Archaeological Evidence of Change in Social Organization at Kiwulan, an Iron Age site in Northeastern Taiwan, during European Colonization

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Abstract

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Colonial encounters between Europeans and Indigenous people have long been an important topic in historical archaeology as scholars seek to explore their effects on Indigenous social, cultural, and material worlds. However, our current understanding heavily relies on studies of European colonies with obvious evidence of direct colonial rule, which provides limited insights into the reactions of Indigenous societies at the periphery of European colonial centers. In those places, Indigenous societies may face a relatively weak or indirect colonial power. Despite the colonization of Taiwan by Europeans from 1624 to 1662, little is known from the archaeological record about the nature of interaction between Indigenous groups and Europeans, and the role of European contact in social change in Indigenous social organization. Our current knowledge of Indigenous settlements in northeastern Taiwan suggests a relatively complex social system in the Iron Age around the 17th century, at the same time as the European presence. Northeastern Taiwan is an especially interesting example of European and Indigenous interaction because the degree of European colonization appears to have been much less pronounced compared to other places in Northern Taiwan. This region serves as a great example to explore the reaction of Indigenous people in the periphery of colonial centers.

The aim of this dissertation is to explore whether there is a relationship between Indigenous social complexity in northeastern Taiwan and the European presence in the 17th century. I hypothesize that the kind of social complexity we observed throughout northeastern Taiwan may have resulted from the indirect impacts of European colonization and associated frequent trade activities. To test my hypothesis, I explore social changes at a major Iron Age site, Kiwulan (1350-1850 AD), by examining multiple lines of archaeological evidence. I use a conceptual framework of corporate/network modes to model changes in social complexity. I studied archeological materials, including trade ornaments, locally made ceramics, and burials, as proxies to investigate changes before and after the European arrival. The core of this dissertation is three research papers that focus on a specific element of the archaeological record of Kiwulan to measure and compare the extent of social inequality. I used novel methods applied for the first time to archaeological materials in this region, such as geometric morphometrics for ceramic shapes and Bayesian network modeling for understanding social changes via burial data. To better understand Indigenous reactions to foreign presence on a long-term scale, I also incorporate a later Chinese phase to provide a diachronic perspective to explore social change at Kiwulan from the 14th to 19th century.

The results indicate that there was a social change from a more corporate mode to a more network mode after the European arrival in the 17th century, and before the influx of Han Chinese immigrants in the 19th century. This finding is supported by an uneven spatial distribution of prestige goods across the residential area, and a centralized pattern of burial networks that demonstrate an increased social inequality after the European presence. These changes suggest a form of indirect colonial impact – indirect stimulus of social reorganization –

that is still not well understood in the archaeological literature. This dissertation demonstrates how an Indigenous society changes in a pericolonial context and shows the potential of this topic in East and Southeast Asia. In addition, an important technical contribution of this research is the use of novel reproducible quantitative methodologies. This dissertation takes an open science approach to enable maximum availability to research data, analytical processes, and final outputs through the practice of reproducible research to advocate research transparency and equal access to knowledge.

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Chapter 1

Introduction: Social Changes in a Pericolonial Context

European expansion into many parts of the world in the 15th to 19th centuries often had substantial economic, cultural, and political impacts on local Indigenous societies. Encounters between Europeans and Indigenous people varied from place to place, depending on different geological, historical, and cultural settings. Despite much prior work focusing on European colonies in Asia, little attention has been given to the colonial experiences of Indigenous societies at the periphery of European colonial centers. This presents a serious gap in the knowledge required for understanding the response of Indigenous people to low-intensity interactions with colonial powers. Low-intensity interactions can be defined as frequent direct or indirect trade events involving colonists or goods and sources from them, where violence was absent or rare.

The aim of the research presented in this dissertation is to explore whether social change occurred in Late Iron Age northeastern Taiwan because of the European presence in the 17th century. I pursue this aim by analyzing a variety of archaeological materials using a conceptual framework of corporate/network modes to detect changes. This research suggests that indirect impacts of the European presence could have led to forms of social complexity that have not been previously identified in this region.

In this introductory chapter, I aim to provide some background and orientation for the three chapters that follow. I will first introduce the topic of social complexity and inequality in archaeology and briefly survey some different approaches to understanding small-scale societies that have some level of complexity. Then, I will present my research questions about social organizations in Iron Age northeastern Taiwan in the period of European presence. After that, I will give a brief historical and cultural background of European colonization in Taiwan relevant to my research area. I will outline my models to examine the relationship between increased social inequality and foreign contacts. To conclude this chapter, I will outline the dissertation structure and briefly preview the main chapters of the dissertation. At the time of writing, the first two of the three main body chapters of this dissertation have been published as peer-reviewed journal articles, and third has been submitted for peer review.

Social Inequality and Complexity in Archaeology

In this section, I will briefly introduce a selection of issues relevant to studies of social complexity and inequality in archaeology that motivated this research. Archaeologists have long studied social changes in a wide range of human societies to understand the characteristics of complex societies, processes that enact social complexity, and mechanisms for the emergence of social inequality. In this dissertation I define social inequality as the organizing principle of hierarchical structures in societies manifested in differential access to goods, information, and power (Price and Feinman, 2010, p. 2). I define social complexity as the extent of internal differentiation, the degree of social integration, and the intricacy of

relations among social units (Blanton, 1981, p. 17; Paynter, 1989, p. 369). Social inequality is often viewed as one criterion to assess the level of social complexity of a society.

The ways that archaeologists have conceptualized social complexity and inequality have changed greatly over time. An earlier view was that inequality is a characteristic of hierarchical societies where vertical status differences are evident, and the emergence of inequality normally is associated with modes of economy, degree of sedentism, or size of settlements (Service, 1971). However, more recent thinking has shown that inequality varies independently of those dimensions of vertical complexity, and exists in hunter-gatherer-fisher societies, for example in the Upper Paleolithic period, and societies in egalitarian contexts (Ames, 2010, pp. 16–19; Bowles et al., 2010; Fitzhugh, 2003; Hayden, 2001; Moreau, 2020; Vanhaeren and d'Errico, 2005; Wengrow and Graeber, 2015; Woodburn, 1982). Since human societies vary from culture to culture with their distinct historical processes, it is challenging for archaeologists to explain cross-cultural variations in the relationship between social complexity and inequality observed in past societies. This leads to more recent studies turning to explore the origin of social inequality instead of treating inequality as just a criterion for assessing social complexity (Moreau, 2020; Paynter, 1989; Price and Feinman, 2010; Smith et al., 2018).

By focusing on emergence or changes in social inequality, archaeologists can understand diverse trajectories to hierarchy. Inequality could be present in many forms, such as economic or political, with varying degrees according to its strength, pervasiveness, and scale of permanence (Ames, 2007, p. 487). Unlike differences between people that represent distinct personality traits, inequality appears when a difference conveys cultural and social meanings given by a society, and people will be rewarded with privileges or prestige

because of that difference (Ames, 2007). There are several conditions under which social inequality has been hypothesized to emerge. Previous work has identified population growth, interaction inside settlements, increased storage behaviors, and subsistence intensification as some relevant internal factors (Abrutyn and Lawrence, 2010; Bentley and Maschner, 2001; Zangrando, 2009). Other researchers have suggested environmental and climate change, warfare and conflicts, and involvement in exchange networks as external pressures (Carter, 2015; Hayden and Mathewes, 2009; Hoopes, 2005; Rhee and Choi, 1992; Smith, 1999).

Although the study of social inequality has many historically- and culturally-specific contingencies that can limit the production of generalizations, the identification of underlying mechanisms can help to understand how inequality develops in each context and elaborate models for explaining social change. In Southeast and East Asia, many prehistoric societies show some level of socio-economic inequalities but lack strong evidence of stratification. Different concepts have been proposed to explain power-gaining strategies in those social organizations, such as heterarchy, referring to fluid and unranked social relationships depending on their contexts (Crumley, 2015, 1995; O'Reilly, 2000; Tucci et al., 2014; White, 1995); transegalitarian, covering societies between egalitarian and hierarchy with an emphasis of surplus use strategies (Hayden, 2003, 2001; Higham, 2011; Kawashima, 2008), and corporate/network modes, representing group-oriented power/individual power as a representation of horizontal hierarchy (Byrd, 1994; Feinman, 2000; Hayden, 2011; Ueda et al., 2016). Previous work on the Iron Age societies of northeastern Taiwan found some level of complexity and social differentiation according to burial contexts around the same time as European arrival in northern Taiwan. These

societies lack an obvious institutional hierarchy and are normally characterized as an egalitarian society (Chen, 2007; Hsieh, 2009). However, the divisions of egalitarian and stratified societies based on evolutionary approaches, as used currently by scholars working in Taiwan, does not well explain the evidence we observed overall in this region. In this dissertation I will adopt a different approach, using corporate/network modes as a main conceptual framework to examine social changes, which I will describe in more detail below.

Research Questions

This dissertation tackles the question of whether the European arrival, with its associated trade network, led to an increase in social inequality in local Indigenous societies. I answer this question by testing the hypothesis of increased social inequality after the presence of Europeans at Kiwulan (1350-1850 AD), an Late Iron Age site in northeastern Taiwan. I evaluate this hypothesis with multiple lines of archaeological evidence from Kiwulan. If this hypothesis is supported by the evidence, it may represent a form of colonial impact – indirect stimulus of social reorganization – that is not well understood in the archaeological literature. This is important because these processes could have been the catalyst for increases in social inequality that we see throughout northeastern Taiwan in the 17th century, and may help us to understand the trajectories of social changes in other places with similar conditions. In the following sections I provide a brief summary of relevant historical background leading up to European contact at Kiwulan, and introduce the conceptual framework that this research is based on. I also outline the specific model that I will evaluate

with the archaeological evidence, and summarize the three main body chapters that detail the evaluation of this model.

Iron Age Northeastern Taiwan in the Period of European Colonization

In this section I provide a brief overview of the history of European colonial activities in Taiwan, the encounters between Europeans and local Indigenous people, and the current discussion of social organizations in late Iron Age Northeastern Taiwan. The purpose of this overview is to give historical and cultural background to contextualize my research about social changes in Indigenous societies in northeastern Taiwan.

Northeastern Taiwan, in the modern region known as Yilan or Kavalan in the Indigenous language, is about 70 kilometers away from the first European northern base with mountains in between. I define northeastern Taiwan as an area at the periphery of colonial center where the European power was indirect with a few sporadic, mostly non-violent direct contacts. This type of context has also been called pericolonialism (Acabado, 2017; Kang, 2016, pp. 31–78; Trabert, 2017). The first encounter between Indigenous people and European colonial powers was in 1632, when seven Indigenous villages were attacked by the Spanish according to the historical record written by soldiers (Borao Mateo, 2009). However, the historical record lacks of details about the specific villages and locations.

European colonization in Taiwan began in the 1620s due to the competition between the Spanish and the Dutch for political and economic control of the Pacific (Nadal, 2009, pp. 154–155). In 1624, the Dutch East India Company (Vereenigde Oost-indische Compagnie,

VOC) established a trading station at the Bay of Tayouan (today's Anping in Tainan) in southwestern Taiwan for access to the trade with China and Japan, and interrupted the Spanish commercial activities (Andrade, 2005, p. 299). To compete against Dutch interference, the Spanish East Indies company (Indias orientales españolas) in Manila set up trading stations in northern Taiwan in 1626 to secure their Asian trade (details in chapter 2) (Berrocal et al., 2018; Borao Mateo, 2013, p. 585). Those two European powers co-existed in different parts of Taiwan for almost two decades. In 1642, the Dutch attacked the Spanish fortress, ousted the Spanish, took over their base, and expanded their power to the eastern part of Taiwan. Since then, Dutch power could access the whole island until 1662, when they were defeated by the army of Koxinga, who established the Kingdom of Tungning in Taiwan as a military base against the Qing Dynasty in China (Andrade, 2007).

European colonization in Taiwan was driven by commercial purposes, with a focus on setting up trading hubs in Asia and exploiting natural resources, instead of acquiring territory or building settlements of colonizing populations (Lange et al., 2006). This mode of colonization has been observed in many places in Asia where the emergence of European dominance mostly relies on effective interactions with local Indigenous groups, usually merchants (Andrade, 2005; Wills Jr, 1993). Such interaction could vary from collaborating with Indigenous people to build alliances, using Indigenous talents for production and trade, to offering colonial support for Indigenous alliances against their local enemy (Wills Jr, 1993). Northern Taiwan can be viewed as one case in this colonial situation during both the Spanish and Dutch colonization periods. For example, after occupying northern Taiwan, the VOC worked closely with the Basay people, a local Indigenous group, who were skilled at speaking different local and foreign languages and handcrafting for trading with other

Indigenous groups. The Basay assisted the Dutch with collecting tributes and coordination between Indigenous villages and Dutch governors (Kang, 2016, pp. 207–211).

In addition to collaborating with local Indigenous groups, the VOC invented an annual-based political ceremony, called landdag in Dutch, in an attempt to display their colonial authority and engage local Indigenous people. The VOC held the first official landdag in 1641 in southern Taiwan (an earlier meeting in 1636 could be viewed as a pre-landdag), and later, two major landdagen for southern and northern Taiwan, respectively, since 1644 (Andrade, 2007, 1997). Each allied village had one Indigenous representative for attending the ceremony, mostly elders or original leaders in their community. The jobs of those representatives include tributes gathering and negotiation with the Europeans on behalf of the whole village. In the ceremony, the Dutch reinforced their dominant power and a hierarchical relationship by collecting tribute and giving symbolic items to Indigenous representatives. Those items included an orange flag, a robe of black velvet, and a rattan staff with a silver head bearing the company's insignia as symbols of authority (Andrade, 1997, p. 59). Each Indigenous representative needed to return the staff the following year when the term ended and the staffs would be given again by the Dutch again to reward high performance (Andrade, 1997). For local Indigenous people, owning staves was a means to obtaining power and being more influential, because staffs represented not just foreign items with colonial images but also the privilege of controlling external relations with the VOC (Kang, 2016, pp. 137–162). As a result, local people might have competed with each other for those symbolic items or taken advantage of colonial symbol, for example by possessing the staff, to expand their power in their communities.

