Quaternary Science Reviews 163 (2017) 209–218

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Increasing temperature exacerbated Classic Maya conflict over the long term

W. Christopher Carleton [a], David Campbell [b], Mark Collard [a, c, *]

[a] Human Evolutionary Studies Program and Department of Archaeology, Simon Fraser University, 8888 University Drive, Burnaby, British Columbia V5A 1S6, Canada

[b] Department of Statistics and Actuarial Science, Simon Fraser University, 8888 University Drive, Burnaby, British Columbia V5A 1S6, Canada

[c] Department of Archaeology, University of Aberdeen, St Mary's Building, Elphinstone Road, Aberdeen, AB24 3UF, UK

A R T I C L E I N F O

Article history:
Received 13 October 2016
Received in revised form
24 February 2017
Accepted 25 February 2017
Available online 31 March 2017

Keywords:
Human-environment interaction
Climate change
Holocene
Archaeology
North America
Conflict
Warfare
Raiding
Classic Maya

A B S T R A C T

The impact of climate change on conflict is an important but controversial topic. One issue that needs to be resolved is whether or not climate change exacerbates conflict over the long term. With this in mind, we investigated the relationship between climate change and conflict among Classic Maya polities over a period of several hundred years (363–888 CE). We compiled a list of conflicts recorded on dated monuments, and then located published temperature and rainfall records for the region. Subsequently, we used a recently developed time-series method to investigate the impact of the climatic variables on the frequency of conflict while controlling for trends in monument number. We found that there was a substantial increase in conflict in the approximately 500 years covered by the dataset. This increase could not be explained by change in the amount of rainfall. In contrast, the increase was strongly associated with an increase in summer temperature. These finding have implications not only for Classic Maya history but also for the debate about the likely effects of contemporary climate change.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

Concern is growing among policy-makers that the current episode of climate change will increase conflict within and among human societies. For example, the European Commission recently advised that climate change will intensify social and political tensions, leading to more conflict (European Commission, 2013). Similar warnings have been issued by the Intergovernmental Panel on Climate Change and the US Department of Defense in the last few years. The IPCC has cautioned that climate change will exacerbate conflict at a range of scales from inter-personal violence to civil war (Adger et al., 2014), while the DoD has classified climate change as a threat multiplier, suggesting it could lead to political instability and increased terrorism (US Department of Defense, 2014). However, a close examination of the scientific literature reveals that there is still uncertainty about the impact of climate change on conflict. The idea that climate change increases conflict levels has been supported by several studies (Hsiang et al., 2013; Hsiang and Burke, 2014), but this work has been heavily criticized (e.g., Buhaug et al., 2014; Hsiang et al., 2014; Hsiang and Meng, 2014; Meierding, 2013; Salehyan, 2008, 2014; Scheffran et al., 2012; Theisen et al., 2011, 2013). Consequently, at the moment it is not in fact clear that present and future global warming can be expected to lead to more conflict.

One important issue that requires clarification is the nature of relationship between climate change and conflict over the long term. A number of studies have compared historical conflict and climate records (Bai and Kung, 2010; Jia, 2014; Tol and Wagner, 2010; Zhang et al., 2006, 2007b, 2007a, 2011, 2010), but these studies suffer from important methodological shortcomings. Few of them use formal modeling techniques, and those that do employ such techniques utilize ones that are not well suited to analyzing the standard, count-based conflict datasets. This casts doubt on the reliability of the studies' results. In addition to these problems, work to date has focused on data from China and Europe.

* Corresponding author. Human Evolutionary Studies Program and Department of Archaeology, Simon Fraser University, 8888 University Drive, Burnaby, British Columbia V5A 1S6, Canada.

E-mail address: mcollard@sfu.ca (M. Collard).

http://dx.doi.org/10.1016/j.quascirev.2017.02.022
0277-3791/© 2017 Elsevier Ltd. All rights reserved.

Consequently, convincing evidence for a worldwide relationship between climate change and conflict over the long term is currently lacking.

With this in mind, we carried out a quantitative analysis of the influence of climate change on conflict among the Classic Maya over a period of several hundred years. The Maya people occupy a region close to the middle of the isthmian portion of the North American continent (Fig. 1). The Classic period of Maya history began around 250 CE and ended between 900 and 1100 CE (Sharer and Traxler, 2006). It is during the Classic period that the Maya constructed most of the extensive cities and massive pyramids that have made them famous. They also developed one of the few writing systems in the Americas (Houston et al., 2001) and began a tradition of recording historical events on stone monuments. The inscriptions that have been translated provide often remarkably detailed accounts of their myths and political events, including conflicts between city-states (Martin and Grube, 2008).

Inter-polity conflict was an important feature of Classic Maya life (Brown and Stanton, 2003; Chase and Chase, 2003; Culbert, 1991; Hassig, 1992; Houston, 1993; Inomata and Triadan, 2009; Webster, 2000). This is indicated by numerous mentions of conflicts between city-states in the epigraphic record, and by artwork depicting scenes of violence (e.g., Chase and Chase, 1989, 2003; Culbert, 1991; Houston, 1993; Miller, 1986). For instance, epigraphers have identified a century-long power struggle between two of the major southern city-states, Tikal and Calakmul (Martin and Grube, 2008). This struggle embroiled numerous Maya centres, and involved both direct confrontations and proxy conflicts between client polities (e.g., Martin, 1993). Among the conflict events mentioned in the epigraphic record are demands for tribute, captive takings, human sacrifices, deliberate destruction of monuments and temples, and large coordinated attacks that may have been timed to coincide with astronomical events and therefore are often called "star wars" (Webster, 2000).

Scholars have long been interested in Classic Maya conflict, and a number of potential drivers have been proposed, including status rivalry, captive taking, resource acquisition, agricultural shortfalls, and drought (Webster, 2000). To date, however, none of these factors has been shown to correspond to changes in past conflict levels through quantitative analysis. Recently, Kennett et al. (2012) argued that increasing dryness from 600 to 900 CE drove Classic Maya conflict, based on a comparison between conflict levels and an oxygen isotope rainfall proxy from Yok Balum Cave, Belize. Their argument, however, was based only on a visual comparison between the palaeoclimatic and conflict data, which means the association they identified between increasing dryness and conflict may be more apparent than real. Currently, then, it is unclear whether climate change influenced conflict levels among the Classic Maya.

