, J. K. (1974) *Preceramic Cultures in the Caribbean,* Krakow, Prace Archeologiczne.

MACKENZIE, F. T. (2003) *Our Changing Planet: an introduction to Earth System Science and Global Environmental Change,* London, Pearson Education.

MCANDREWS, J. H. & RAMCHARAN, E. K. (2003) Holocene pollen diagram from Lake Antoine, Grenada. *INQUA Congress Programs with Abstracts,* XVI**,** 122.

MCCLOSKEY, T. A. & KELLER, G. (2009) 5000 year sedimentary record of hurricane strikes on the central coast of Belize. *Quaternary International,* 195**,** 53-68.

MEGGERS, B. (1954) Environmental Limitation on the Development of Culture. *American Anthropologist,* 56**,** 801-824.

MILNE, G. A., LONG, A. J. & BASSETT, S. E. (2004) Modelling Holocene relative sea-level observations from the Caribbean and South America. *Quaternary Science Reviews,* 24**,** 1183-1202.

NYBERG, J., KUIJPERS, A., MALMGREN, B. A. & KUNZENDORF, H. (2001) Late Holocene changes in precipitation and hydrography recorded in marine sediments from the Northeastern Caribbean sea. *Quarternary Research,* Vol. 56**,** 87-102.

NYBERG, J., MALMGREN, B. A., WINTER, A., JURY, M. R., KILBOURNE, K. H. & QUINN, T. M. (2007) Low Atlantic hurricane activity in the 1970s and 1980s compared to the past 270 years. *Nature,* 447**,** 698-701.

OVERPECK, J. T., PETERSEN, L. C., KIPP, N., IMBRIE, J. & RIND, D. (1989) Climate change in the circum-North Atlantic region during the last deglaciation. *Nature,* 338**,** 553-557.

PANÉ, F. R. (1498 (1990)) *Relacion Acerca de las Antiguedades de los Indios,* La Habana, Editorial de Ciencias Sociales.

PEROS, M. C. (2005) Middle to Late Holocene Environment Change and Archaeology on the North Coast of Central Cuba. *Department of Geography.* Toronto, University of Toronto.

PEROS, M. C., GRAHAM, E. & DAVIS, A. M. (2006) Stratigraphic Investigations at Los Buchillones, a Taìno Site on the North Coast of Central Cuba: Evidence from Geochemistry, Mineralogy, Paleontology, and Sedimentology. *Geoarchaeology,* 21**,** 403-428.

PEROS, M. C., REINHARDT, E. G. & DAVIS, A. M. (2007a) A 6000 cal yr record of ecological and hydrological changes from Laguna de la Leche, north coastal Cuba. *Quarternary Research,* 67**,** 69-82.

PEROS, M. C., REINHARDT, E. G., SCHWARCZ, H. P. & DAVIS, A. M. (2007b) High-resolution paleosalinity reconstruction from Laguna de la Leche, north coastal Cuba, using Sr, O, and C isotopes. *Palaeogeography, Palaeoclimatology, palaeoecology,* 245**,** 535-550.

RAMCHARAN, E. K. (2004) Mid-to-late Holocene sea level influence on coastal wetland developmen in Trinidad. *Quaternary International,* 120**,** 145-151.

RICHERSON, P., BOYD, R. & BETTINGER, R. (2001) Was agriculture impossible during the Pleistocene but mandatory during the Holocene? *American Antiquity,* Vol. 66**,** 387-412.

ROSEN, A. (2007) *Civilizing Climate: Social Responses to Climate Change in the Ancient Near East,* Plymouth, Alta Mira Press.

SAUNDERS, M. A. & LEA, A. S. (2008) Large contribution of sea surface warming to recent increase in Atlantic hurricane activity. *Nature,* 451**,** 557-560.

SCHEFFERS, S. R., HAVISER, J., BROWNE, T. & SCHEFFERS, A. (2009) Tsunamis, hurricanes, the demise of coral reefs and shifts in prehistoric human populations in the Caribbean. *Quaternary International,* 194**,** 69-87.