Before European arrival in the early 17th century, there was a local regional trade network in northern Taiwan developed in the 14th century (Chen, 2005; Liu and Wang, 2017). In this pre-existing trade network, Chinese traders brought goods, such as textiles, ceramics, metal items, and ornaments, to northern Taiwan to exchange for natural resources, such as gold, animal hides, and sulfur, collected by the Basay people via another local exchange network with Kavalan people in northeastern Taiwan (Chen, 2005; Hsieh, 2009, pp 60). During the European colonization period, Europeans actively participated in these local networks to obtain natural resources from Basay and Kavalan people, in exchange for Japanese and Chinese silver (Israel, 1989, p. 18). Indigenous communities in Taiwan experienced different levels of colonial influence, depending on their geographic locations and the extent to which the colonists established their economic or political bases (Borao Mateo, 2009; Kang, 2016, pp. 30–78; 2012). In 1647, to better investigate gold mines in the southernmost area near Yilan and control Indigenous people, the Dutch attacked several Yilan Indigenous villages, including Kiwulan, and asked them to pay annual tributes (Kang, 2012, pp. 296–297). However, Dutch control in Yilan was generally weak, only a few villages paid tributes. As the largest tribute-paying community in this region, Yilan is a good example to explore the indirect impacts of European colonial activities on local social organizations.

What does previous research tell us about social changes at Kiwulan during the European colonization period? Archaeological evidence at Kiwulan indicates some degree of social complexity around the 17th century, including increased settlement size and population, well-arranged house layouts, cultivation of rice, complex inter- and intra-trade networks, the use of prestige goods, and differences in accumulation of goods in burial contexts (Chen, 2004; Cheng, 2008; Li and Chiu, 2014). Previous studies of the social organization of

Kiwulan suggest two different interpretations: a stratified society (Cheng, 2008) and a relatively egalitarian society (Hsieh, 2012). These apparently contradictory conclusions are based on observations of differential accumulations of goods in burial contexts, without the findings of institutional power structures. A clear understanding of the dynamic anthropological processes and underlying variables of social change has not yet been produced. Furthermore, despite the colonization of Taiwan by Europeans from 1624 to 1662 (Israel, 1989, pp. 173–174), there has been little discussion by archaeologists about the effect of European contact on Taiwanese Indigenous societies. In addition to Europeans, Indigenous communities in Yilan also experienced an influx of Han Chinese immigrants since the end of the 18th century. It remains unclear whether social differentiation developed during the contact period, or emerged earlier and shifted in degree later. To fill the gap, this research reported in this dissertation takes a diachronic perspective to explore social inequality in northeastern Taiwan from the 14th to 19th century, with the main focus on the European presence with the Han Chinese presence as a compliment.

Theoretical Framework for Investigating Social Changes in a Pericolonial Context

In this section, I introduce the theoretical framework I employ for investigating social changes in local Indigenous societies in a pericolonial context. To detect change, I use the concept of corporate-network modes proposed by Feinman (2000). This provides a comparative basis for discussing social structures based on distinct strategies for power. As a complement to this model, to understand the dynamic process of change in social

inequality potentially associated with the contact period, I use the competition model proposed by Clark and Blake (1994) to understand the mechanisms of social change.

Understanding Social Organization: The Corporate/Network Modes

Corporate-based and network-based societies reflect two distinct strategies (Figure 1.1) for obtaining individual power, which can be viewed as a horizontal axis crosscutting traditional vertical hierarchy, also termed horizontal hierarchy (Drennan et al., 2010; Feinman, 2000). In the network mode, inequality develops when individuals accumulate wealth through individual networks and use the wealth to attract followers, control resources, or monopolize trade networks. In contrast, the corporate mode stresses shared power between individuals within a single leadership group, integrative ceremonies and rituals, and large cooperative labor tasks (Feinman, 2000; Siegel, 1999). Inequality in the corporate mode is group-oriented which means significant power is normally found associated with a single leadership group where power is shared between individuals (Blanton et al., 1996, p. 2; Feinman, 2000). Compared to the network mode, the corporate mode has less obvious signs for social ranking and presents the corporate type of hierarchy (Drennan et al., 2010). That means power is less individualized and social inequality, if any, is more obvious between a leadership council and people outside of the council. Also, inequality is not necessarily defined by one's kinship association to the leader as inequality in conventional hierarchical societies.

Corporate and network modes may be found in a wide variety of societies, regardless of whether the society is mostly hierarchical or egalitarian; however, one of the two strategies will often dominate at any given time (Skoglund, 2009). For example, modern and

prehistoric Puebloan groups in the American Southwest (Feinman et al., 2000) and Neolithic Beidha in Southwest Asia (Byrd, 1994) are recognized as corporate societies, while Bantam in northwest Java before the Dutch contact (Ueda et al., 2016) and Cahokia after 1200 AD in the American South are identified as network societies (Trubitt, 2000). Corporate/network modes can be viewed as a continuum or spectrum with one mode at each end, where a society could shift along the spectrum when the dominant power-seeking strategy changes. As noted above, there is currently no agreement about whether Late Iron Age cultures in northeastern Taiwan were egalitarian or stratified societies. Applying the concept of corporate/network modes may resolve this debate by shifting the focus from binary conditions to a focus on changes in strategy for gaining power. The corporate/network modes may have been a common form of social structure for many Indigenous communities in Yilan, where societies may change between those two modes. Thus, the corporate/network continuum can provide a more suitable and flexible theoretical framework to compare the degree of social inequality before and after European contact in this region.

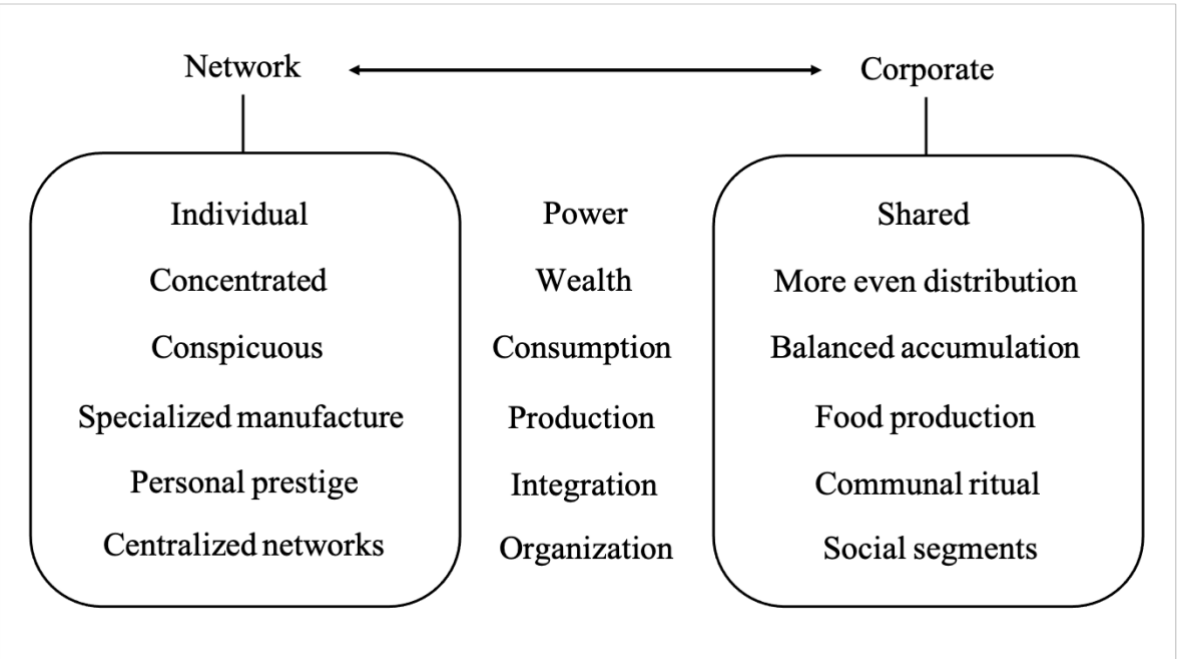

Figure 1.1: Characteristics of Corporate and Network organizational modes (Feinman, 2000)

Mechanisms of Social Change: The Competition Model

The corporate/network modes provide a convenient framework for identifying changes in social inequality, but they provide only a limited vocabulary for exploring the causes of these changes. Previous research into causal explanations for social change can be divided roughly into two categories: ecological (natural) and social (cultural), with two analytical levels: group and individual (Fitzhugh, 2000). Ecological explanations assume that group or individual motivations for survival and reproduction are key mechanisms for social change. According to the ecological view, the structure of the environment, such as the quantity, quality, distribution, stability, and accessibility of resources, is crucial to understanding the process of group formation and the basis of inequality (Billman, 2001; Boehm, 1993; Boone, 1992; Woodburn, 1982). In contrast, social approaches, inspired by practice theory

(Bourdieu, 1977; Giddens, 1984), suggest that the force of social change comes from internal symbolic systems or actions conveying cultural meanings (Brumfiel, 1994; Clark and Blake, 1994; Silliman, 2001). Social approaches hold that competitions among ambitious individuals for prestige, wealth, or power are key contributors to the emergence of social inequality (Brumfiel, 1994; Clark and Blake, 1994; Hayden and Villeneuve, 2010). Competitions between people are based on two basic conditions for a society where prestige can be accumulated and ambitious persons are tolerated. In this way, aggrandizers are able to build up their factions by manipulating accessible, productive resources, and providing physical, social, and spiritual benefits to attract followers. It should be noted that those approaches are not exclusive. Societies can be explained by both ecological and social factors that interact with each other (Fitzhugh, 2020).

In northeastern Taiwan, it could be a case of changes caused by social factors, competitions among the inhabitants of Kiwulan for prestige or wealth, stimulated by the arrival of Europeans with associated trade activities. In other parts of the world, the introduction of foreign materials into Indigenous exchange networks has been associated with substantial social and political change (Mitchell, 2000, p. 182). For example, Brenner (1988)'s study social organization in Southern New England in the 17th century reveals that Indigenous people viewed European materials as markers of prestige and political status, and they displayed these materials in death rituals to show social differentiation. Archaeological sites in northeastern Taiwan show some evidence of accumulation of imported prestige goods in burials (Chen, 2005; Cheng, 2008), which might indicate the pursuit of prestige or wealth. In addition to prestige, European colonial powers could have provided military support to Indigenous allies. For example, Voss (2005)'s study of a colonial outpost in California

shows that colonial residents have different identities and higher social status than other local Indigenous people. A general model to summarize these case studies might be that the support of a colonial power combined with high local values for imported goods, might lead to competition among individuals. In this study, I will explore using the concept of competition to explain the changes in social inequality at Kiwulan before and after European contact.

Models and Predictions for Kiwulan

Building on the theoretical concepts of corporate/network modes (Feinman, 2000) and competition (Clark and Blake, 1994), I have developed two models about changes in social inequality during the European contact period based on three assumptions. First, I assume that the corporate mode, based on age or kinship, was a common strategy at Kiwulan prior to the arrival of the Europeans. This assumption is based on ethnographic data describing the presence of age-based groups for Kavalan people, where groups consisting of middle-aged men normally make decisions on behalf of the village's residents (Zhan, 1995). Second, I assume the storage behavior of surplus and accumulation of wealth or prestige goods were allowed. This is a reasonable assumption because storage or accumulation behaviors are necessary to reduce the risk of periodic disasters, such as typhoons and strong monsoons in this area. The presence of corporate groups at Kiwulan during the pre-contact period can be predicted from the environmental circumscription of Yilan which fostered pooling of resources, combined with social conditions promoting cooperation in order to survive natural disasters (Boone, 1992). At the arrival of Europeans, I assume colonial power and long-distance trade networks provided opportunities for potentially ambitious and

competitive individuals to become more influential by maintaining good relationships with Europeans and accumulating foreign prestige goods. Based on these assumptions, I propose two models to describe the possible impact of European colonization on Kiwulan society.

The first model is a shift from corporate mode to network mode was associated with the presense of European colonial power. On one hand, economic demands from Europeans for tribute, such as rice and deerskin, motivated Indigenous people to cultivate or hunt more than their needs. On the other hand, foreign trade goods, which were often viewed as prestige goods coming into the community, led to accumulation behaviors due to their rarity and their symbolic association with colonial power. With frequent trade activities in this region, influential and ambitious individuals who have a better economic basis could obtain more trade items or have better relations with the Europeans or other Indigenous merchants (eg. Billman, 2001). Since these competitive aggrandizers may have had more opportunities to access the limited prestige goods, they could then accumulate and use those resources to attract followers and increase their influence beyond the corporate group (eg. Boone, 1992). Inequality associated with individuals then increases, leading to the transformation of social organization from a corporate mode to a network mode. If this model is credible for Kiwulan, then I predict the archaeological record will show a differentiation in the distribution of trade goods, an emergence of ceramic specialization, and a centralized social structure evident in burial networks that can indicate an increased social inequality in local societies after the European arrival.

The second model is one of relative cultural continuity or even resistance during the European contact period. This model takes the view that although there was colonial influence in the local exchange network, a high degree of continuity of social organization

from pre-contact times were maintained in the Kiwulan community. This model predicts that the European influence had only a minor effect on local social structure. Individuals did not compete with each other for trading with the Europeans, perhaps because the benefit of competing did not match the costs of acquiring the scarce European trade goods. Some degree of social inequality had existed before the European contact but was limited and mainly associated with corporate groups, such as kinship or age-based. The Europeans did not increase social inequality so much as replace or add rare commodities into the pre-existing social structure. If this model is appropriate, then the degree of social inequality at Kiwulan did not change greatly before and after the European contact period. I predict the archaeological record will show no differentiation in the distribution of trade goods, consistent ceramic production, and the burial evidence should show that same social structure without signs of changes in social inequality in local societies before and after the European arrival.