To assess whether Classic Maya conflict was driven by climate

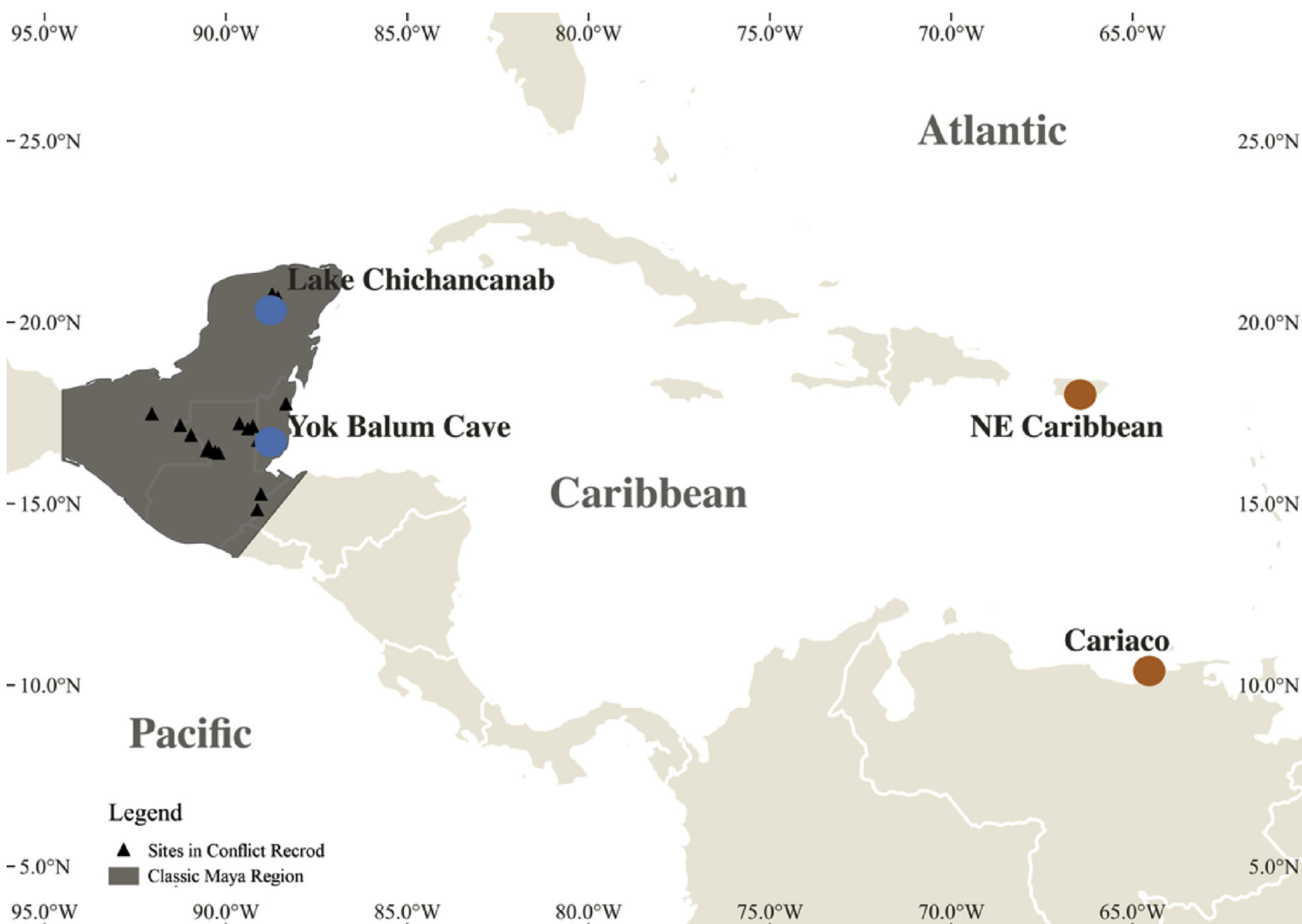

Fig. 1. Map of study area. This map shows the Classic Maya region (shaded red-brown) and the source locations of the palaeoclimate proxy data (the rainfall proxies are blue and the temperature proxies are red-orange).

change, we compiled a time series of conflict levels from the Classic Maya historical record and then identified several published high-resolution palaeoclimate proxies for temperature and rainfall. Subsequently, we used a recently developed time series regression technique called the Poisson Exponentially Weighted Moving Average (PEWMA) method (Brandt et al., 2000) to construct a set of statistical models, each of which used a different climate proxy as a covariate and included monument numbers to control for the possibility that conflict trends reflected only trends in the number of erected monuments. Lastly, we compared the models to each other and to a null model without any climate variables.

2. Materials and methods

The conflict time series we analyzed consists of 144 unique conflict events that are inscribed on Classic Maya monuments from more than 30 major centres (Fig. 2). The monuments and inscriptions are described in dozens of scholarly works (see Supplementary Information [SI]). The inscriptions are mainly from sites in the Southern Maya Lowlands, a region formed by the southern portions of the Mexican states of Campeche, Quintana Roo, the Petén of northern Guatemala, and Belize. Many of the conflict records were taken from Kennett et al. (2012) dataset, which itself was drawn from the Maya Hieroglyphic Database Project (http://mayadatabase.faculty.ucdavis.edu/). The remaining conflict records were identified in the course of a systematic search of literature (see SI). The records describe specific historical events and are associated with Classic Maya calendar dates that are precise to the day in many cases. An illustrative example comes from an altar at Caracol, a large civic-ceremonial centre in southern Belize. It states that the ruler of Caracol "decapitates/attack holy Mutal ajaw [a lord connected to Tikal, another important centre]" in 820 CE (Kennett et al., 2012). We turned the 144 dated conflict events into a time series of conflict levels with a 25-year resolution by counting the number of events that occurred in each 25-year period spanning approximately 350–900 CE. The size of the interval (i.e. 25 years) was chosen to be consistent with previous work on Classic Maya conflict (e.g., Kennett et al., 2012), but we explored the effect of the interval size in a sensitivity analysis (see SI).

Next, we created comparably-binned palaeoclimate time series from two sets of temperature records and three sets of rainfall records (See Fig. 2 and SI). The nearest temperature records we could find with sufficient resolution are sea surface temperature (SST) reconstructions from the Cariaco Basin, including summer and winter estimates (Wurtzel et al., 2013). The rainfall data included the Yok Balum oxygen isotope record, a titanium concentration

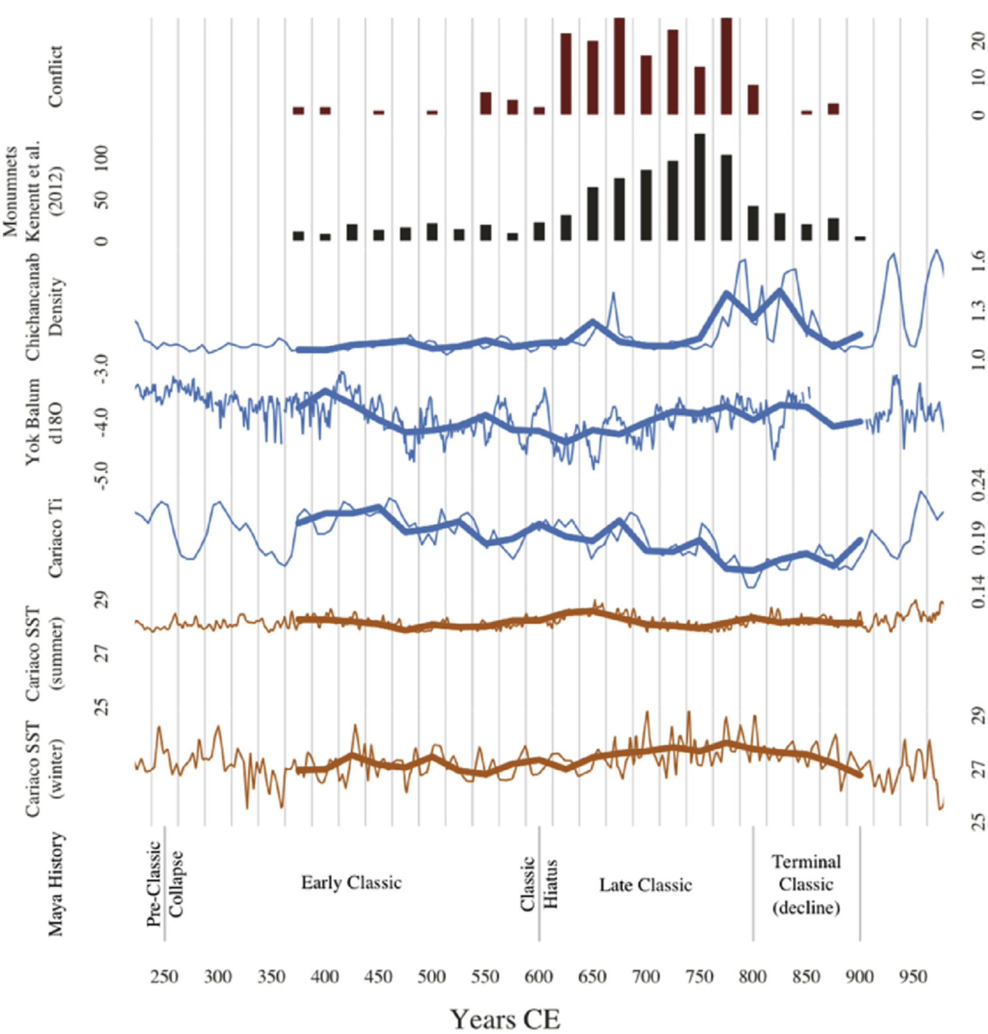

Fig. 2. Conflict and climate proxy data (25-year resolution). The first row is conflict counts. The second row is monument counts taken from (Kennett et al., 2012). The next five rows are the climate records with the thick lines showing the data at 25-year resolution and the thin lines showing the raw palaeoclimate data. The last row shows the approximate boundaries of Classic Maya historical periods according to (Sharer and Traxler, 2006).