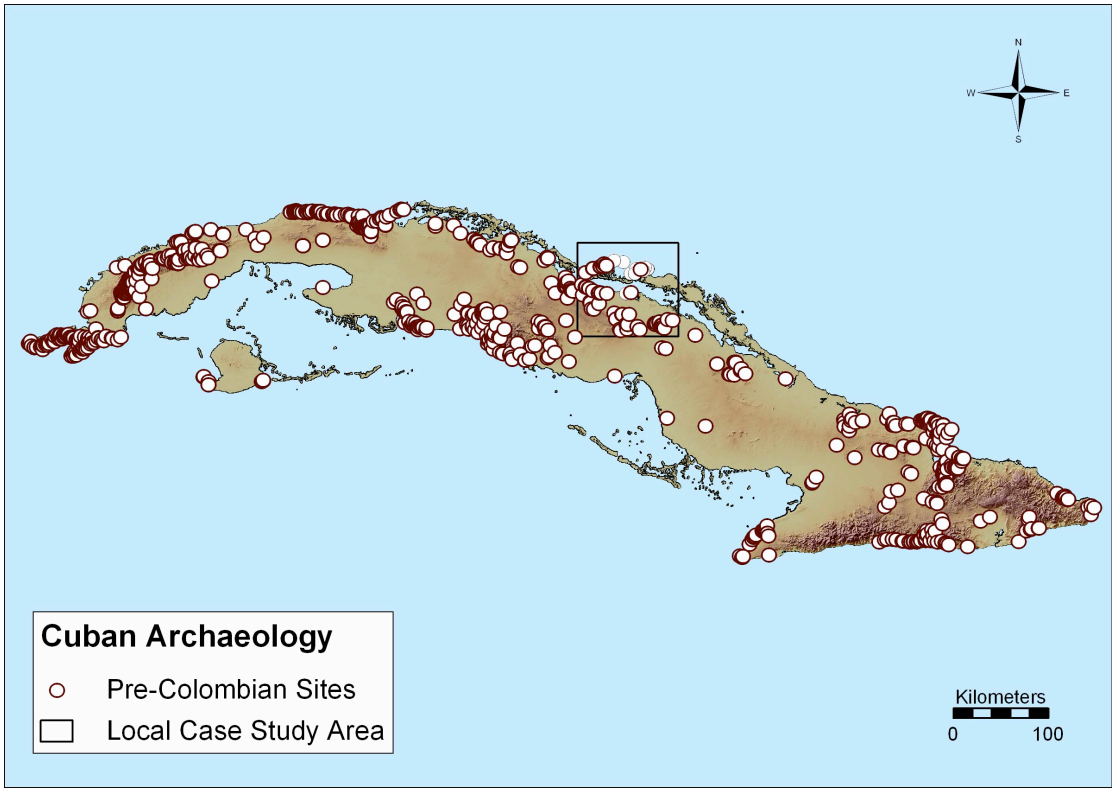
TABIO, E. E. (1995) *Introducción a la Arqueología de las Antillas,* La Habana, Editorial de Ciencias Sociales.

TOSCANO, M. A. & MACINTYRE, I. G. (2003) Corrected western Atlantic sea-level curve for the last 11,000 years based on calibrated 14C dates from *Acropora palmata* framework and intertidal mangrove peat. *Coral Reefs,* 22**,** 257-270.

VALCÁRCEL ROJAS, R. (2002) Inundaciones y Sociedad Aborigen en el Territorio de los Municipios Mayari y Sagua de Tanamo. Holguin, Departamento Centro, Oriental de Arqueologia.

VALCÁRCEL ROJAS, R., COOPER, J., CALVERA ROSÉS, J., BRITO, O. & LABRADA, M. (2006) Postes en el Mar: Excavación de una estructura constructiva aborigen en Los Buchillones. *El Caribe Arqueológico,* 9**,** 76-88.

Figure 1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Cuban Archaeology
Pre-Colombian Sites
Local Case Study Area
Kilometers
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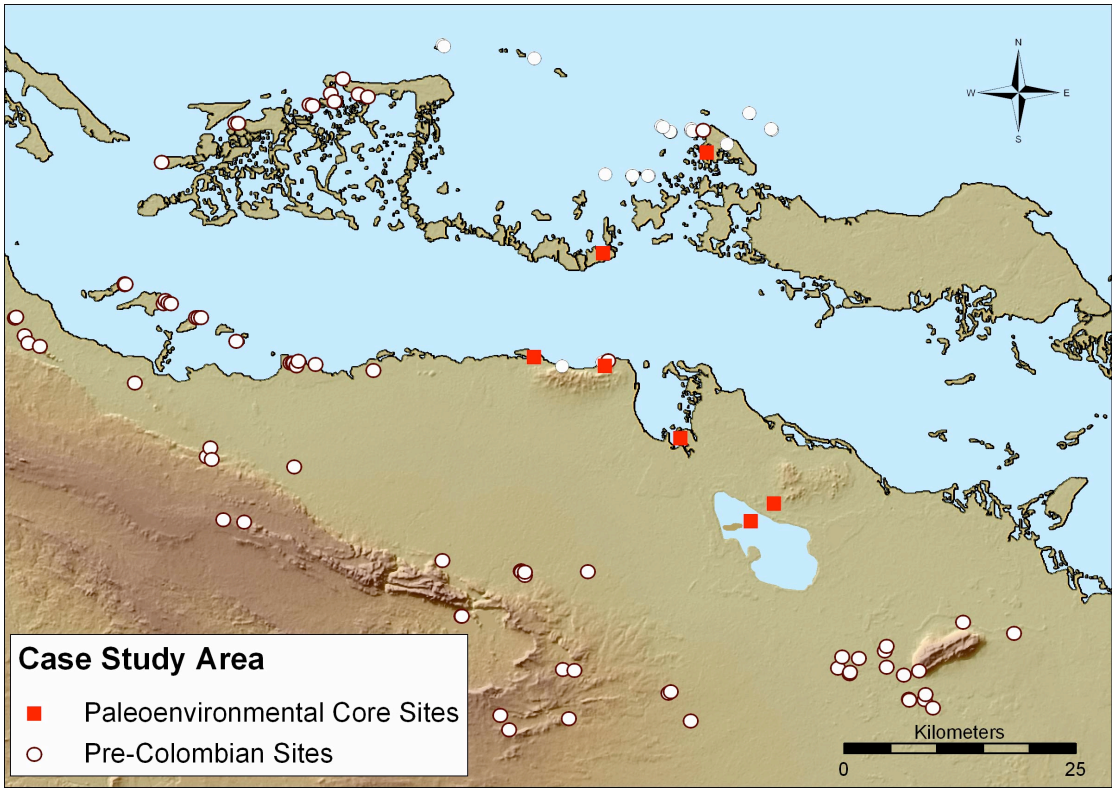
Figure 2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Case Study Area
Paleoenvironmental Core Sites
Pre-Colombian Sites
Kilometers
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Figure 3