I evaluate these two models by examining multiple lines of archaeological data at Kiwulan, including imported trade items, pottery production, and mortuary practices to measure social inequality. I find that that the long-distance trade network introduced by the Europeans resulted in the appearance of a network mode, indicating a shift in strategies for achieving power. In the next section I outline how I evaluate these models in this dissertation.

Dissertation Structure and Chapter Summaries

In the following chapters of this dissertation I evaluate these two models of social change in a pericolonial context by examining multiple lines of archaeological data at Kiwulan, including imported trade items, pottery production, and mortuary practices. Here I provide

an orientation and brief summary for each chapter in this dissertation. Each chapter contributes to the overall aim of examining whether there is an emergence or increased social differentiation relevant to inequality after European arrival at Kiwulan. Each of the three core papers of this dissertation presents a unique approach to exploring social inequality using distinctive quantitative methods for detecting changes, and engaging with a specific part of the archaeological record for Kiwulan. Here are brief summaries of the major goals of each paper:

1. A major contribution of the first paper (Chapter 2), is re-evaluating the chronology of Kiwulan to build three temporal phases relevant to foreign presence that are used throughout this dissertation. This is important for providing a robust foundation for the following two papers. The substantive topic of the first paper is analyzing the quantity and spatial distribution of trade ornaments commonly found in Yilan, including glass beads, carnelian beads, and metal artifacts. Ethnohistoric records show they were used as prestige goods in local culture and largely imported to Kiwulan because of frequent trade activities. The goal of this paper is to explore the spatial distribution of ornaments across the residential area of Kiwulan to identify clustered patterns that may indicate wealth accumulation. I use point pattern analysis with statistical testing to assess if the distribution of ornaments is random or patterned. This paper was peer-reviewed and published in *Archaeological Research in Asia* in December 2020 (Wang and Marwick, 2020a). An open access pre-print is online at https://osf.io/preprints/socarxiv/z9p5k/. The research compendium containing data and R code for reproducing the published results is at http://doi.org/10.17605/OSF.IO/R8YGA.

2. The second paper (Chapter 3) focuses on locally made pottery to measure ceramic standardization. I use outline analysis, one approach of geometric morphometrics to measure shape standardization of food vessels at Kiwulan. The goal is to examine whether ceramics present a more standard shape after the European presence is established. I take increased shape standardization as an indicator of the emergence of craft specialization, which in turn may reflect changes in social organization towards increased social inequality. Outline analysis provides a way to examine the overall shape of pottery to better capture the subtle differences between pottery groups from each temporal phase. The novel methodological contribution of this chapter is the use of a significance test for coefficients of variation of shape coefficients extracted by PCA. To my knowledge this has not been previously attempted in archaeology. This paper was peer-reviewed and published in the *Journal of Archaeological Science: Reports* in October 2020 (Wang and Marwick, 2020b). An open access pre-print is online at https://osf.io/preprints/socarxiv/q8hn9/. The research compendium containing data and R code for reproducing the published results is at https://doi.org/10.17605/OSF.IO/ABVGF.

3. The third paper (Chapter 4) focuses on burial data as a representation of social structure using network analysis approaches. The goal is to test our prediction of a shift in social structure after the European presence is established. The novel methodological contribution of this chapter is the use of exponential random graph models within a Bayesian framework to understand the anthropological factors that characterize the burial network before and after European arrival. This approach, which to my knowledge has not been previously reported in archaeology, enables an

analysis of the hidden structures of burial networks from pre- and post- European periods to compare their formation of relationships with associated underlying mechanisms that structure the material configurations. This paper was submitted for publication to the *Journal of Archaeological Science* in March 2021 and is under peer review at the time of writing (March 2021). An open access pre-print is online at https://osf.io/preprints/socarxiv/3vfea. The research compendium containing data and R code for reproducing the published results is at http://doi.org/10.17605/OSF.IO/XGA6N.

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Chapter 2

Ornaments as indicators of social changes resulting from indirect effects of colonialism in northeastern Taiwan

Note: This chapter was published in the *Archaeological Research in Asia* in December 2020 (Wang and Marwick, 2020a). An open access pre-print is online at https://osf.io/preprints/socarxiv/z9p5k/. The research compendium containing data and R code for reproducing the published results is at http://doi.org/10.17605/OSF.IO/R8YGA. Supplementary materials discussed in this chapter can be found in appendix A.

Abstract

Long-lasting indirect impacts on Indigenous peoples in the periphery of colonial control are poorly understood, especially in East Asia. Trade ornaments from Kiwulan (1350-1850 AD) in northeastern Taiwan show the indirect impacts of European colonial activities on local societies. The diversity of ornaments was greater during the period of European presence compared to previous periods, and their spatial distribution was more clustered. This hints at increasing social inequality resulting from colonial influence. Ornaments give insights into

the increasing social inequality stimulated by the European colonial presence, and show the agency of Indigenous people to incorporate ornaments into their social system.

Introduction

The direct impacts of European colonialism on Indigenous communities in East Asia were much less conspicuous than in island Southeast Asia and Oceania. Direct European colonial rule throughout East Asia was rare and limited, and the question of long-lasting indirect impacts on local Indigenous communities remains largely unanswered. Understanding the indirect effects of colonialism are important for detecting colonial impacts on Indigenous peoples in the periphery of colonial control (Acabado 2017; Trabert 2017). In many parts of the world, the introduction of foreign trade goods by colonial traders into local Indigenous societies caused substantial transformations of Indigenous economic, cultural, and socio-political systems (Dietler 2005; Dietler 1997; Junker 1993; Silliman 2005). Consumption patterns of foreign goods can give insights into negotiations between colonized and colonizer, and the resistance and accommodations of Indigenous people through their daily cultural practices (Dietler 2015; Given 2004; Mullins 2011; Scaramelli & Scaramelli 2005; Silliman 2001; Torrence & Clarke 2000; Voss 2005). Northeastern Taiwan is an ideal context to study peripheral colonial influence because although there was a prominent Spanish and Dutch colonial presence in parts of Taiwan, the northeastern region was isolated from intensive direct contact by the Xueshan Mountains.

This article describes personal ornaments excavated from the upper component of Kiwulan (1350 AD-1850 AD), the largest Iron Age settlement on the Yilan plain in northeastern Taiwan. Ornaments are found at many Iron Age sites in Yilan, but only Kiwulan shows clear

stratigraphic contexts from pre-European period to modern time. The first recorded European presence in Yilan was a Spanish revenge attack on Indigenous villages in 1632 (Borao 2001: 163). In 1647 the Dutch attacked villages and forced them to accept colonial rule and pay an annual tribute (Andrade 2007). According to Dutch census reports in 1650, Kiwulan was the largest Indigenous settlement in the plain, with a population of 840 adults (Nakamura 1938: 12). Following defeat of Dutch by the Chinese general Koxinga in 1661-1662, the Dutch abandoned northern Taiwan. Direct contact with Han Chinese is indicated by Qing dynasty census reports mentioning Yilan villages in 1821 (Yao 1996).

One of the most commonly traded types of object in this region were ornaments such as glass and stone beads (Chen 2007; Li & Chiu 2014; National Musuem of Taiwan History 2005). Personal adornments in the archaeological record are useful as signal of an individual's status (Joyce 2005; Scaramelli & Scaramelli 2005). The consumption of stone beads in Southeast Asia during Iron Age is often associated with increasing social stratification or socio-political complexity (Bellina 2014; Carter 2016; Francis 2002; Theunissen *et al.* 2000; Kenoyer 2000). In this paper, we explore archaeological ornaments from Kiwulan spanning the pre-European contact period, period after the Spanish and Dutch presence, and the following period after the Chinese presence. We address the question of whether indirect colonial influences on the Indigenous populations can be detected through the ornament assemblages.

Ornaments in complex exchange network during the late Iron Age and early historical period

The island of Taiwan lies at the junction of mainland China, Southeast Asia, and Northeast Asia in the Pacific Ocean. The prehistory of Taiwan island could be roughly divided into three major periods, Palaeolithic (c. 27,000 BP- 5000BP), Neolithic (c. 6500- 2000BP), and Iron age (c. 2000- 400BP) with slight regional differences in onset of each period and variations in style of artifacts and assemblages (Chen 2017; Liu 2011). It is generally accepted that Taiwan entered the historical period in the early 17th century due to the colonial activities of the Spanish and the Dutch who played an important role in keeping written records about Taiwan. The European colonial presence in Taiwan ended in 1662 when the Dutch were defeated by the kingdom of Tungning, founded by Koxinga from China. Later in 1683, Taiwan was incorporated into the Qing dynasty in China and a large wave of Han Chinese migrated to Taiwan during the late 18th century. Because of natural safe harbors, northeastern Taiwan was involved in a regional trade network through cross-culture interactions with Chinese merchants since the 14th century, and later the global trade network with the Europeans in the 17th century brought more trade goods circulated in Southeast Asia into Taiwan (Chen 2005; Liu & Wang 2017). Although located on the periphery of regional trade centers, Yilan was connected to trade networks via visits of other Indigenous groups, Chinese merchants, and Europeans, via sea.

The European presence in northern Taiwan started with the Spanish who founded Fort San Salvador at Heping Dao, Keelung in 1626, and Fort San Domingo in 1629 at Tamsui (Figure 2.1). They sent missionaries to local Indigenous settlements in this region (Blussé & Everts

2000: 343) and kept records about their observations of Indigenous communities. A Dominican priest in 1632 reported that the Taparri, an Indigenous tribe from northern Taiwan, exchanged carnelian beads with other Indigenous groups. This form of exchange was widespread and even the Spanish soldiers used carnelian beads as bargaining chips for gambling (Li & Wu 2006: 132–49). The use of beads as prestige goods is further indicated by their role in bride price payments, and compensation to resolve disputes (Li & Wu 2006: 132–49). Other records mention that the women shamans in the tribe would use carnelian beads as magical items in ritual healing practices (Borao 2009: 122–51). Records of an Indigenous funeral describe the use of carnelian beads in ritual contexts, with more carnelian beads, pottery, and cloth placed into the graves of more influential people to indicate their family's higher status (Li & Wu 2006: 153). While a full critical analysis of these historical accounts remains to be produced, we take them to minimally indicate that carnelian beads were already treated as prestige goods in Yilan before the arrival of Europeans. In 1642, the Dutch Vereenigde Oostindische Compagnie (VOC) defeated the Spanish and took over their forts in northern Taiwan. They introduced a feudal system in an attempt to control the Indigenous communities by asking Indigenous leaders to attend an annual ceremony for demonstrating their loyalty and paying tribute (Andrade 2007, ch. 9; Kang 2016, ch. 4). The Dutch provided beads and other goods based on negotiations with Indigenous communities to secure alliances in the annual ceremony or during their travels (Kang 2016, ch. 6). We might predict that the activities of the Dutch feudal system to build and maintain alliances resulted in an increase in the amount and diversity of ornaments in northeastern Indigenous communities during this period.

Chinese historical records from 1829, 1837, and 1852 during the Qing dynasty (1616-1911) contain some notes on the purposes of ornaments from Yilan (Chen 1963: 228, 308; Ke 1993: 11, 126; Yao 1996: 77). According to those records, Indigenous people in Yilan wore ornaments in ceremonial contexts to display their wealth and status. Among those ornaments, fish-shaped necklaces made of metal threads had high value due to their delicacy and the exotic materials invested in production. These were usually possessed by wealthy people. Other people wore carnelian beads or glass beads on their head or neck to participate in ceremonies. In 1895, at the beginning of Japanese colonization, an academic field survey for plains Indigenous groups reported that fish-shaped metal necklaces were not used in Yilan at that time, but elderly people still used beads (Ino 1996: 227–32). Although these historical records are fragmentary and may contain some biases (Galloway 2006) that have not yet been studied in detail, we find consistency among multiple sources in their descriptions of how ornaments represent high status or specialized social roles in Indigenous communities in Yilan. Compared to the European period, there are fewer documentary mentions of beads in the Chinese period and the descriptions are limited to clothing, but these generally confirm the role of beads as status markers.

Ornaments found in northeastern Taiwan in the early historical period, including glass beads, stone beads, and metal ornaments, are considered to have been imported from other regions. This is because of a lack of archaeological evidence of beadmaking waste, metalworking, or accessible local raw materials. The chemical composition of glass beads from this region shows a high content of lead and, together with the winding/folding technique, these details suggest a Chinese beadmaking tradition (Cheng 2008; Gan *et al.* 2006; Wang 2018). Although there is a wide variety of metal ornaments such as bells,

bracelets, rings, and pendants, the common components of metal ornaments are brass and copper, with a small number made from lead and tin that indicates multiple origins that include Southeast Asia (Chen 2011). There is no direct evidence showing European delivery of beads, however, a large amount of the glass beads containing gold foil (hereafter, gold-foil beads) at Kiwulan might have been introduced by the Spanish through economic activities because similar beads were found at Luzon, northern Philippines, as part of the trading route of the Spanish between 16-19th century (Wang & Liu 2007). Both archaeological evidence and historical records indicate northeastern Taiwan was involved in regional networks with East Asia in the late Iron age. These included Chinese merchants trading metal items, clothes, and beads with local Indigenous people in Taiwan in exchange for local resources. The foreign-made large dark brown glazed stoneware jars frequently found in European shipwrecks were also commonly found from many sites in Taiwan, suggesting direct or indirect interactions. Despite the Chinese origin of some ornaments at Kiwulan, there is compelling evidence that a large amount of ornaments found at 17th century sites resulted from European colonial and economic activities in the region.