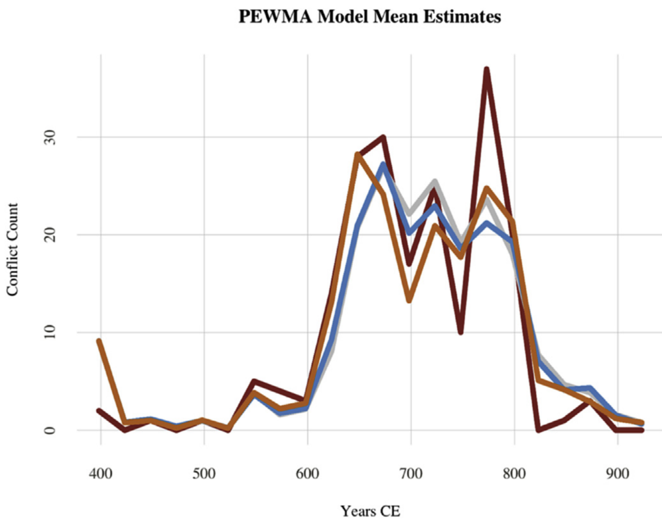

Fig. 3. PEWMA model predictions. This figure shows the PEWMA model predictions compared to the 25-year conflict count data. The 25-year conflict data is represented by the black line; the model predictions using the null model are represented by the grey line; the predictions using the Yok Balum rainfall proxy are represented by the blue line; and the predictions using the Cariaco SST summer estimates are represented by the orange line.

record from the Cariaco Basin, and a sediment density record from Lake Chichcancanab (Haug et al., 2001; Hodell et al., 2005; Kennett et al., 2012). Caution must be exercised when extrapolating palaeoclimatic reconstructions over large geographic areas because local conditions may not be strongly correlated with conditions farther afield. However, climatological processes in the Cariaco basin are known to be related to the conditions in Maya region (Bhattacharya et al., 2015; Haug et al., 2001; Knudsen et al., 2011) and our own comparisons of the Cariaco basin SST reconstructions with nearby temperature time-series suggest that the former adequately reflect a regional trend in temperature change throughout the Caribbean (see SI). Including both temperature and rainfall records allowed us to simultaneously test the drought hypothesis and the hypothesis that increases in temperature drove Classic Maya conflict.

In the next step of the study, we compared the conflict record to the five palaeoclimate records using the PEWMA method, which is a Poisson regression technique (Brandt et al., 2000). Poisson regression was appropriate because it takes into account two important characteristics of conflict time series. The first is that conflict time series always comprise counts of positive integer numbers because there is no such thing as a fractional or negative conflict. The Poisson distribution is suitable for such data because it is discrete, meaning it has only integer-valued outcomes, and it can never be negative. The second characteristic of conflict time series that favours Poisson regression is that the time between conflicts often follows an exponential distribution (e.g., Helmbold, 1998; Houweling and Siccama, 1985; Mansfield, 1988; Richardson, 1944, 1960; Sarkees et al., 2003; Tang et al., 2010). This means that the average number of conflicts in a given span of time conforms to a Poisson distribution. Thus, a Poisson regression model is appropriate for estimating the mean conflict level while testing for the influence of covariates, such as climatic variation. We opted to use PEWMA over standard Poisson regression because it is designed to model autocorrelated count data. Looking at the conflict record, it was clear that the data contain autocorrelation, suggesting that there was "momentum" in Classic Maya conflict levels (see Fig. 3 and SI Fig. 1). We used the Akaike Information Criterion (AIC) to compare competing models, specified with different covariates (Akaike, 2011). Models with lower AICs involve less information loss than those with higher AICs and, thus, are better approximations of the underlying process (Akaike, 2011; Burnham and Anderson, 2004; Kuha, 2004).

In the regression analyses, we compared the rainfall and temperature models with each other and with a null model in which variation in conflict was not affected by changes in temperature or rainfall. We constructed the null model using just a constant and a time-series of monument numbers. As such, the null model allowed us to control for the possibility that the variation in conflict was only a function of previous conflict levels and/or of changes in monument use—i.e., that there was a change in the practice of inscribing monuments or the number of groups erecting monuments rather than a change in the number of conflicts. We then estimated a separate model for each climate proxy, using the proxy as the predictor variable in the model along with the time-series of monument numbers and a constant. We reasoned that if reduced rainfall drove conflict, the models with rainfall proxy predictor variables should have the lowest AICs. Alternatively, if temperature drove conflict, then the models with temperature predictor variables should have the lowest AICs. For any of the climate predictors to be accepted as a potential driver of conflict, the model containing it had to substantially outperform the null model. To negate the potentially biasing effects of arbitrarily selecting bin edge locations, we ran the analysis 25 times, shifting the bin edge locations by +1 years each time. We also performed several additional sensitivity tests looking at how temporal bin widths affected our results and explored whether the increase in time alone could explain the increase in conflict levels (see the SI for details).

3. Results

The change in conflict levels between 350 and 900 CE was considerable. The number of conflicts increased from 0 to 3 every

Table 1
This table contains a summary of the results of the PEWMA analyses obtained after shifting the temporal bins 25 times by +1 year each time. The second column indicates the percentage of the 25 analyses that a given model outperformed the null model (i.e., the model with only a constant and the time-series of monument numbers). The third column indicates the median of the AIC-based likelihoods for each model computed for each of the 25 analyses—the median was used to account for outliers in a small sample. These values indicate how many times more likely a given model is than the null model—*i.e,* a given model is 'x' times more likely than the null model to explain conflict levels, where 'x' is the value in the third column. Note that every model included monument numbers, so these results are showing the improvement in the models that comes from including a given climate variable *after accounting for increasing monument numbers.*

Model	% of times a given model beat the null model	Median AIC weight-based comparison
Yok_d18O	0	1
Chich_Dens	36	19.3
Cariaco_Ti	52	172.1
Cariaco_ssts	100	545490.4
Cariaco_sstw	16	10.6

25 years in the first two centuries to 24 conflicts every 25 years near the end of the period. This increase cannot be explained by change in the amount of rainfall. None of the rainfall proxies had AICs that were substantially and consistently lower than the null model (See SI and Table 1), which suggests that variation in rainfall had no long-term effect on Classic Maya conflict. In contrast, the temporal variation in the number of conflicts might be explained by changes in temperature. One of the temperature proxies—the Cariaco basin winter SST—was no better than the null model in any analyses. But the model involving the Cariaco basin summer SST was consistently hundreds to thousands of times more likely than the null model, depending on where the bin edges were located (SI). This finding indicates that the increase in conflict is best explained by a combination of past conflict levels, increasing numbers of monuments, and increasing summer temperatures. These results were robust to changes in data bin edge locations and width (SI). In sum, our analyses indicate that summer temperature increases led to increased levels of conflict during the Classic Period but rainfall variation had little or no effect (see Fig. 3).

4. Discussion

Two issues need to be addressed before discussing the implications of our findings. First, we need to consider the possibility that the political nature of the epigraphic record biased the results of our study. Not surprisingly, propaganda was an important tool of the Classic Maya elite (Lucero, 2003; Marcus, 1974; Rice, 2009; Sanchez, 2005). One way they spread propaganda was by carving politically favourable inscriptions into monumental architecture. In these inscriptions, the Classic Maya elite told stories about their lineages, connections to the gods, and their conflicts with other elites in order to increase their political capital (Martin and Grube, 2008). To improve the political effect of these narratives, they would sometimes leave events out of the record. Consequently, individual conflict events are often not corroborated at multiple locations, especially at the centres that lost a given conflict, unless recording it served the ruler's political narrative in the long run (Webster, 2000). This means that the conflict record at any given centre is probably biased in favour of the elites at that centre. This in turn raises the possibility that the epigraphic record as a whole does not accurately reflect the variation in conflict levels.

While the political nature of the epigraphic record may be a problem when investigating some issues—e.g. the relationship between particular polities or conflict history at a solitary centre—we think it is unlikely to have negatively affected our results. This is because the use of propaganda can be expected to have been widespread among Classic Maya elites. Essentially, if every leader was recording events that favoured their own historical narrative, then these biases should counter balance each other when all conflict mentions are combined into a single record. While the leader of the losing side in a battle might have been motivated to ignore the loss, the leader of the winning side can be expected to have recorded it. Consequently, taking all recorded conflicts together should produce a relatively unbiased proxy for conflict levels. Thus, there is no reason to believe that the political nature of the conflict record is responsible for our key finding—that temperature and conflict increase in a correlated manner through time.