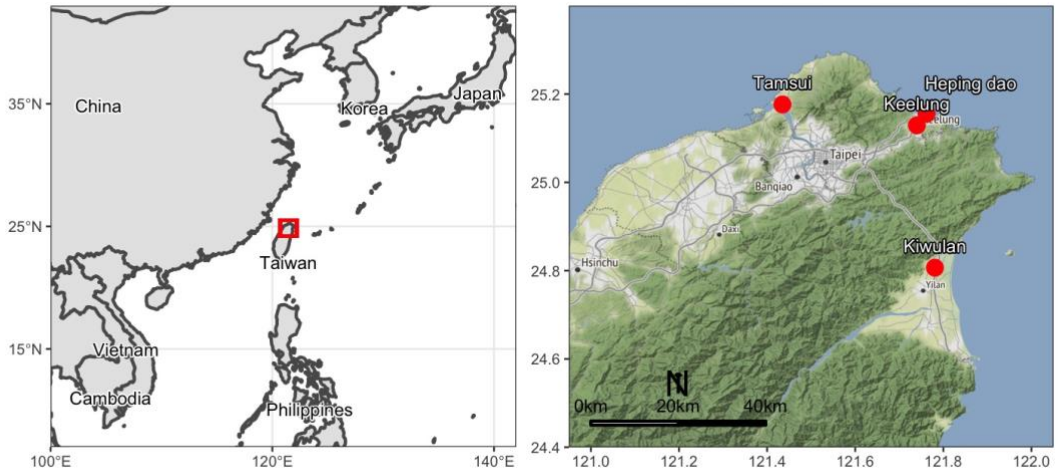


Figure 2.1: Map showing the location of Kiwulan, and other places in northern Taiwan named in the text. Map data from naturalearthdata.com

Excavations at Kiwulan in northeastern Taiwan

Archaeological ornaments from Kiwulan (Figure 2.1) come from a rescue archaeology project that was conducted between 2001-2004 in advance of a water diversion project and road bridge construction. The excavations used 2 mm and 1.5 mm mesh screens and covered eight open area sections in total of 262 squares (4 m by 4 m) reaching 3,814 m^2 (Chen 2007). The nearly 2 m thick archaeological deposits reveal a large amount of artifacts, burials, middens, post-holes, wooden pillars, and stone structures, all of which indicates it was a long-term settlement. Artifact locations were recorded to the 2 x 2 m sub-square they were recovered in; they lack individual point provenance. Based on the continuity of deposition and the frequency of artifacts, the center of the site is the open area consisting of the A and D sections, which is also the study area where our samples come from (Figure 2.2). In the AD area, post-holes were found aligned in a north-south direction in intervals

with construction marks, which have been interpreted as the remains of stilt house structures. At the north margin of the dwelling place were burials that are mostly oriented in an east-west direction.

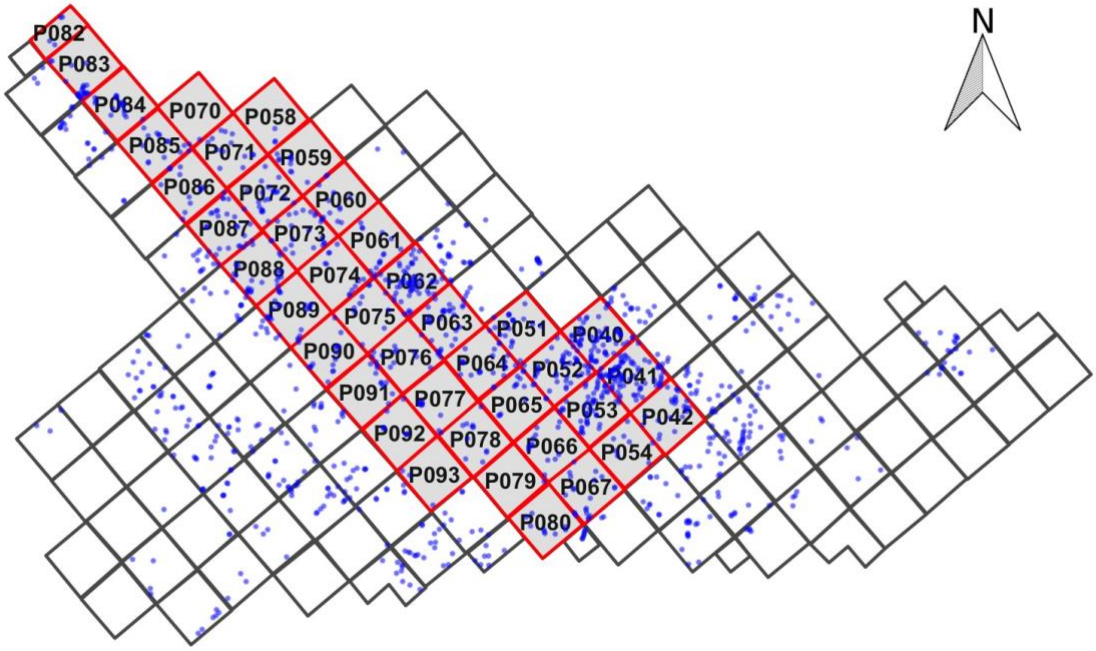


Figure 2.2: Map showing the largest section of excavation areas at Kiwulan, and the distribution of forty squares sampled in this paper presented in red with square ID numbers. Small dots represent the locations of post-holes. Each square is 4 x 4 m

Chronology

Studying change over time at a site like Kiwulan has some distinct challenges. First, the archaeological deposits are relatively thin. This makes it difficult for excavators to clearly identify distinct chronological phase boundaries. In thin deposits, site formation processes can quickly blur the boundaries or completely mix deposits from different time periods. Second, the time periods we aim to compare are relatively short, just a few human generations. This limits the usefulness of common chronometric methods such as radiocarbon dating, where the age errors are relatively large compared to the periods we are studying. Most of the previously obtained radiocarbon ages from Kiwulan do not span the time period we are investigating here (Figure 2.3 and Table 2.1). Third, pericolonial contexts such as Kiwulan can involve non-Western notions and experiences of time. For example, a Western concept of time seeks clear temporal divides, and may create material signature of this, but Indigenous experiences of time may prioritize continuity and continuums of gradual change, and their material culture traces may reflect that intentional experience of time (Trabert 2018; Scheiber & Finley 2012). Despite the relatively short period of the European colonization in Taiwan (38-years-long Dutch occupation and 16-years-long Spanish occupation), the indirect impacts of the Europeans through trade networks could go beyond these temporal boundaries and last longer. This is because the use of foreign goods in many Indigenous societies often goes through processes of negotiations, resistance, and transformation. A static time frame may not capture the processes well (Scheiber & Finley 2012). Fourth, the circulation of foreign goods that we use as chronological indicators might start earlier than the historically documented European presence in Taiwan. Similarly, the use of the foreign goods in Indigenous societies could continue after the end of the European

colonization (Mitchell & Scheiber 2010). This limits the usefulness of specific artifact types as chronological markers, and implies they have an error range similar to radiocarbon ages. Unfortunately, we do not have a way to accurately estimate these errors at Kiwulan. Ideally, we would divide the deposits at Kiwulan into many time slices to investigate the possibility of a gradual versus sudden change, and assess errors in the accuracy of artefacts as temporal markers. However, this would result in many analytical units with no finds, so we have grouped excavation units together to create minimum sample sizes suitable for addressing our research questions. The details about the distribution of the temporal indicators, accompanied with stratigraphy data, radiocarbon dates, and archaeological contexts for each sampled excavation unit are provided in Supplementary Online Materials.

A first step to outlining chronology of Kiwulan is indicated by the stratigraphy. There is an upper component (1350-1850 AD, 600-100 BP) and a lower component (650-1150 AD, 1200-800 BP) based on 32 radiocarbon ages, previously published by Chen (2007), and shown here in Figure 2.3 and Table 2.1. There is a sterile deposit between these two components spanning c. 150 years that may be related to dry weather, according to pollen analysis, leading to site abandonment (Chen 2007; Lin 2015). These component divisions present the differences in color and texture of the deposit, and the content of artifacts such as pottery types. Whether these two components suggest a countinuity of culture from the same people is still under debate (Chiu 2004; Chen 2007). We focus on the upper component because this component spans the periods when local residents interacted with the Europeans and the Chinese. In our study area, all excavation squares demonstrate signs of continuous human occupation throughout the upper component. Previous work divided the upper component into six analytical units, spanning from the 14th century to the 19th

century, according to the types of chronologically diagnostic ceramics, excavation depth, consistency of contexts, and radiocarbon dates (Hsieh 2009; Wang 2011). To achieve sample sizes suitable for exploring changes in ornament assemblages over time associated with foreign impacts, we assigned the original excavation levels into three phases: before the European contact, after the European presence, and the presence of large Chinese immigrants.

Chronological markers in the artefact assemblages

We made refinements of the original chronology to assign contexts into the pre-European, European, and the Chinese periods with six steps of assigning and evaluations using copies of original excavation records and fieldwork notes. First, for each unit, we determined the artificial layer (mostly 10 cm) with indirect colonial impacts in terms of the higher frequency of time indicators representing the European and the Chinese period. Second, we identified the archaeological context (normally 2-3 layers) where the layer belongs to based on the description of soil color, soil texture, and density of potsherds and charcoal. We assumed that a larger population would be reflected by denser distributions of potsherds and charcoal. Third, we checked if there are radiocarbon ages associated with the context as a cross-validation. Since some radiocarbon ages represent long time ranges, we did not consider the ages could determine a phase by themselves, but only as a cross-validation. Fourth, we explored any post-depositional issues that might affect the deposition of time indicators to ensure an appropriate assignment based on the fieldwork notes and excavation report. Fifth, we cross evaluated all adjacent squares to confirm a consistent and continuous context between them. Sixth, we compared our chronology with six analytic units classified by previous studies to make a final decision (Hsieh 2009; Wang 2011). More detailed data

information is provided in Supplementary Online Materials. After assigning the contexts into three analytical units, pre-European contact, the European presence, and the Chinese presence, we assigned ornaments to one of these units according to their find context. We did not use the ornaments themselves as temporal markers because many of the ornaments have been found throughout long time periods in Taiwan. Through those assigning steps with these validation rules, we believe our chronology is reasonable and suitable for discussing the indirect colonial impacts led by trade networks.

Archaeological indicators of indirect impacts of the Europeans at Kiwulan are the higher frequency of light grey glazed jars, known as "An-ping" jars in China and Taiwan, and large dark brown glazed stoneware jars that were introduced to Taiwan during the early 17th century. Large dark brown glazed stoneware jars may have been made in Southeast Asia, but are frequently found in European shipwrecks from this period as vessels for transporting water, wine or other liquids on long voyages. The earliest evidence of light gray glazed jars in this region has been found among the cargo of the Spanish shipwreck *San Diego*, which sunk in 1600 AD (Dizon 2016; Hsieh 1995). Southeast China is assumed to be the origin of the light gray glazed jars, however these are commonly found at sites in Taiwan that were associated with European activities, such as the Zeelandia fort site in Tainan (Wang & Liu 2007). The jar shapes found at Kiwulan are typical of those found elsewhere in VOC sites occupied during the 17th century (Berrocal *et al.* 2018: 917; Cort 2017: 282; Grave & McNiven 2013; Ketel 2011; Klose & Schrire 2018: 131). We cannot be sure of the exact process that brought them to Kiwulan: they might have been directly imported by Europeans, by Chinese merchants, or by Indigenous groups via regional networks in north

Taiwan. In any case, the high volume of ceramics transported by Europeans, and their high mobility in the shipping trade played an important role in introducing foreign jars to Taiwan.

Those jars were widely distributed across the site and can serve as indicators, together with the radiocarbon dates, to identify the excavation units associated with the pre-European period and the start of European influence at Kiwulan. In addition to stoneware jars as indicators of European presence, around 300 pieces of locally made clay pipes and a few imported pipes were found at Kiwulan. Smoking is likely to have been introduced by Europeans. This custom was widely adopted in many European countries in the 16th century and spread to other regions through interactions (Uçar 2019). We found that the presence of pipe bowls in the archaeological record here is consistent with distributions of glazed jar fragments, which are far more numerous and widespread across the site (n = 1685). It should be noted that these temporal indicators might have been introduced before direct European contact by Chinese traders, and this could result in some uncertainty in identifying the start of European phase. However, the archaeological evidence shows that the layers with abundant trade ceramics match the 17th century according to the excavation report and previous studies (Hsieh 2009; Wang 2011). Thus, we focus on identifying the contexts with high frequencies of those ceramics as indicators the early 17th century.

The archaeological signature of the Chinese period at Kiwulan is the large amount and diversity of Chinese porcelains in many styles and forms such as bowls, plates, and cups. Other indicators include opium pipe-bowls and distinctive architectural bricks and tiles used by Chinese (Hsieh 2009). Chinese migrations to Yilan were also recorded in official Chinese records written in the early 19th century recording the first immigrants in 1768 (Chen 1963; Ke 1993).