The second issue we need to address is the possibility that the conflict record contains a temporal bias that favours the Late Classic. This potential bias has two possible sources. One involves our knowledge of the Classic period. As is often the case in archaeology, we have more information about younger periods than older ones. In part this is because younger deposits tend to cover older ones, making older material less visible and harder to find. This is especially true for the Classic Maya because Late Classic structures were often built over earlier ones, covering the earlier architecture. In addition, the epigraphic and architectural evidence indicates that the number of elites was increasing throughout the Classic Period, and this likely resulted in greater numbers of inscribed monuments being built during the Late Classic (Demarest et al., 2014; Fox et al., 1996; O'Manksy, 2013). Taken together, these factors mean that we generally have more information about the Late Classic than the Early and Middle Classic. The other possible source of temporal bias involves conflict events at the beginning of the record. Some of the conflicts dated prior to about 550 CE are recorded on monuments that were erected many years after the events in question, raising some concern about the reliability of the record before that time (Webster, 2000). It is possible that only the most prominent conflicts were remembered long enough to be recorded. This could have biased the record by making it look as if there were fewer conflicts in earlier periods than actually occurred. Together, these two potential sources of bias mean that the Late Classic may be over-represented in the epigraphic record, making it possible that the increase in conflict indicated by our dataset is an artifact.

However, there are reasons to think that our results were not in fact negatively affected by the temporal bias. To begin with, our models account for the bias by including the number of monuments as a covariate. The time-series of monument numbers can be expected to reflect the amount of archaeological information we have from the Classic period, including any over-representation of material dated to the Late Classic. If the latter were responsible for our results, then the increase in monument numbers would explain the increase in conflict entirely with no improvement from adding a temperature covariate. But this is not what we found. The models that included the temperature covariate outperformed all other models. While the increase in monument numbers and temporal autocorrelation in conflict levels explain some of the variation in conflict levels at any given time, adding the summer temperature covariate greatly improved the models according to the AICs. In fact, the models that incorporated the summer temperature covariate were on average several thousand times more likely to explain conflict levels than the null model which included only a constant and the number of monuments (see Table 1). Thus, we think it is unlikely that overrepresentation of Late Classic conflict events in the epigraphic record accounts for our findings.

That our key result is not an artifact of a temporal bias in the conflict record is further supported by the fact that several lines of archaeological evidence indicate conflict increased from the Middle to Late Classic. One of these lines of evidence is fortifications. The Late Classic is notable for defensive walls at several civic-ceremonial centres and for settlements located on highly strategic terrain, such as hilltops and elevated areas with commanding views of the surrounding landscape. Examples include Mayapan, Chunchucmil, Dos Pilas, and Punta De Chimino, and Aguateca, all of which contain well-known evidence of Late Classic fortification (Borgstede and Mathieu, 2007; Dahlin, 2000; Demarest et al., 1997; Rice and Rice, 1981; Russell, 2013; Webster, 1976, 1978, 2000). At Chunchucmil, for example, a rubble wall was erected during the Late Classic that runs over top of other Classic period architecture (Dahlin, 2000). The rubble was robbed from nearby buildings, suggesting the wall was urgently constructed in response to a novel impending threat. Weaponry is a second line of evidence that indicates that conflict increased from the Middle to Late Classic. Aoyama (2005) conducted a typological and microscopic use-wear analysis of stone spear, dart, and arrow points at Aguateca, a site near Copan in western Honduras that is famous for its evidence of Classic period conflict. He concluded that the points were often used as weapons and that the proportion of the lithic artifacts classifiable as weapons increased during the Classic period, indicating an increase in conflict levels. According to Ayoama, his lithic analysis corroborates the archaeological and epigraphic evidence from the region around Copan, which also point to increasing levels of conflict through time. The last line of evidence involves direct evidence of violence in the form of destruction and violent death (e.g., Barrett and Scherer, 2005; Demarest et al., 2016). For example, at Cancuen located in northern Guatemala, Demarest and colleagues discovered a mass grave containing the massacred bodies of an entire royal court dated to the Late Classic (Demarest et al., 2016). They also discovered unfinished defensive walls, scatters of spear and dart points, and evidence for rapidly abandoned buildings. Evidence of this sort is rare, but illustrates severe conflict toward the end of the Classic period, especially in the Peten and Pasion regions of northern Guatemala.

It appears, then, that the relationship we identified between conflict and temperature is not the product of biases in the conflict record. Consequently, we can now consider the implications of our findings.

The literature on climate change and conflict suggests there are two potential mechanisms by which the increase in temperature could have led to greater conflict (e.g., Anderson, 2001; Hsiang and Burke, 2014; Salehyan, 2014; Van Lange et al., 2016). One is psychological. Several recent studies have found evidence that regional heat waves coincide with waves of violent crime (Anderson, 2001; Hsiang et al., 2013; Hsiang and Burke, 2014; e.g., Van Lange et al., 2016). This relationship between increasing temperature and interpersonal violence has been argued to be the result of a psychological link between heat and aggression because there is no connection between crime-related economic gains and increased temperature (Anderson, 2001). The possibility that there is a psychological link between temperature and violence is also supported by a study that found that baseball pitchers target the bodies of batters more often when it is hot than when it is cold, and by a study that discovered that car-drivers use their horns more in hot weather than in cold weather (Kenrick and MacFarlane, 1986; Larrick et al., 2011). Together, these studies suggest it is possible that increased average summer temperatures served to make the Classic Maya more combative and therefore more prone to engage in raiding and warfare.

The other potential mechanism is economic and involves maize, which was the staple crop for the Classic Maya. Our conflict time-series shows the strongest interaction with the high-resolution summer Cariaco SST record spanning approximately June–August (Wurtzel et al., 2013), which overlaps substantially with the primary agricultural season for maize in the Maya region (Sharer and Traxler, 2006; Webster, 2000). Researchers have long been aware that heat stress can reduce maize yields by inhibiting the growth and development of kernels. This has been observed in maize from North America, Africa, and Europe (Barnabás et al., 2008; Cheikh and Jones, 1994; Crafts-Brandner and Salvucci, 2002; Hawkins et al., 2013; Jones and Thornton, 2003; Lobell et al., 2011). While the research is ongoing, recent work involving African maize indicates that temperature has a nonlinear effect on maize productivity (Lobell et al., 2011). Up to 30 °C, maize yields improve as temperature increases. If temperature rises above 30 °C, however, yields decline precipitously. Specifically, for each day spent above 30 °C, maize yields drop by 1%, even under optimal moisture conditions (Lobell et al., 2011). Under drought conditions—caused by decreased rainfall or increased evapotranspiration—the effects are worse still because of the role of water in mitigating heat stress. Because the effect occurs even with careful water management, ultimately there is little a Classic Maya farmer could have done to maintain or improve yields if temperatures were too high during the growing season even for only a few days.

While both mechanisms are feasible, we think the psychological one is less likely than the economic one. Given the 25-year resolution of our analysis and the slight increase in average temperature over the 600-year study period, we suspect that the economic mechanism provides a more compelling explanation for the relationship we identified between temperature and conflict.

The nonlinear effect of heat stress on maize yields suggests the following possible scenario for the Classic Maya, we think. Throughout the Classic period, average temperature fluctuated between 28 °C and 29 °C (SI Fig. 2). During periods when the temperature was around 28 °C or less, maize yields were reasonably stable, with the exception of occasional drought caused by reduced precipitation. Periods of food shortage were infrequent and, when they occurred, brief. Consequently, there was relatively little conflict caused by resource stress. Intermittently, however, average summer temperatures rose, which occurred the first time at around 325 CE, then at around 550 CE and again at around 750 CE (SI Fig. 2). As the average temperature increased to 28.5–29 °C the number of crop growing days with temperatures above 28.5–29 °C increased, too. Initially, the increases led to larger yields for several years or even decades, which raised the carrying capacity and therefore allowed population size to increase (Culbert and Rice, 1990). However, as temperature continued to rise, the region experienced more days at or above 30 °C, which meant that crop shortfalls occurred more frequently. In addition, large-scale deforestation throughout the Classic period caused by urban expansion and agricultural intensification might have led to increased evapotranspiration, worsening the effect of increasing regional temperatures by reducing soil moisture availability (Oglesby et al., 2010; Shaw, 2003). As a consequence of this, the recently expanded population experienced longer, more frequent periods of food shortage, leading to increased levels of conflict.

Food shortages among the Classic Maya might have led to conflict via two pathways. One of these involves starvation. While there is no direct archaeological evidence for starvation as far as we know, it is theoretically possible that maize yield shortfalls propelled Classic Maya rulers and their followers to attack nearby city-states and steal their food. Conflict over food might have been especially prominent during the Terminal Classic, a period of several decades leading up to the so-called collapse that began in the southern lowlands around 900 CE. The recently identified impact of deforestation and droughts during the Late and Terminal Classic might have combined to reduce crop yields so substantially that starvation was a real threat (Oglesby et al., 2010). This hypothesis is consistent with recent research indicating that resource scarcity drives interpersonal conflict by making the need for resources outweigh the personal costs of violence (Allen et al., 2016). For most of the Classic period, however, we suspect the starvation scenario is not particularly likely because potential combatants would have been suffering the same food shortages, given the regional effect of temperature change, making stealing food an unsustainable long-term strategy. Furthermore, without draft animals, transporting enough maize through the jungle on foot over potentially hundreds of kilometers to support an entire population after a conflict would be difficult for the victor, even if some transport of maize over long distances might have been possible (Drennan, 1984a, 1984b; Sluyter, 1993). It is also worth noting in connection with this that epigraphic and iconographic data indicate that tribute extracted from clients or demanded after conflict was often paid in the form of elite goods like cacao, jade, feathers, fine polychrome pottery, and cotton textiles, rather than large amounts of staple resources like maize (Chase et al., 2008; Foias, 2002; Inomata, 2001). In light of these points, we think the starvation scenario is unlikely to account for the long-term trend in conflict levels.

The other pathway that might have linked food shortage to conflict involves kingly legitimacy. Like many ancient kings, Classic Maya rulers had to demonstrate their legitimacy in order to retain their power (Iannone et al., 2016). One of the main sources of legitimacy among Classic Maya rulers was their ability to ensure prosperity for their states, especially agricultural prosperity (Iannone, 2016; Lucero, 2002). Because maize was the primary staple crop for the Classic Maya, local maize yields likely would have been directly linked to the perceived legitimacy of the rulers. We can see that the Maya rulers' identities during the Classic period became increasingly tied to maize because many rulers adopted special epithets that included the Maya term for maize (Tokovine, 2013). With their legitimacy tied to maize yields, any declines in yields could have created a "crisis of legitimacy" (Iannone, 2016), which the rulers needed to overcome by reaffirming or accruing cachet. The available evidence indicates that Classic Maya elites had several ways to accrue cachet, including building monuments, bestowing titles and land on client rulers, exacting tribute from clients, hosting ritual festivals, and successfully attacking other elites (Chase and Chase, 1998; Inomata, 2006; LeCount, 2001; Marcus, 1974; Sanchez, 2005; Webster, 1975, 2000). Importantly for present purposes, however, a decline in maize yields would have made some of these tactics difficult. With less maize, a ruler could not have relied as heavily on opulent festivals or fed large labour forces. Consequently, he or she would have had to place more emphasis on bestowing rewards and assailing others.

While the economic mechanism provides a plausible explanation for how temperature change impacted Classic Maya conflict frequency over the long-term, internal conflict dynamics must also be considered. To reiterate, elite competition was an important source of conflict (O'Manksy, 2013; Webster, 2000). It is clear from the monument record that Classic Maya kings and elites were in competition with one another over resources and power (Martin and Grube, 2008; Sharer and Traxler, 2006). As such, much of the increase in conflict may have been caused by political ratcheting, whereby rulers engage in conflict as retribution for past transgressions leading to escalating conflict levels over time irrespective of resource shortfalls. Such ratcheting would be reflected in the serial dependence of the record because conflict would beget conflict. Conflict levels might also have increased with the proliferation of elites vying for power because of the polygamous marriage rules for elites and their system for status inheritance (O'Manksy, 2013). The proliferation led to an increase in the number of polities competing for power and resources, as indicated by the increase in the number of named political entities in the epigraphic record—the so-called "emblem glyphs" (Marcus, 1976). These internal processes would have created "momentum" in conflict.

The relatively strong performance of the null model, which includes no external variables, suggests that internal conflict dynamics, such as political ratcheting and elite proliferation, may indeed have been responsible for much of Classic Maya conflict (Fig. 3 and SI Fig. 2). However, the approximation still falls short of the observed conflict levels. According to our analysis (Fig. 3 and SI Fig. 2), including the summer Cariaco SST record produced a better approximation of past conflict levels than was possible using internal dynamics alone. Hence, the internal dynamics of Classic Maya conflict are insufficient to explain all of the temporal variation in conflict—it is necessary to look at external forces, too.

We envisage a situation in which early in the Classic period relationships among elites were often tense but only rarely reached the point at which conflict was deemed preferable to peace. As the population grew, and the number of competing elites increased, conflict became an increasingly common part of Classic Maya life for political reasons, as mentioned earlier. Critically, however, temperature also began to rise in the early Classic period and crop shortages became more common, leading to resource stress and more frequent crises of legitimacy. Because the strategies available for responding to the legitimacy crises became limited as crop failure became more common—e.g., the rulers did not have the maize required to hold large feasts or feed the corvee labour forces needed to build impressive monuments—the threshold to conflict was reduced. In other words, conflict became an increasingly important tool for regaining and maintaining legitimacy. Consequently, rulers decided more often to attack their neighbours, sometimes in order to acquire the resources necessary to feed their communities but more often to maintain or increase their political capital. Memories of past conflict fuelled this process by decreasing tolerance of words and actions of competitors. Thus, conflict levels increased in part because conflict begets conflict and in part because maize crop failures were occurring more frequently, creating crises of legitimacy for the elite. Eventually, the growth in conflict became explosive, rising from 0 to 3 per quarter century to 24 per quarter century.

Our findings have several implications. One concerns our understanding of the Classic Maya. Most of the literature about the impact of climate change on the Classic Maya has focused on drought caused by rainfall shortages. Droughts have been implicated in the demise of the Classic Maya civilization and argued to be a driver of cultural change (e.g., Kennett et al., 2012; Dunning et al., 2012; de Menocal, 2001; cf. O'Manksy, 2013). Even though several rainfall proxies indicate that droughts occurred during the Classic period (e.g., Kennett et al., 2012), our results indicate that drought might have had less of an impact on Classic Maya society than previously thought. While individual droughts may have contributed to specific conflicts, our results show that the trend in conflicts cannot be explained by rainfall shortages. Instead, the key environmental variable seems to have been temperature. The effects of temperature on conflict levels could have been further exacerbated by deforestation, soil depletion, and rainfall shortage in certain cases. But the overall long-term trend in conflict levels is still best explained by a combination of internal conflict dynamics and temperature. This may lead to new insights about the patterns that have been documented in the Classic Maya archaeological and epigraphic records.

Our results also have policy implications. Most obviously, our results indicate that it is necessary take into account the long-term, potentially nonlinear, effects of climate change on conflict. Over the short-term, the effects in some areas might appear benign, as with initially increasing maize yields. But, over longer time scales the effects could be dire, contributing to substantial increases in conflict and violence. Perhaps more perniciously, though, our results also imply that we need to consider the interaction between our current political ideology and the impact of climate change. In the Maya case, the increase in conflict levels might not have been an inevitable outcome of climate change had their political ideology been different. The symbolic connection between maize yields and power might have driven their leaders into conflict unnecessarily. So, perhaps we need to look more closely at the role political ideology may play in determining the long-term impact of climate change on our societies. If we ignore the long-term effects and the role of ideology in determining outcomes we could drastically underestimate the scale of the problems caused by climate change and miss opportunities to adapt by addressing problematic ideologies.

Our study has implications for the role of archaeological data in discussions about modern climate change too. Several scholars have argued that archaeology can contribute to the discussion about contemporary climate change and some policy organizations like the IPCC have recently begun including archaeological case studies in their reports. The idea here is that the archaeological record contains important examples of past societies affected by climate changes, which can serve as a basis for improving our predictions about future impacts and persuade people to take action. Our results reinforce this notion, but they also underscore archaeology's ability to shed light on another critical issue—namely the long-term effects of climate change. The impact of temperature on Classic Maya conflict appears to have been significant at the centennial scale, something we could only see with long-term records. So, in addition to being a source for case studies, archaeology is important because of the long-term, time-transgressive vantage point it affords us. In fact, since long-term effects can be quantitatively and qualitatively different than short term ones, the archaeological record is a crucial source of information about human responses to climate change. Needless to say, the same holds for the palaeontological record and current attempts to predict the impact of climate change on non-human animals.