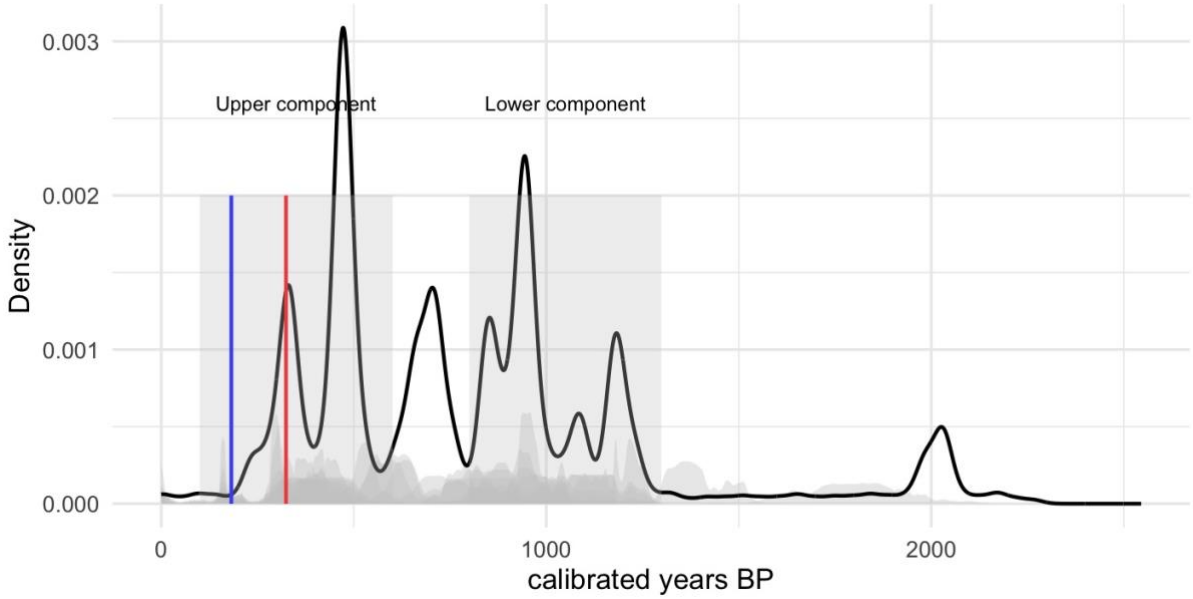


Figure 2.3: Summed probability distributions for dates from Kiwulan. The dark line represents the summed probabilities of all radiocarbon ages, and the grey lines in the background are the probabilities of individual ages. Grey rectangles indicate the approximate chronology of the major archaeological components of the deposit. For the upper component, the red line indicates the start of European presence, while the blue line is the Chinese presence. Ages calibrated with the Bchron package (Parnell et al. 2008)

Lab code	Pit-Layer	Depth (cm)	Uncalibrated Age BP	Calibrated Age BP (95% credible interval)	Context
NTU-3803	P052-L7	0 to -10	<200		artefact-bearing deposit
NTU-3925	P051-L17	-36 to -56	<200		sterile deposit

NTU-3943	P051-L19	-70 to -90	<200		sterile deposit
NTU-4283	P063-L12	-30 to -70	<200		midden H044
NTU-4293	P089-L11	-50 to -70	<200		artefact-bearing deposit
NTU-4305	P089-L7	-20 to -30	<200		artefact-bearing deposit
NTU-4322	P051-L11	0 to -40	<200		midden H026
NTU-4323	P070-L3	20 to -57	<200		burial M095
NTU-3993	P041-L7	-25 to -45	250±40	4-433	artefact-bearing deposit
NTU-4419	P162-L3	-10 to -110	280±70	10-486	midden H172
NTU-4311	P052-L16	-110 to -130	310±100	17-514	artefact-bearing deposit
NTU-4320	P168-L1	6 to -51	340±100	30-529	midden H193
NTU-4016	P028-L9	-44 to -80	270±40	151-455	burial M020
NTU-4310	P018-L2	-28 to -70	360±100	83-546	burial M039
NTU-3791	P049-L11	-20 to -30	340±30	315-484	artefact-bearing deposit
NTU-4292	P052-L6	4 to -56	510±75	345-648	burial M009
NTU-4304	P066-L11	-40 to -60	600±75	516-676	artefact-bearing deposit
NTU-4423	P144-L5	-10 to -30	610±90	499-713	artefact-bearing deposit
NTU-4315	P248-L5	-100 to -120	800±120	564-949	artefact-bearing deposit
NTU-3926	P041-L9	-70 to -90	900±50	713-918	sterile deposit
NTU-4421	P162-L11	-160 to -180	920±70	705-953	artefact-bearing deposit
NTU-4319	P154-L3	10 to -10	920±105	683-1051	artefact-bearing deposit
NTU-4430	P238-L10	-130 to -150	1020±60	795-1061	sterile deposit
NTU-3788	P028-L15	-130 to -150	1050±40	863-1051	artefact-bearing deposit
NTU-4422	P237-L4	-70 to -90	1030±80	772-1157	artefact-bearing deposit
NTU-4428	P154-L13	-170 to -180	1080±90	800-1221	artefact-bearing deposit
NTU-4427	P246-L8	-160 to -180	1170±70	956-1254	artefact-bearing deposit
NTU-4316	P019-L5	-100 to -120	1190±70	969-1266	burial M066
NTU-3792	P041-L13	-150 to -170	1240±30	1077-1264	artefact-bearing deposit

NTU-4434	P144-L11	-130 to -150	1480±70	1292-1524	artefact-bearing deposit
NTU-4321	P154-L14	-180 to -190	1870±110	1560-2082	artefact-bearing deposit

Table 2.1: Radiocarbon ages from charcoal samples excavated from Kiwulan (Chen 2007), calibrated using IntCal13 Atmospheric curve. All depth is recorded in centimeters above mean sea level. The codes in the context column refer to the excavator's feature labels, cf. Chen 2007

The personal ornaments

Ornaments (Figure 2.4) were found in a variety of archaeological contexts including post-holes area, burials, and middens. For the ornament categories, we follow the well-established topology based on raw materials and shapes for the region of northeastern Taiwan (Chen 2007; National Musuem of Taiwan History 2005). This study focuses on 406 ornaments from 40 sampling squares located at the main habitation areas of Kiwulan, indicated by aligned post-holes with *in-situ* posts (Figure 2.2). Occupation floors were not identified during excavation. We choose these units because they were stratigraphically intact and undisturbed by modern construction activity, compared to excavation squares on the periphery of the site. There are 35 burials in the sampling area, one third of the total number of burials at Kiwulan. Intact ornaments are commonly found in burials used as personal adornment, indicating the property of ornaments as prestige goods. The majority burials from the sampling area date to the European period (n = 21), limiting the usefulness of comparisons between the periods. In general, there are some differences between the number of gold-foil beads, carnelian beads, and glass beads across burials. For example,

over a thousand beads are found in a few burials, but none is found in some burials. This is also because of the presence of bead strands or patterned bands of beads, which sometimes contain thousands of beads in an individual burial (Chen 2007). The uneven distribution of beads likely indicates some social differentiation. However, the complexity of the taphonomy and chronology of the burial features at Kiwulan mean that a full discussion of these is beyond the scope of this paper.

We focus on ornaments from the habitation contexts (Figure 2.5, Table 2.2) because these give us the greatest spatial and temporal representation across the three time periods, and so are most informative of social inequality as indicated by uneven distributions of ornaments. A possible limitation to our chronological resolution is that ornaments could be heirlooms inherited over multiple generations and well-preserved for a long time. This is difficult to rule out completely, but we consider that because there is no continuous increase in ornament frequency over time, we conclude that accumulation and discard of ornaments is not constant, but was affected by contemporary conditions. Thus, we assume that changes in the abundance of ornaments reflect changes to otherwise relatively continuous discard behaviors rather than accumulations due to collecting of heirlooms.

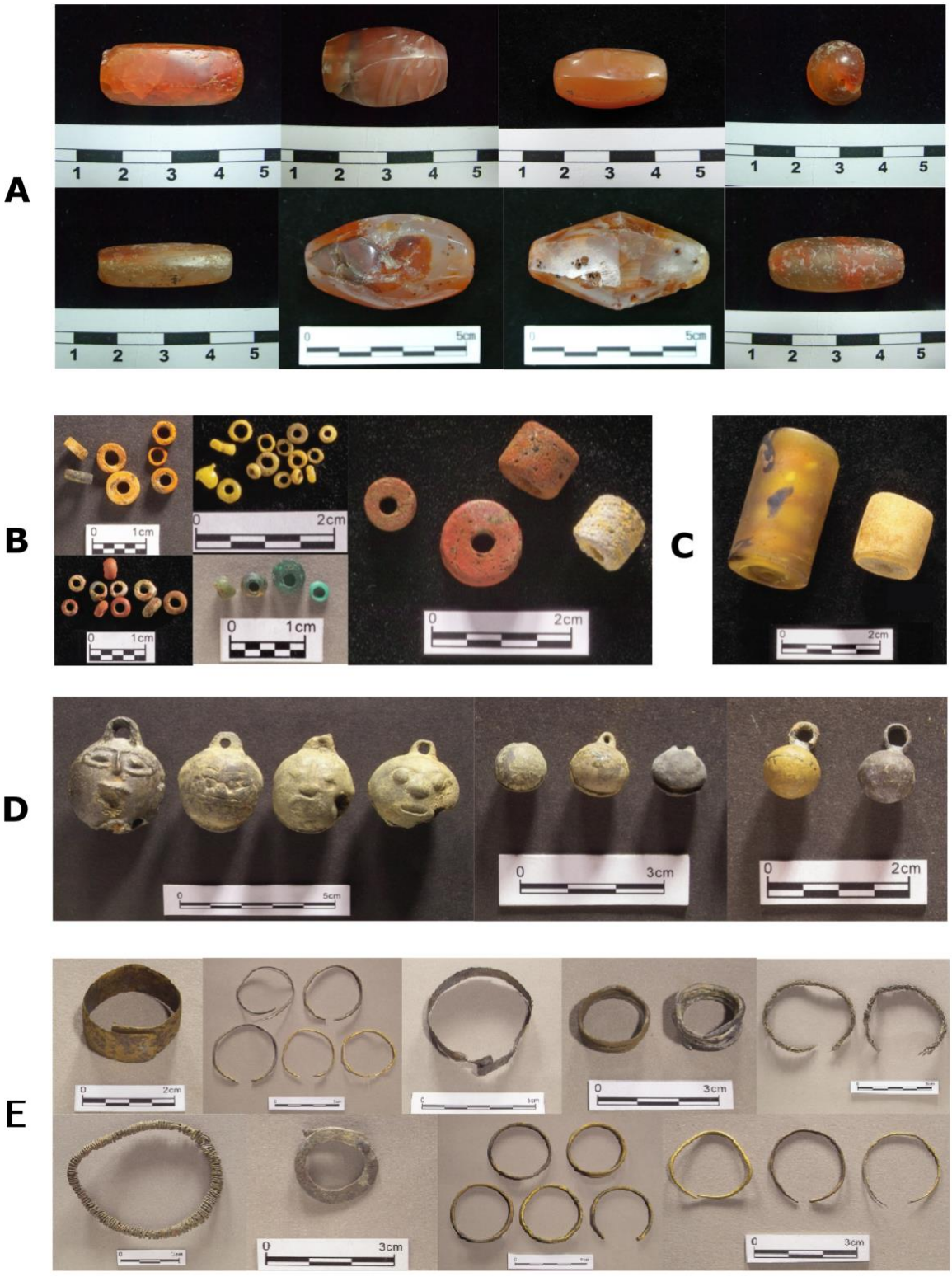

A
B
C
D
E

Figure 2.4: Subtypes of ornament in each major class. A: carnelian beads, B: glass beads, C: gold-foil beads, D: bells, E: metal rings. Photographs are presented in the same order as those subtypes in the table but from left to right instead. The photographs of B, C, D, E classes are from the original excavation report (Chen 2007)

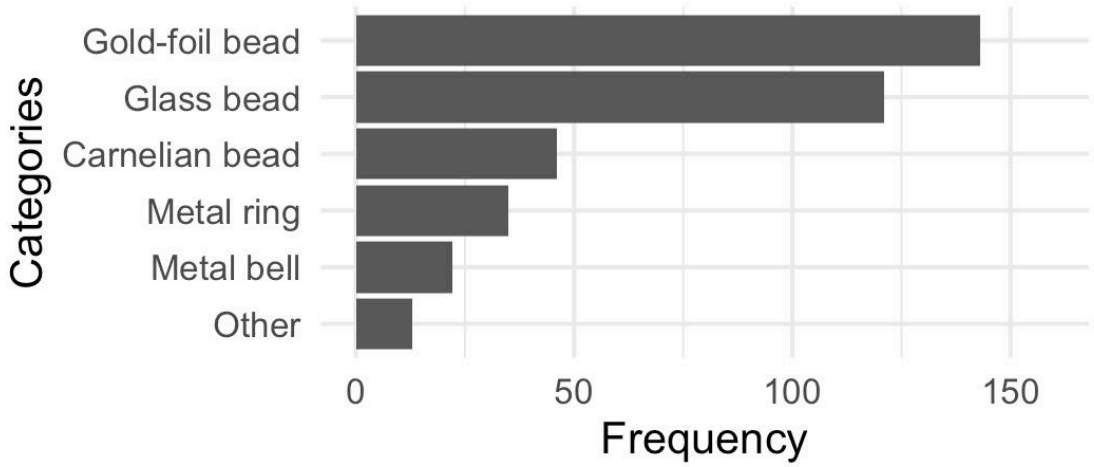


Figure 2.5: Frequency of the major class of ornaments at Kiwulan. Frequency represents artifact counts totalizaing three periods

Categories	Type	Before European Contact	European Presence	Chinese Presence
Carnelian bead	hexagonal	6	17	5
Carnelian bead	waxy oval	0	4	0
Carnelian bead	small oval	3	3	0
Carnelian bead	globular	0	1	0
Carnelian bead	pentagonal	0	1	0
Carnelian bead	big oval	0	0	1

Carnelian bead	long bicone	0	0	1
Carnelian bead	octagonal	0	0	1
Glass bead	small (0.5-1 cm)	60	37	1
Glass bead	medium (1-2 cm)	8	15	0
Gold-foil bead	NA	48	93	2
Metal bell	large	3	8	3
Metal bell	plain small	0	4	1
Metal bell	thin small	0	1	1
Metal ring	wide small	1	9	1
Metal ring	thin large	4	5	2
Metal ring	wide large	0	5	0
Metal ring	overlapped	0	2	0
Metal ring	braid	0	1	0
Metal ring	entwined	1	1	0
Metal ring	flat	0	1	0
Metal ring	large thick string	0	1	0
Metal ring	small thin string	0	1	0

Table 2.2: Frequencies of ornaments by subtype at Kiwulan. Frequency represents artifact counts

Reproducibility and open source materials

To enable re-use of materials and improve reproducibility and transparency (Marwick 2017), the entire R code (R Core Team 2019) used for all the analysis and visualizations contained in this paper is included in the Supplementary Online Materials at

http://doi.org/10.17605/OSF.IO/R8YGA. Also in this version-controlled compendium (Marwick *et al.* 2018) are the raw data for all the visualizations and tests reported here. All of the figures, tables, and statistical test results presented here can be independently reproduced with the code and data in this repository. The code is released under the MIT license, the data as CC-0, and figures as CC-BY, to enable maximum re-use.