With regard to future research, we think at least three avenues could be explored. One involves determining the extent to which the pattern we identified holds for the whole Maya region. As we explained in the Materials and Methods section, the conflict record pertains mostly to the Southern Maya Lowlands, with relatively few inscriptions from elsewhere. That said, some archaeological evidence in the form of defensive architecture points to an increase in conflict at the end of the Classic period in the northern Yucatan as well, suggesting that the trend might be the same (e.g., Dahlin, 2000; Webster, 1978). So, future research should aim to determine whether the pattern we identified pertains to the whole Maya region by collecting more epigraphic data or perhaps using construction dates for defensive architecture as a proxy for increased militarism. Another avenue for future research involves our hypothesis about the causal pathway from temperature to conflict. While it seems plausible that increasing temperature could have caused maize yields to decline thereby precipitating greater levels of conflict, this hypothesis needs to be evaluated. One possible test would be to compare a proxy for maize yields, such as pollen frequencies in sediment cores, to palaeoclimate records using the PEWMA method. This test should be possible in the near future because high-resolution pollen records are being collected from the region by a team led by David Wahl of the University of California Berkeley (Pers. Comm. August 10, 2015). The third and final avenue for future research involves finding local high-resolution temperature records. While the temperature increase we identified appears to have been a regional phenomenon that probably affected all Classic Maya centres, local records might expose some important variability. A better understanding of that variability could improve the predictions of our model and reveal important variation in the climate-conflict relationship.

Acknowledgements

We received financial support from the Social Sciences and Humanities Research Council of Canada (767-2011-0159 and 895-2011-1009), the Natural Sciences and Engineering Research Council of Canada (RGPIN04040-2014), the Canada Research Chairs Program, the Canada Foundation for Innovation, the British Columbia Knowledge Development Fund, MITACS, and Simon Fraser University. We thank Michael Blake, Julia Cole, James Conolly, Arthur Demarest, Keith Dobney, Gyles Iannone, Douglas Kennett, Mark Maslin, Arne Mooers, Stephen Shennan, Adrian Timpson, Seam Ulm, Andrew Weaver, David Webster, Bernard Wood, and Jennifer Wurtzel for their helpful feedback on this paper.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.quascirev.2017.02.022.

References

Adger, W., Pulhin, J., Barnett, J., Dabelko, G., Hovelsrud, G., Levy, M., Oswald Spring, U., Vogel, C., 2014. Human security. In: Field, C., Barros, V., Dokken, D., Mach, K., Mastrandrea, M., Bilir, T., Chatterjee, M., Ebi, K., Estrada, Y., Genova, R., Girma, B., Kissel, E., Levy, A., MacCracken, S., Mastrandrea, P., White, L. (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part a: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp. 755–791.

Akaike, H., 2011. Akaike's information criterion. In: Lovric, M. (Ed.), International Encyclopedia of Statistical Science. Springer, Berlin Heidelberg pp. 25. http://dx.doi.org/10.1007/978-3-642-04898-2_110.

Allen, M.W., Bettinger, R.L., Codding, B.F., Jones, T.L., Schwitalla, A.W., 2016. Resource scarcity drives lethal aggression among prehistoric hunter-gatherers in central California. PNAS 113, 12120–12125. http://dx.doi.org/10.1073/pnas.1607996113.

Anderson, C.A., 2001. Heat and violence. Curr. Dir. Psychol. Sci. 10, 33–38.

Aoyama, K., 2005. Classic Maya warfare and weapons: spear, dart, and arrow points of Aguateca and Copan. Anc. Mesoam. 16, 291–304. http://dx.doi.org/10.1017/S0956536105050248.

Bai, Y., Kung, J.K., 2010. Climate shocks and sino-nomadic conflict. Rev. Econ. Statistics 93, 970–981. http://dx.doi.org/10.1162/REST_a_00106.

Barnabás, B., Jäger, K., Fehér, A., 2008. The effect of drought and heat stress on reproductive processes in cereals. Plant Cell & Environ. 31, 11–38. http://dx.doi.org/10.1111/j.1365-3040.2007.01727.x.

Barrett, J.W., Scherer, A.K., 2005. Stones, bones, and crowded plazas: evidence for terminal classic Maya warfare at Colha, Belize. Anc. Mesoam. 16, 101–118. http://dx.doi.org/10.1017/S0956536105050091.

Bhattacharya, T., Byrne, R., Böhnel, H., Wogau, K., Kienel, U., Ingram, B.L., Zimmerman, S., 2015. Cultural implications of late Holocene climate change in the Cuenca Oriental, Mexico. Proc. Natl. Acad. Sci. U. S. A. 112, 1693–1698. http://dx.doi.org/10.1073/pnas.1405653112.

Borgstede, G., Mathieu, J.R., 2007. Defensibility and settlement patterns in the Guatemalan Maya highlands. Lat. Am. Antiq. 18, 191–211. http://dx.doi.org/10.2307/25063104.

Brandt, P.T., Williams, J.T., Fordham, B.O., Pollins, B., 2000. Dynamic modeling for persistent event-count time series. Am. J. Political Sci. 44, 823–843. http://dx.doi.org/10.2307/2669284.

Brown, M.K., Stanton, T.W., 2003. Ancient Mesoamerican Warfare. AltaMira Press, Walnut Creek, CA.

Buhaug, H., Nordkvelle, J., Bernauer, T., Böhmelt, T., Brzoska, M., Busby, J.W., Ciccone, A., Fjelde, H., Gartzke, E., Gleditsch, N.P., Goldstone, J.A., Hegre, H., Holtermann, H., Koubi, V., Link, J.S.A., Link, P.M., Lujala, P., O'Loughlin, J., Raleigh, C., Scheffran, J., Schilling, J., Smith, T.G., Theisen, O.M., Tol, R.S.J., Urdal, H., Uexkull, von, N., 2014. One effect to rule them all? A comment on climate and conflict. Clim. Change 127, 391–397. http://dx.doi.org/10.1007/s10584-014-1266-1.

Burnham, K.P., Anderson, D.R., 2004. Multimodel inference: understanding AIC and BIC in model selection. Sociol. Methods & Res. 33, 261–304. http://dx.doi.org/10.1177/0049124104268644.

Chase, A., Chase, D., 1998. Late classic Maya political structure, polity size, and warfare arenas. In: Ruíz, A.C. (Ed.), Anatomía de una civilización: aproximaciones interdisciplinarias a la cultura Maya. Sociedad Española de Estudios Mayas, Madrid, pp. 11–29.

Chase, A.F., Chase, D.Z., 1989. The Investigation of Classic Period Maya Warfare at Caracol, pp. 5–18. Belize. Mayab.

Chase, A.F., Chase, D.Z., Zorn, E., Teeter, W., 2008. Textiles and the Maya Archaeological Record. http://dx.doi.org/10.1017/S095653610700003X. Ancient Mesoamerica 19.

Chase, D., Chase, A., 2003. Texts and contexts in classic Maya warfare: a brief consideration of epigraphy and archaeology at Caracol, Belize. In: Brown, M., Stanton, T. (Eds.), Ancient Mesoamerican Warfare. AltaMira Press, Walnut Creek, pp. 171–188.

Cheikh, N., Jones, R.J., 1994. Disruption of maize Kernel growth and development by heat stress (role of cytokinin/abscisic acid balance). Plant Physiol. 106, 45–51. http://dx.doi.org/10.1104/pp.106.1.45.

Crafts-Brandner, S.J., Salvucci, M.E., 2002. Sensitivity of photosynthesis in a C4 plant, maize, to heat stress. Plant Physiol. 129, 1773–1780. http://dx.doi.org/10.1104/pp.002170.

Culbert, T.P., 1991. Classic Maya Political History: Hieroglyphic and Archaeological Evidence. Cambridge University Press, Cambridge, UK.

Culbert, T.P., Rice, D.S., 1990. Precolumbian Population History in the Maya Lowlands. University of New Mexico Press, Albuquerque.

Dahlin, B.H., 2000. The barricade and abandonment of Chunchucmil: implications for northern Maya warfare. Lat. Am. Antiq. 11, 283–298. http://dx.doi.org/10.2307/972179.

de Menocal, P.B., 2001. Cultural responses to climate change during the late holocene. Sci. New Ser. 292, 667–673.

Demarest, A.A., Andrieu, C., Torres, P., Forné, M., Barrientos, T., Wolf, M., 2014. Economy, exchange, and power: new evidence from the late classic Maya port city of Cancuen. Anc. Mesoam. 25, 187–219. http://dx.doi.org/10.1017/S0956536114000121.

Demarest, A.A., O'Mansky, M., Wolley, C., Van Tuerenhout, D., Inomata, T., Palka, J., Escobedo, H., 1997. Classic Maya defensive systems and warfare in the petexbatun region: archaeological evidence and interpretations. Anc. Mesoam. 8, 229–253. http://dx.doi.org/10.1017/S095653610000170X.

Demarest, A.A., Quintanilla, C., Suasnavar, J., 2016. The collapses in the west and the violent ritual termination of the classic Maya capital center of Cancuen: causes and consequences. In: Iannone, G., Houk, B., Schwake, S. (Eds.), Ritual, Violence, and the Fall of the Classic Maya Kings. University Press of Florida, Gainesville, FL, pp. 159–186.

Drennan, R.D., 1984a. Long-distance movement of goods in the mesoamerican formative and classic. Am. Antiq. 49, 27–43. http://dx.doi.org/10.2307/280510.

Drennan, R.D., 1984b. Long-distance transport costs in pre-hispanic mesoamerica. Am. Anthropol. 86, 105–112.

Dunning, N.P., Beach, T.P., Luzzadder-Beach, S., 2012. Kax and kol: collapse and resilience in lowland Maya civilization. Proc. Natl. Acad. Sci. U. S. A. 109, 3652–3657. http://dx.doi.org/10.1073/pnas.1114838109.

European Commission, 2013. Joint communication to the European Parliament and the Council: the EU's comprehensive approach to external conflict and crises. accessed February 2016 http://www.eeas.europa.eu/archives/docs/statements/docs/2013/131211_03_en.pdf.

Foias, A., 2002. At the Crossroads: the economic basis of political power in the Petexbatun Region. In: Masson, M.A., Freidel, D.A. (Eds.), Ancient Maya Political Economies. AltaMira Press, Walnut Creek, CA, pp. 223–248.

Fox, J.W., Cook, G.W., Chase, A.F., Chase, D.Z., 1996. Questions of political and economic integration: segmentary versus centralized states among the ancient Maya. Curr. Anthropol. 37, 795–801.

Hassig, R., 1992. War and Society in Ancient Mesoamerica. University of California Press, Berkeley, CA.

Haug, G.H., Hughen, K.A., Sigman, D.M., Peterson, L.C., Röhl, U., 2001. Southward migration of the intertropical convergence zone through the holocene. Sci. New Ser. 293, 1304–1308.

Hawkins, E., Fricker, T.E., Challinor, A.J., Ferro, C.A.T., Ho, C.K., Osborne, T.M., 2013. Increasing influence of heat stress on French maize yields from the 1960s to the 2030s. Glob. Change Biol. 19, 937–947. http://dx.doi.org/10.1111/gcb.12069.

Helmbold, R.L., 1998. Trends in Land Combat (TLC). DTIC Document, Accessed February 2016. http://www.dtic.mil/get-tr-doc/pdf?AD=ADA344866.

Hodell, D.A., Brenner, M., Curtis, J.H., 2005. Terminal classic drought in the northern Maya lowlands inferred from multiple sediment cores in lake Chichancanab (Mexico). Quat. Sci. Rev. 24, 1413–1427.

Houston, S.D., 1993. Hieroglyphs and History at Dos Pilas: Dynastic Politics of the Classic Maya. University of Texas Press, Austin, TX.

Houston, S.D., Chinchilla Mazariegos, O.F., Stuart, D., 2001. The Decipherment of Ancient Maya Writing. University of Oklahoma Press, Norman, OK.

Houweling, H.W., Siccama, J.G., 1985. The epidemiology of war, 1816-1980. J. Confl. Resolut. 29, 641–663.

Hsiang, S.M., Burke, M., 2014. Climate, conflict, and social stability: what does the evidence say? Clim. Change 123, 39–55. http://dx.doi.org/10.1007/s10584-013-0868-3.

Hsiang, S.M., Burke, M., Miguel, E., 2014. Reconciling climate-conflict meta-analyses: reply to Buhaug et al. Clim. Change 127, 399–405. http://dx.doi.org/10.1007/s10584-014-1276-z.

Hsiang, S.M., Burke, M., Miguel, E., 2013. Quantifying the influence of climate on human conflict. Science 341. http://dx.doi.org/10.1126/science.1235367, 1235367.

Hsiang, S.M., Meng, K.C., 2014. Reconciling disagreement over climate–conflict results in Africa. Proc. Natl. Acad. Sci. U. S. A. 111, 2100–2103. http://dx.doi.org/10.1073/pnas.1316006111.

Iannone, G., 2016. Cross-cultural perspectives on the scapegoat king: the anatomy of a model. In: Iannone, G., Houk, B., Schwake, S. (Eds.), Ritual, Violence, and the Fall of the Classic Maya Kings. University Press of Florida, Gainesville, FL, pp. 23–60.

Iannone, G., Houk, B.A., Schwake, S.A., 2016. Ritual, Violence, and the Fall of the Classic Maya Kings. University Press of Florida, Gainesville, FL.

Inomata, T., 2006. Plazas, performers, and spectators: political theaters of the classic Maya. Curr. Anthropol. 47, 805–842. http://dx.doi.org/10.1086/ca.2006.47.issue-5.

Inomata, T., 2001. The power and ideology of artistic creation: elite craft specialists in classic Maya society. Curr. Anthropol. 42, 321–349. http://dx.doi.org/10.1086/320475.

Inomata, T., Triadan, D., 2009. Culture and practice of war in Maya society. In: Nielsen, A.E., Walker, W.H. (Eds.), Warfare in Cultural Context: Practice, Agency, and the Archaeology of Violence. University of Arizona Press, Tucson, AZ, pp. 56–83.

Jia, R., 2014. Weather shocks, sweet potatoes and peasant revolts in historical China. Econ. J. 124, 92–118. http://dx.doi.org/10.1111/ecoj.12037.

Jones, P.G., Thornton, P.K., 2003. The potential impacts of climate change on maize production in Africa and Latin America in 2055. Glob. Environ. Change 13, 51–59. http://dx.doi.org/10.1016/S0959-3780(02)00090-0.

Kennett, D.J., Breitenbach, S.F.M., Aquino, V.V., Asmerom, Y., Awe, J., Baldini, J.U.L., Bartlein, P., Culleton, B.J., Ebert, C., Jazwa, C., Macri, M.J., Marwan, N., Polyak, V., Prufer, K.M., Ridley, H.E., Sodemann, H., Winterhalder, B., Haug, G.H., 2012. Development and disintegration of Maya political systems in response to climate change. Science 338, 788–791. http://dx.doi.org/10.1126/science.1226299.

Kenrick, D.T., MacFarlane, S.W., 1986. Ambient temperature and horn honking a field study of the heat/aggression relationship. Environ. Behav. 18, 179–191. http://dx.doi.org/10.1177/0013916586182002.

Knudsen, M.F., Seidenkrantz, M.-S., Jacobsen, B.H., Kuijpers, A., 2011. Tracking the Atlantic multidecadal oscillation through the last 8,000 years. Nat. Commun. 2, 178. http://dx.doi.org/10.1038/ncomms1186.

Kuha, J., 2004. AIC and BIC: comparisons of assumptions and performance. Sociol. Methods & Res. 33, 188–229. http://dx.doi.org/10.1177/0049124103262065.

Larrick, R.P., Timmerman, T.A., Carton, A.M., Abrevaya, J., 2011. Temper, temperature, and temptation heat-related retaliation in baseball. Psychol. Sci. 22, 423–428. http://dx.doi.org/10.1177/0956797611399292.

LeCount, L.J., 2001. Like water for chocolate: feasting and political ritual among the late classic Maya at Xunantunich, Belize. Am. Anthropol. 103, 935–953. http://dx.doi.org/10.1525/aa.2001.103.4.935.