Results

Changes in the frequencies of ornament types over time

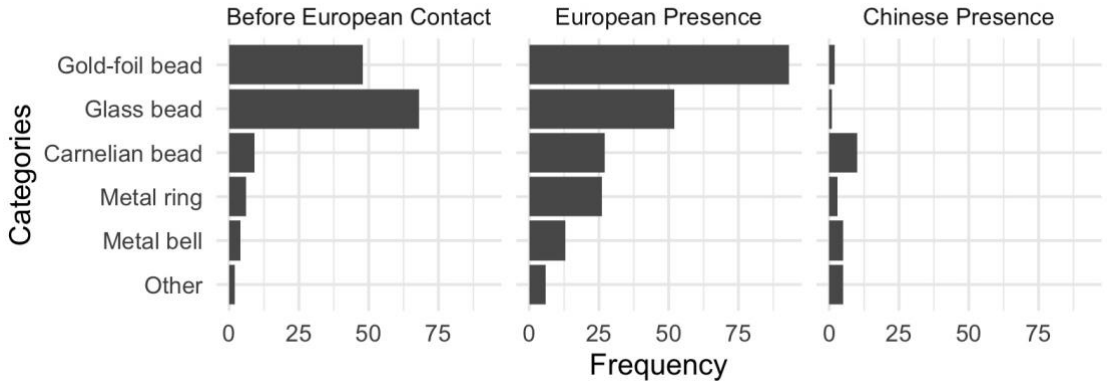


Figure 2.6: Frequency of the major ornament types across different time periods.

Figure 2.6 shows the comparison of frequencies of the major classes of ornaments for different time periods at Kiwulan. The difference in frequencies between the three time periods reflect significant differences in the use of ornaments (chi-square = 71.82, df = 8, p-value = 2.14×10^{-12}). Most ornament types were present before European contact. Ornament frequencies reached a peak during the European period and then dropped during the Chinese period, especially gold-foil beads. This trend can be also seen on other

ornaments including carnelian beads, metal rings, and bells. However, glass beads show a different pattern that indicates a higher frequency in the pre-European contact, and then a decrease in the European period and a further decrease in the Chinese period. To model the number of ornaments as a function of the mass of ceramics in each period, we used a Poisson GLM with a log link function. The model reveals that ceramic abundance strongly predicts the number of ornaments ($\beta = 1.94 \times 10^{-5}$, $p = 4.225 \times 10^{-29}$). If ceramic abundance is a suitable proxy for population at Kiwulan due to its basic role as cooking vessels, then ornament quantities per period may be influenced by the number of people living at the site.

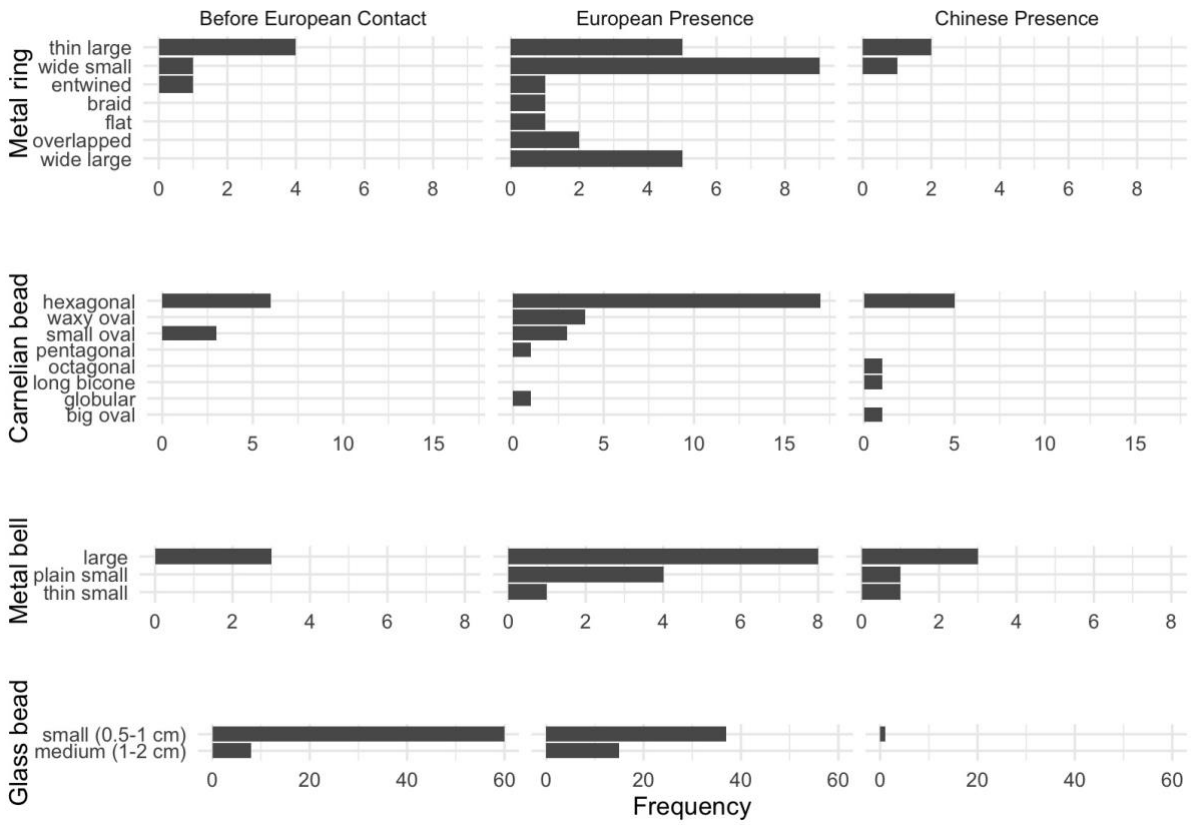


Figure 2.7: Frequency of ornament subtypes showing the changes in frequency across time periods for metal rings, carnelian beads, bells, and glass beads.

Figure 2.7 shows the distribution of frequencies for subtypes in each major class. Spearman's correlation test shows that there is no significant relationship between diversity of subtypes and sample size (S = 1660.07, rho = 0.59, $p = 7.3 \times 10^{-4}$). This indicates that the increases in diversity can be explained by the effects of culture interaction instead of the effects of sample size. Carnelian beads and metal rings have greater quantity and variety of shapes compared to copper bells and glass beads during the European period. The greater varieties for carnelian beads and metal rings might indicate multiple origins due to participation in large scale trade networks stimulated by the European presence. In contrast,

copper bells have less variety, typically >2 cm long with a wide variety of human faces as a motif. Although glass beads have less variety in size, presenting as small (0.5-1 cm) or medium (1-2 cm), they have a wide variety of colors or patterns mostly made by a winding technique and with high lead content indicating possibly from China (Cheng 2008).

Although we are not certain of the specific origin of the kinds of beads found at Kiwulan, the glass beads and metal ornaments have similar production techniques and composition to those found in China, while gold-foil beads may relate to the economic activities of the Spanish in the South China Sea region (Chen 2011; Wang 2018). There seem to be no obvious changes in the sources of glass beads or metal ornaments at different phases in the upper component of Kiwulan (1350-1850 AD). However, the glass beads from the lower component (650-1150 AD) demonstrate the composition of m-Na-Al glass and soda plant ash glass that are subtypes of the Indo-Pacific beads, frequently seen in Southeast Asia (Carter 2016; Francis 2002; Wang & Jackson 2014). A transition in the origin of glass beads from mainly Southeast Asia to multiple regions including China might indicate different trading networks. A regional network in the South China Sea in the earlier period and later involved in a larger scale trading network stimulated by the Europeans and the Chinese (Hung & Chao 2016; Wang & Liu 2007).

Changes in patterns of the spatial distribution of ornament types

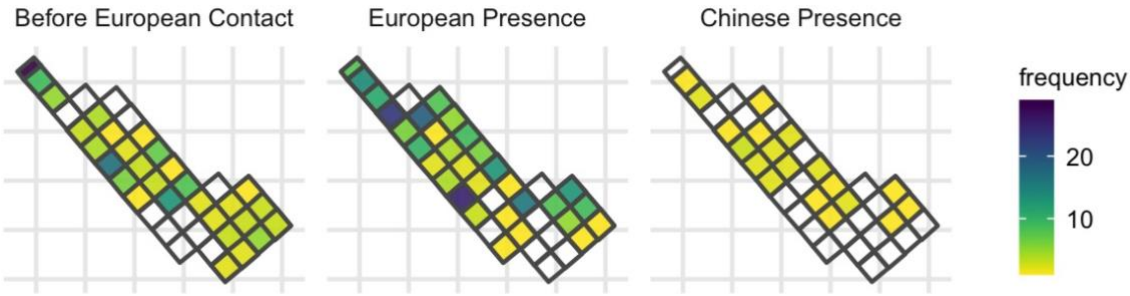


Figure 2.8: Spatial densities of all class of ornament by time periods.

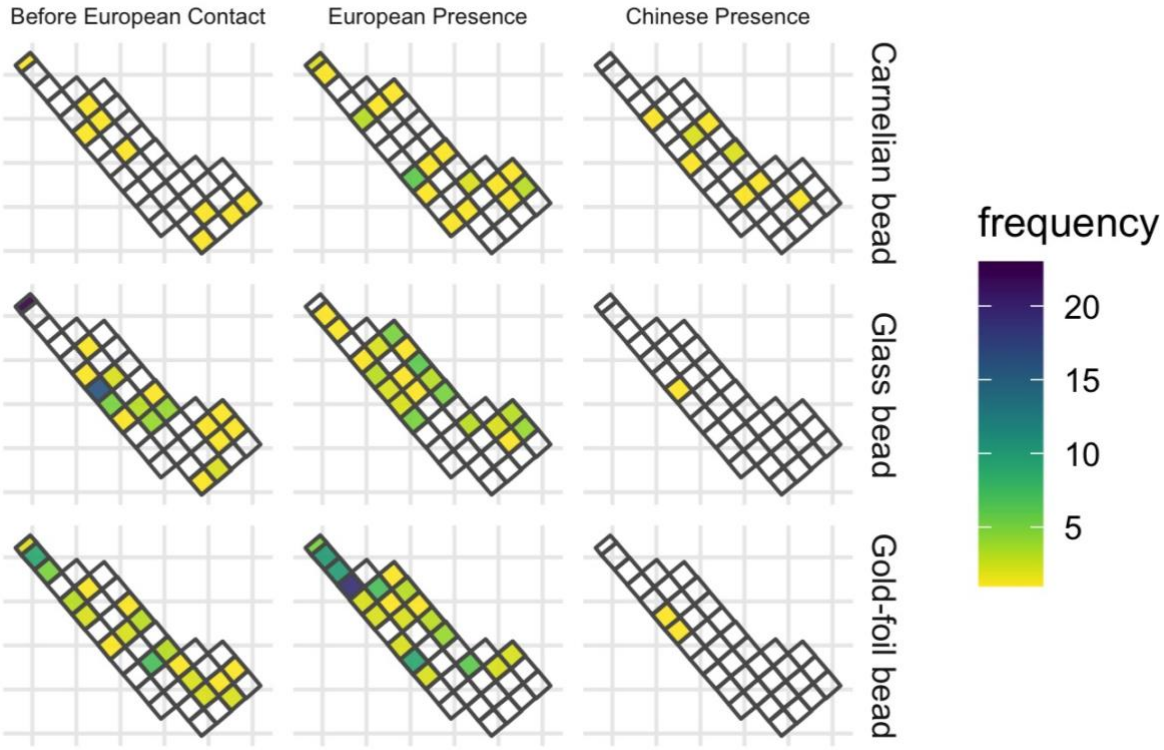


Figure 2.9: Spatial densities for ornament class by time periods, only those types with more than 5 pieces are shown here.

Figure 2.8 presents the spatial distribution of all ornaments from the research area for each time period. For deposits predating the European arrival, a greater amount of ornaments were found at the northern and middle parts of the research area. In European period deposits, ornaments were more widespread, with some clusters on the northern part. In units dating to the Chinese period the distribution is more even without clear clusters. Figure 2.9 presents the distribution for the major ornament classes individually, some clusters across the area can be observed during the European period, such as gold-foil beads and carnelian beads. However, there seems to be no consistent pattern across those different ornaments. Each class shows its own pattern where the squares with higher numbers of ornaments distributed separately and independently. For example, a cluster of gold-foil beads was found at the northern part, while a cluster of carnelian beads was found in the middle part. In contrast, there are multiple clusters of metal rings that are distributed separately across the research area. Copper bells were usually found individually and appear randomly distributed across the area. In the Chinese period, both the amount and density of different classes of ornaments decreased.

Point pattern analysis of ornament distribution

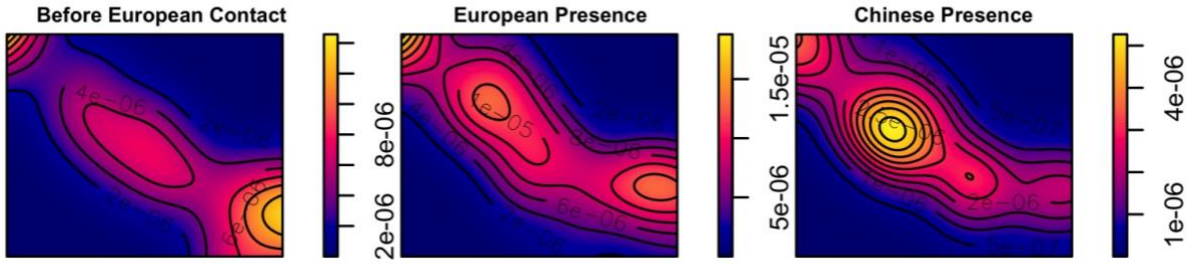
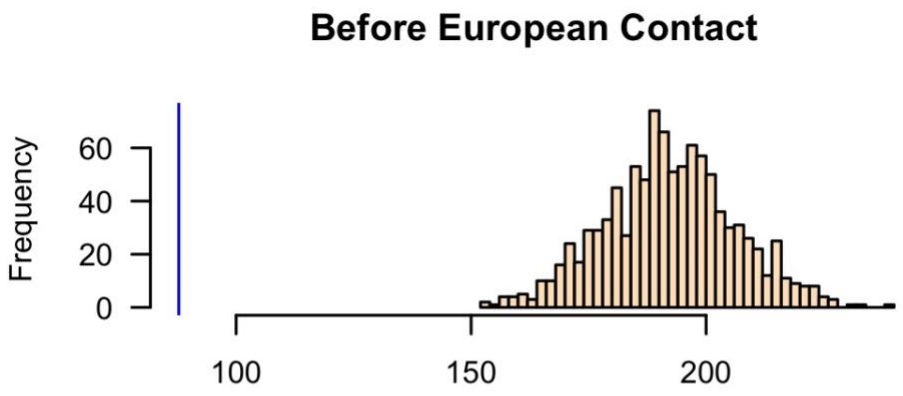


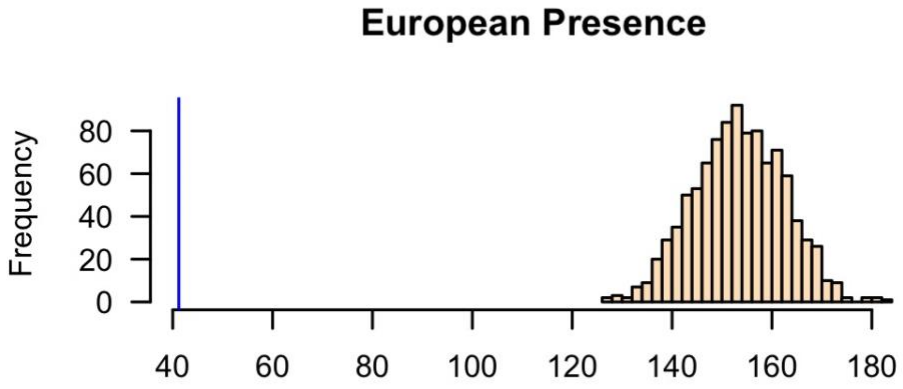
Figure 2.10: Kernel density map for ornaments by periods, using a bandwidth based on Silverman (1986)'s rule of thumb

The distribution and density of prestige goods across the residential area can provide information on social structure based on the assumption that distribution patterns observed from spatial data can reveal cultural processes (Kintigh & Ammerman 1982). The differential accumulation of artifacts, especially high value goods, in many archaeological contexts can reflect social differentiation or hierarchy in a society (Halstead 1993; Orser 1988; Pearson 1993; Trubitt 2003; Wason 2004). We used point pattern analysis to assess whether the distribution of artifacts represents hotspots produced by non-random processes (Bevan & Lake 2016; Ducke 2015), such as concentrations of ornaments in specific households that might result from social inequality stimulated by a colonial presence. To prepare the ornament location data for point pattern analysis, we assigned each ornament to a random coordinate pair in the square it was recovered from because artifacts from Kiwulan lack exact piece-provenance data. The next step was to divide the ornaments into three time periods. Finally we computed the density maps for each time period for comparison. Density values of artifacts per square meter were calculated for each cell. Here we use kernel density

estimation (KDE) for visualization and identification of spatial clusters (Baxter *et al.* 1997), in this case the core areas of ornaments and surrounding neighborhoods. KDE is a method of spatial analysis that computes the probability of the density of ornaments across space by creating a continuous, smooth density surface across space (Bonnier *et al.* 2019; Cortegoso *et al.* 2016).

Figure 2.10 shows that there is one major core area during the pre-European period, multiple core areas during the European period, and a single core during the Chinese period. There are three consistent sub-regions with a core area that shifts over time. The distribution might indicate an increase and decrease in the number of social groups who possessed ornaments. The multiple groups during the European period might reflect unequal consumption of ornaments across the site, relative to other periods, or random patterns resulting from a bigger sample size. In addition, the generation of core areas might be biased due to small sample sizes, for example, a few ornaments found at one single square during the Chinese period could create an obvious hotspot. Whether the observed clustering is random or non-random is crucial for making reliable interpretations of intentional human activities at Kiwulan.


Before European Contact
Frequency
0
20
40
60
100
150
200


European Presence
Frequency
0
20
40
60
80
40
60
80
100
120
140
160
180

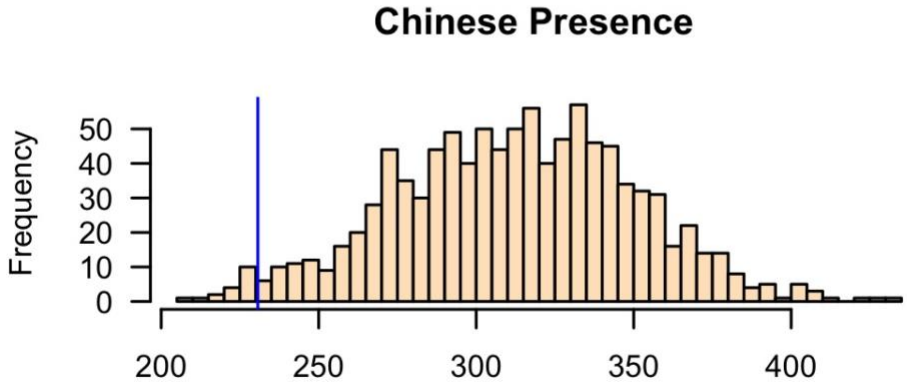

Chinese Presence
Frequency
0
10
20
30
40
50
200
250
300
350
400

Figure 2.11: Histograms of simulated ANN values from 1000 simulations for three time periods. X-axis values represent ANN expected values under a completely random process resulting from a simulated pattern. Each sample distribution presents the null hypothesis with the blue line indicating the observed ANN value

To test for randomness in spatial locations, we used a Monte Carlo method to simulate average nearest-neighbour distances (ANN). Figure 2.11 shows the observed ANN distances with the distributions of the ANN distances calculated on 1000 simulations of random ornament locations. The results show that 100% of the simulated values are much greater than our observed ANN value during the European period, which means the ornaments have non-randomly clustered distributions. A similar, but less extreme, result is also observed during the pre-European period. The observed distribution of ornaments is more similar to the random distributions during the Chinese period, with about one third of the simulated values are greater than our observed ANN value. The Chinese period has fewer artifacts in any category, likely reflecting a smaller population at Kiwulan at this time, making spatial patterns and hotspots difficult to discern with confidence. Our Monte Carlo testing reveals that clustering of ornaments during the European period is highly non-random, potentially indicating different degrees of access to foreign ornaments or a concentration of power to control the distribution of ornaments at Kiwulan during this period.

Discussion

An indirect colonial influence may be indicated at Kiwulan by the greater diversity of ornament types and materials during the European period. Yilan was involved in complex trading networks both on a regional scale with other Indigenous groups and Chinese

merchants, and at a global scale with Europeans, including the Dutch and the Spanish. Those trade ornaments have multiple origins, including Southeast Asia and China, and were first introduced into northeastern Taiwan by Chinese merchants before the 17th century. Later, trade activities became more frequent and intense in the 17th century due to European activities. The greater diversity and quantity of ornaments likely resulted from participation in large scale exchange networks that stimulated the circulation of different ornament classes. The frequency of overall ornaments and each subtype declines significantly after European influence fades during the Chinese period in the early 19th century. This may be due to a smaller scale of trading networks, the overall decline of Indigenous populations in Yilan, or the adoption of Han Chinese practices. The decline of the population at Kiwulan may be related to the movement of many Indigenous people southwards to Hualien due to the increasing numbers of Han Chinese immigrants who took over their lands at the end of the 18th century (Chen 2007). Houses and burials may also be a useful source of evidence to understand population size but a proper treatment of those is beyond the scope of the paper

Archaeological contexts at Kiwulan show that ornaments are especially abundant in burial contexts serving as grave goods (Chen 2007). This supports the interpretation of ornaments as valuable objects functioning as status indicators. Spatial patterns of ornaments in dwelling contexts show that their distribution was clustered during the pre-European and European periods. These clusters are non-random, and are most highly concentrated during the European period. This may indicate that a degree of social inequality based on the uneven distribution of ornaments was already present before European contact, and then it was reinforced and amplified during the European period. A further indicator of increased social inequality is a burial dated to the 17th century that included 60 gold-foil beads, well above

the average of 2-3 pieces in the pre-European period (Chen 2007; Cheng 2008). Based on the finding of that burial, Cheng (2008) proposed a more hierarchical structure of Kiwulan. However, Hsieh (2012)'s research on burial data suggested a more egalitarian society since a few burials with rich goods are elders that indicate accumulated wealth over time instead of inherited status. Although both Cheng and Hsieh use the same burial data, their inferences about Kiwulan social structure are the opposite. Our results provide an additional insight by focusing on the residential area which demonstrates an uneven distribution of ornaments during the European presence, indicating increasing social inequality, supporting Cheng's conclusions. Nevertheless, we still need to explore and compare with other archaeological records to make more robust inferences about the social structure of Kiwulan.

How might these results fit into a bigger picture of social change at periphery of colonial systems? We may get some insight into the general pathways that led to social inequality in northeastern Taiwan by considering how people have achieved and maintained power in a wide variety of societies (Ames 2010; Bowles *et al.* 2010; Drennan *et al.* 2010; Feinman 2000). The corporate/network model proposed expands traditional hierarchical complexity to provide a comparative basis for distinct strategies for power (Feinman 2000). In the network mode, inequality develops when individuals accumulate wealth through their individual networks and people use their wealth to attract factions, control resources, and monopolize trade networks. In contrast, the corporate mode stresses shared power across different groups and sectors, integrative ceremonies and rituals, and large cooperative labor tasks (Feinman 2000; Siegel 1999).

The Kiwulan ornament data may be interpreted as indicating that Yilan social organization moved from a corporate mode, before the European arrival, to a network mode during

European presence. The changes from a less concentrated to a more concentrated distribution of ornaments before and after the presence of Europeans appears consistent with the shift from shared power and wealth to accumulated wealth and monopolization. One possible explanation for the shift could be the long-distance trade network introduced by Europeans. The rarity and the image of colonial power of foreign trade goods resulted in the emergence of competition among ambitious individuals for prestige, wealth, or power through collecting them (Boone 1992; Brumfiel 1994; Clark & Blake 1994). Because of the weak direct control from the European colonizers in northeastern Taiwan, local leaders may have had the flexibility to manipulate European colonial images, expand personal power, and monopolize the high-value trade goods (Kang 2012).

That said, the evidence from Kiwulan may be consistent with a variety of scenarios of Indigenous-colonial relations. The increasing number and concentrated spatial patterns of ornaments may also suggest a practice of cultural resistance against the European intrusion. Resistance to European economic and political demands may be inferred if ornaments were used as a display of social identity and to emphasize the local customs that had existed before European contact (cf. Rubertone 2000). We know the custom of wearing ornaments in Indigenous societies for attending ceremonial events based on the Chinese historical records in the 19th century (Chen 1963; Ke 1993). Also, an ethnographic photo photographed by Mackey (1895) presents a weaving practice by an Indigenous woman at Yilan, who wore beaded necklace and headpiece. This indicates that the ornaments commonly found in the residential area were part of their daily life and customary displays. This custom might be reinforced during the foreign presence as a form of resistance, but we

need more specific evidence from Kiwulan to prefer resistance as the primary mechanism behind the distribution of ornaments over colonial influence.

Conclusion

Analyses of the archaeological record at the peripheries of colonial activity offers an opportunity to understand pervasive but not necessarily dominant European colonial processes at remote Indigenous groups (Trabert 2018). Similar impacts can be also seen in modern societies today when adopting western products (Al-Ghanim *et al.* 2017; Zheng 2015). Kiwulan in northeastern Taiwan is an exceptional case study as an East Asian location that was relatively isolated and peripheral, and yet connected by regional and global trade networks. Kiwulan provides valuable insights into the discussion of indirect colonial influence on local societies living beyond the reach of direct European colonial occupation. The frequency and spatial distribution of personal ornaments at Kiwulan present three distinct patterns during different dominant culture interaction periods. The greater amount and diversity of ornament types during the European period reflects an increasing use in ornaments in a colonial context. Before European contact, ornaments were traded into local Indigenous societies via the regional exchange network with Chinese merchants, and viewed as prestige goods in the local Indigenous culture. After the arrival of the Europeans, the exotic and powerful image carried by those ornaments may have intensified, further signaling wealth and privileged trading connections among the inhabitants of Kiwulan. This may have stimulated more competition between aggrandizing individuals for prestige and wealth accumulation at Kiwulan, which might have resulted in an increase in social inequality. This might also indicate an act of intentional resistance to the intrusion of the

Europeans by using more ornaments that are symbolic of cultural tradition, but additional evidence is required to confirm this.

By focusing on the distribution patterns in a settlement site, the Kiwulan ornaments suggest that foreign ornaments can be a proxy to detect indirect colonial influence on local Indigenous populations. Ornaments give insights into the amplification of social inequality stimulated by European colonization. It also shows the agency of Indigenous people to incorporate ornaments into their social system and use them in their life or social occasions to display or intensify status differences. We are still far from understanding the full variety of colonial impacts on peripheral Indigenous communities. We have introduced here the corporate/network model for understanding the dynamics of social inequality at Kiwulan, and further provenance analysis of imported ceramics and ornaments such as X-ray fluorescence analysis would provide more information to construct a clear picture of complex trade networks during this periods.

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Chapter 3

Standardization of ceramic shape: A case study from the Iron Age pottery from northeastern Taiwan

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Abstract

The emergence of ceramic specialization in prehistoric societies is often linked to shifts in the complexity of social structures, because standardized ceramic production can reflect craft specialization and the presence of elite control. Previous work on identifying specialization relies on typological or linear metric analysis. Here we demonstrate how to investigate ceramic standardization by analyzing outlines of ceramic vessels. Outline analysis is useful because, unlike more commonly-used landmark analysis methods, it can effectively quantify shape differences for objects that lack distinctive measurement points

needed for landmark analysis. We demonstrate this method using pottery from Kiwulan, a large multi-component Iron Age site (AD 1350-1850) in northeastern Taiwan. To measure ceramic specialization, we quantified pottery standardization by analyzing shape variables with reproducible geometric morphometric methods. We computed coefficients of variation (CVs) for shape coefficients obtained by elliptical Fourier analysis to test for shape standardization. We found significant differences in pottery shape and shape standardization that indicate changes in pottery production resulting from contact with mainland Han Chinese groups in northeastern Taiwan. Our case study, which includes an openly available research compendium of R code, represents an innovative application of outline-based methods in geometric morphometry to answer the anthropological questions of craft specialization.