Lobell, D.B., Bänziger, M., Magorokosho, C., Vivek, B., 2011. Nonlinear heat effects on African maize as evidenced by historical yield trials. Nat. Clim. Change 1, 42–45. http://dx.doi.org/10.1038/nclimate1043.

Lucero, L.J., 2003. The politics of ritual: the emergence of classic Maya rulers. Curr. Anthropol. 44, 523–558. http://dx.doi.org/10.1086/ca.2003.44.issue-4.

Lucero, L.J., 2002. The collapse of the Classic Maya: a case for the role of water control. Am. Anthropol. 104, 814–826.

Mansfield, E.D., 1988. The distribution of wars over time. World Polit. 41, 21–51. http://dx.doi.org/10.2307/2010478.

Marcus, J., 1976. Emblem and State in the Classic Maya Lowlands: an Epigraphic Approach to Territorial Organization. Dumbarton Oaks, Washington, DC.

Marcus, J., 1974. The iconography of power among the classic Maya. World Archaeol. 6, 83–94.

Martin, S., 1993. Tikal's "star war" against Naranjo. In: Macri, M.J., McHargue, J. (Eds.), Eighth Palenque Round Table, 1993. Pre-Columbian Art Research Institute, San Francisco, pp. 223–236.

Martin, S., Grube, N., 2008. Chronicle of the Maya Kings and Queens: Deciphering the Dynasties of the Ancient Maya. Thames & Hudson Ltd., London, UK.

Meierding, E., 2013. Climate change and conflict: avoiding small talk about the weather. Int. Stud. Rev. 15, 185–203. http://dx.doi.org/10.1111/misr.12030.

Miller, M.E., 1986. The Murals of Bonampak. Princeton University Press, Princeton, N.J.

Oglesby, R.J., Sever, T.L., Saturno, W., Erickson, D.J., Srikishen, J., 2010. Collapse of the Maya: could deforestation have contributed? J. Geophys. Res. Atmos. 115 http://dx.doi.org/10.1029/2009JD011942.

O'Mansky, M., 2013. Collapse without drought. In: Iannone, G. (Ed.), Great Maya Droughts in Cultural Context: Case Studies in Resilience and, University Press Of Colorado, Boulder, CO, pp. 157–176.

Rice, D.S., Rice, P.M., 1981. Muralla de Leon: a Lowland Maya Fortification. J. Field Archaeol. 8, 271–288. http://dx.doi.org/10.2307/529569.

Rice, P.M., 2009. On Classic Maya political economies. J. Anthropol. Archaeol. 28, 70–84. http://dx.doi.org/10.1016/j.jaa.2008.09.001.

Richardson, L.F., 1960. Statistics of Deadly Quarrels. Boxwood Press, Pacific Grove, CA.

Richardson, L.F., 1944. The distribution of wars in time. J. R. Stat. Soc. 107, 242–250. http://dx.doi.org/10.2307/2981216.

Russell, B.W., 2013. Fortress mayapan: defensive features and secondary functions of a post-classic Maya fortification. Anc. Mesoam. 24, 275–294. http://dx.doi.org/10.1017/S0956536113000217.

Salehyan, I., 2014. Climate change and conflict: making sense of disparate findings. Political Geogr. Special Issue Clim. Change Confl. 43, 1–5. http://dx.doi.org/10.1016/j.polgeo.2014.10.004.

Salehyan, I., 2008. From climate change to Conflict? No consensus yet. J. Peace Res. 45, 315–326.

Sanchez, J.L.J., 2005. Ancient Maya royal strategies: creating power and identity through art. Anc. Mesoam. 16, 261–275. http://dx.doi.org/10.1017/S0956536105050121.

Sarkees, M.R., Wayman, F.W., Singer, J.D., 2003. Inter-state, intra-state, and extra-state wars: a comprehensive look at their distribution over time, 1816-1997. Int. Stud. Q. 47, 49–70.

Scheffran, J., Brzoska, M., Kominek, J., Link, P.M., Schilling, J., 2012. Disentangling the climate-conflict Nexus: empirical and theoretical assessment of vulnerabilities and pathways. Rev. Eur. Stud. 4, 1–13.

Sharer, R.J., Traxler, L.P., 2006. The Ancient Maya. Stanford University Press, Redwood City, CA.

Shaw, J.M., 2003. Climate change and deforestation: implications for the Maya collapse. Anc. Mesoam. 14, 157–167. http://dx.doi.org/10.1017/S0956536103132063.

Sluyter, A., 1993. Long-distance staple transport in western mesoamerica: insights through quantitative modeling. Anc. Mesoam. 4, 193–199. http://dx.doi.org/10.1017/S0956536100000882.

Tang, D.-H., Han, X.-P., Wang, B.-H., 2010. Stretched exponential distribution of recurrent time of wars in China. Phys. A Stat. Mech. its Appl. 389, 2637–2641. http://dx.doi.org/10.1016/j.physa.2010.03.012.

Theisen, O.M., Gleditsch, N.P., Buhaug, H., 2013. Is climate change a driver of armed conflict? Clim. Change 117, 613–625. http://dx.doi.org/10.1007/s10584-012-0649-4.

Theisen, O.M., Holtermann, H., Buhaug, H., 2011. Climate Wars?: assessing the claim

that drought breeds conflict. Int. Secur. 36, 79–106.
Tokovine, A., 2013. Place and Identity in Classic Maya Narratives. Pre-Columbian Studies, Dumbarton Oaks, Washington, DC.
Tol, R.S.J., Wagner, S., 2010. Climate change and violent conflict in Europe over the last millennium. Clim. Change 99, 65–79. http://dx.doi.org/10.1007/s10584-009-9659-2.
US Department of Defense, 2014. Quadrennial Defense Review. Accessed February 2016. http://archive.defense.gov/pubs/2014_Quadrennial_Defense_Review.pdf.
Van Lange, P.A.M., Rinderu, M.I., Bushman, B.J., 2016. Aggression and violence around the world: a model of CLimate, aggression, and self-control in humans (CLASH). Behav. Brain Sci. 1–63. http://dx.doi.org/10.1017/S0140525X16000406.
Webster, D., 2000. The not so peaceful civilization: a review of Maya war. J. World Prehistory 14, 65–119.
Webster, D., 1978. Three walled sites of the northern Maya lowlands. J. Field Archaeol. 5, 375–390. http://dx.doi.org/10.2307/529492.
Webster, D., 1976. Lowland Maya fortifications. Proc. Am. Philosophical Soc. 120, 361–371.
Webster, D., 1975. Warfare and the evolution of the state: a reconsideration. Am. Antiq. 40, 464–470. http://dx.doi.org/10.2307/279334.
Wurtzel, J.B., Black, D.E., Thunell, R.C., Peterson, L.C., Tappa, E.J., Rahman, S., 2013. Mechanisms of southern Caribbean SST variability over the last two millennia. Geophys. Res. Lett. 40 http://dx.doi.org/10.1002/2013GL058458, 2013GL058458.
Zhang, D.D., Brecke, P., Lee, H.F., He, Y.-Q., Zhang, J., 2007a. Global climate change, war, and population decline in recent human history. Proc. Natl. Acad. Sci. U. S. A. 104, 19214–19219. http://dx.doi.org/10.1073/pnas.0703073104.
Zhang, D.D., Jim, C.Y., Lin, G.C.-S., He, Y.-Q., Wang, J.J., Lee, H.F., 2006. Climatic change, wars and dynastic cycles in China over the last millennium. Clim. Change 76, 459–477. http://dx.doi.org/10.1007/s10584-005-9024-z.
Zhang, D.D., Lee, H.F., Wang, C., Li, B., Pei, Q., Zhang, J., An, Y., 2011. The causality analysis of climate change and large-scale human crisis. Proc. Natl. Acad. Sci. U. S. A. 108, 17296–17301. http://dx.doi.org/10.1073/pnas.1104268108.
Zhang, D.D., Zhang, J., Lee, H.F., He, Y., 2007b. Climate change and war frequency in eastern China over the last millennium. Hum. Ecol. 35, 403–414.
Zhang, Z., Tian, H., Cazelles, B., Kausrud, K.L., Bräuning, A., Guo, F., Stenseth, N.C., 2010. Periodic climate cooling enhanced natural disasters and wars in China during AD 10–1900. Proc. Biol. Sci. 277, 3745–3753. http://dx.doi.org/10.1098/rspb.2010.0890.