Introduction

A major historical factor of social change in small-scale societies is often linked to the introduction of foreign or exotic trade goods to local Indigenous societies (Mullins, 2011). Monopolization of long-distance trade goods has caused substantial transformations in Indigenous economic, cultural, and socio-political systems (Dietler, 2005, 1997; Junker, 1993; Silliman, 2005). Pericolonial archaeology is the study of these indirect effects of colonialism, investigating areas where direct European colonial rule was limited, their conquests were often short-lived and unsuccessful, but commercial activities yielded economic and political impacts on Indigenous peoples living on the periphery of colonial control (Acabado, 2017; Trabert, 2017). Pericolonial situations were common during the 17th to 19th centuries in East and Southeast Asia where European trading activity was

extensive, but direct European rule less widespread. An emerging priority in archaeological research in Asia is identifying the indirect influences that are apparent on Indigenous communities during the colonial period. For example, Acabado (2017)'s study of Ifugao society in the Philippines highland suggests economic and political intensification during the Spanish presence in the lowlands as a strategy of Indigenous peoples to resist Spanish conquests.

Indigenous societies' responses to colonial contact ranges from passive acceptance to active negotiation with the colonists, and accommodation or resistance of foreign intrusion (Torrence and A. Clarke, 2000a). The responses can be identified through their daily cultural practices, such as their consumption patterns of foreign goods (Dietler, 2015; Given, 2004; Mullins, 2011; Scaramelli and Scaramelli, 2005; Silliman, 2001). In this paper we investigate the archaeology of a pericolonial situation at Kiwulan (ca. AD 1350-1850) (Chen, 2007), a large multi-component archaeological site in Yilan County, northeastern Taiwan, to identify the indirect impacts of colonial settler activity on local Indigenous societies. Yilan is an ideal context to study peripheral colonial influences because the Indigenous communities were isolated by geographical barriers, limiting the frequency of direct contact with the Spanish and the Dutch settlers in northern Taiwan (cf. Berrocal et al., 2020). Kiwulan is situated on a hill near a riverside at the northern margin of Yilan County, which is characterized by a triangular alluvial plain facing east toward the Pacific with high mountains on three other sides.

This research investigates if there was increasing ceramic specialization resulting from Indigenous interaction with Europeans in the 17th century, or Chinese in the 19th century. These were the two major foreign influences in early historical Taiwan that may relate to

social changes in Indigenous societies. We predict that competition within the Indigenous community at Kiwulan for foreign resources and trade partnerships with European or Chinese colonizers may have led to the emergence of craft specialization, caused by greater economic and social control of ceramic production by a small group of individuals. Using standardization in ceramic shapes as a proxy for craft specialization, we ask: Did colonial trade impact the shape of locally-produced Indigenous pottery vessels? Did pottery shape become more homogeneous after foreign contacts with European colonizers or Chinese immigrants?

Several measurements have been used for investigating ceramic standardization that include metric, compositional, and technological variables (Arnold, 2000; Blackman et al., 1993; Boness et al., 2015; Costin, 1991; Rice, 1991; Roux, 2015; Tite, 1999). Among those variables, metric measurements are most widely applied to archaeological assemblages. The coefficient of variation (CV) statistic is regularly used to quantify the degree of standardization in ceramic assemblages (Eerkens and Bettinger, 2001; Junker, 1999; Roux, 2003; Stark, 1995). However, because pottery vessels typically have curved shapes, linear measurements have limited sensitivity to many kinds of shape variations. Thus, to capture subtle shape variations that might also be relevant to standardization, we analyze ceramic shapes using geometric morphometric methods (GMM).

Geometric Morphometrics

Geometric morphometrics (GMM) differs from traditional linear measurements through its use of Cartesian coordinates of morphological structures to quantify and analyze shape (Adams et al., 2004; Bookstein, 1997; Lawing and Polly, 2010; Slice, 2007). Landmarks,

curves or outlines of objects can be represented by coordinates in terms of their unique point locations with respect to numerical values on coordinate axes. There are two common morphometric approaches: landmark and outline methods (Adams et al., 2004). Landmark GMM approaches assign a set of landmarks and/or semilandmarks onto objects as reference points. Generalized Procrustes analysis (GPA) is used to superimpose landmark data on a common coordinate system by translating, rotating, and scaling (Bookstein, 1991). After the GPA procedure, superimposed landmark coordinates become shape variables that allow further statistical analyses (Slice, 2007). A common procedure is using dimensional reduction techniques, such as Principal Components Analysis or Canonical Variate Analysis, to capture the key features that represent the overall shape. Visualization of the reduced data enables the identification of groups, followed by statistical tests to robustly distinguish them. Landmark-based morphometrics have been widely applied to archaeological objects with obvious morphological features that provide unambiguous reference points for landmark placement, such as tips and edges of stone or metal tools (Birch and Martinón-Torres, 2019; Lycett and Cramon-Taubadel, 2013), visually distinctive bone features (Haruda et al., 2019; Meloro et al., 2015), or ceramic assemblages with distinct components (Selden Jr, 2019; Topi et al., 2017). This approach is often used to answer research questions related to lithic typological and technological change (Doyon, 2019; Eren et al., 2015; Perez, 2007; Presnyakova et al., 2018; Selden et al., 2018), animal domestication or mobility (Haruda et al., 2019; Owen et al., 2014), or hominid activities through cutmarks and taphonomic traces (Aramendi et al., 2019; Courtenay et al., 2019).

Key questions in archaeological shape analysis normally involve measuring shape standardization over time, or between geographical areas. Standardization is often

investigated using multivariate analysis of shape variables computed from landmark data, along with coefficients of variation on associated metric data, especially for lithic assemblages. For example, Archer et al. (2015)'s case study of stone points in Southern Africa suggests an increase in shape standardization over time that may relate to increased maintenance of finished points. Buchanan et al. (2018) analyzed lithic morphology with metric data and identified a more uniform base-shape of Folsom points compared to Clovis points across the western US. With similar methods, Smith and DeWitt (2016) found standardized bases of fluted points in Alaska and northern Yukon that might indicate a risk management strategy to ensure the ease of replacement during long-distance travel. Other factors, such as low levels of cultural innovation in a small group, could also lead to an increase in standardization of point shapes (Okumura and Araujo, 2014). To test the effectiveness of measuring standardization, Birch and Martinón-Torres (2019) compared landmark-based GMM to traditional metric analysis with CVs using European iron weapons as an example. They demonstrated that landmark-based GMM can capture more variation in not only overall shape, but also bilateral symmetry.

For ceramics, Topi et al. (2017) identified that two types of the Casas Grandes vessels in northwest Mexico tend to have standardized shapes, using coefficients of variation for the positions of semi-landmarks across shape groups. They suggested standardization might hint at the presence of specialized producers, reflecting social complexity. Another way to explore standardization is pairwise testing of variations in morphological disparity between shape groups by calculating their distances in morphospace, an n-dimensional space that shape groups occupy (Wills, 2001). In this manner, Seldon (2019, 2018) examined Caddo ceramics in northeast Texas using semi-landmark approaches and found an increase in shape

standardization over time, providing a basis for further discussion of craft specialization or group identity. Similarly, the Gahagan bifaces from the central Texas exhibit less size standardization than those from the southern Caddo area, indicating different uses or tool types (Selden Jr et al., 2020). Other applications, such as studies of cranial deformation, demonstrate that landmark approaches with multivariate analyses of shape variances are useful to evaluate shape standardization (Kuzminsky et al., 2016; Natahi et al., 2019; Perez, 2007).

A key limitation of landmark approaches in archaeology is that landmarks may be difficult to reproducibly locate for structures that are mostly or entirely curves, if not mathematically-defined. In those cases, outline approaches, such as Elliptic Fourier Analysis (EFA), are more effective for assessing morphological variations in the whole structure of two-dimensional closed shapes (Cardillo, 2010). EFA uses periodic functions to capture geometric information, where an outline is decomposed into a series of ellipses described by trigonometric functions (Adams et al., 2004; Bonhomme et al., 2014; Claude, 2008). That is, coordinates along a curve are converted into Fourier function coefficients, called harmonic coefficients or harmonics (Kuhl and Giardina, 1982). The number of harmonics determines the quality and precision of the geometric representation of an object. The harmonic power, a cumulative sum of squared harmonic coefficients, provides a robust rule for determining the desired number of harmonics (Bonhomme et al., 2014). The first systematic use of Fourier series to analyze shapes of artifacts in archaeology was Gero and Mazzullo (1984)'s study of lithic flakes in Peru. They successfully identified the changes in tool shape from a more angular to rounded shape over time. Later, Saragusti et al. (2005) introduced more functions allowing the calculation of the specific shape attributes, such as symmetry,

roughness, and deformation. This demonstrated the potential of EFA for the analysis of curves in detail. Ioviţă (2009) demonstrated a protocol, including outline digitization, EFA procedure, and multivariate linear regression, to compare resharpening trajectories of European Middle Paleolithic stone tools. He found that resharpening can be independent of morphology, suggesting that functional attributes should be studied separately. Recent case studies further support the effectiveness of EFA for examining lithic assemblages, e.g. for typological classification of Late Woodland points (Fox, 2015), analysis of the function of flaked obsidian tools in Easter Island (Lipo et al., 2016), study of the shape and symmetry standardization of the British Acheulean (Hoggard et al., 2019), and investigating cultural taxonomies of the European Late Palaeolithic (Ivanovaitė et al., 2020).

Despite few ceramic studies using EFA to date, this approach is promising for analyzing ceramic taxonomy and standardization. For example, Wilczek et al. (2014) evaluated the concordance between EFA and Discrete Cosine Transform (DCT), and a traditional typology by studying 154 complete ceramic vessels with varied shapes from the Bibracte oppidum in France. They found that the variation indicated by EFA and DCT matches the traditional ceramic typology, which supports the claim that outline-based approaches can be efficiently used for studying variations in ceramic shapes. Wilczek et al. (2014)'s findings demonstrate the potential of EFA for detecting variation in ceramic standardization. In this paper we use EFA to evaluate the level of standardization of ceramics data from Kiwulan, northeastern Taiwan around the time of foreign colonial presence to gain insight into the emergence of ceramic specialization. The globular shape of the vessels in our sample means that our specimens lacks visually distinctive landmarks, so EFA is an ideal method because of its focus on the overall shape of an artifact. In addition, we use a novel significance test

for the equality of coefficients of variation of shape variables to statistically compare vessel standardization from different periods.

Archaeological background and materials

Ceramics analyzed in this study come from 40 units (4m by 4m each) sampled from the central, undisturbed area of archaeological excavations at Kiwulan (Figure 3.1; Figure 3.2). The chronology of the archaeological deposits consists of two cultural components, the upper and the lower, with a sterile layer in between (Chen, 2007). We focus on the upper component, dated from AD 1350 to 1850, because it spans the late Iron Age and the historical period. The historical period in Taiwan started with the presence of the Europeans in the early 17th century. The Dutch first occupied southern Taiwan in 1624, followed by the Spanish in northern Taiwan in 1626 (Andrade, 2007). In 1642, the Spanish were expelled by the Dutch, who then took over the Spanish forts at Helping Dau in Keelung, and in Tamsui. Western Taiwan remained under Dutch colonial rule until 1662 when the Kingdom of Tungning in Taiwan was founded by Koxinga, a loyalist of the Ming dynasty of China (Andrade, 2007).

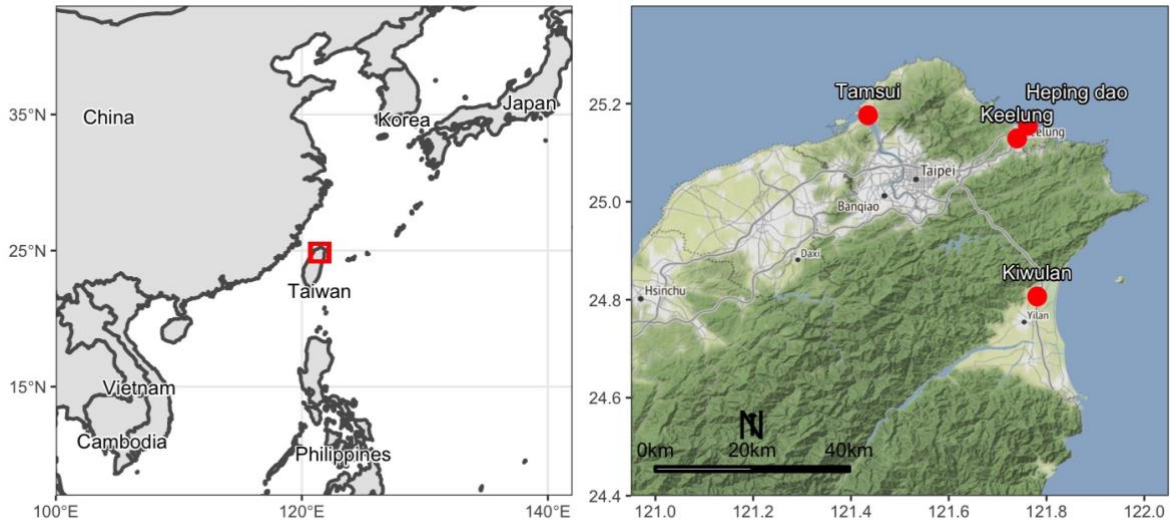


Figure 3.1: Map illustrating the location of Kiwulan, and other locations in northern Taiwan that are named in the text. Map data is from naturalearthdata.com

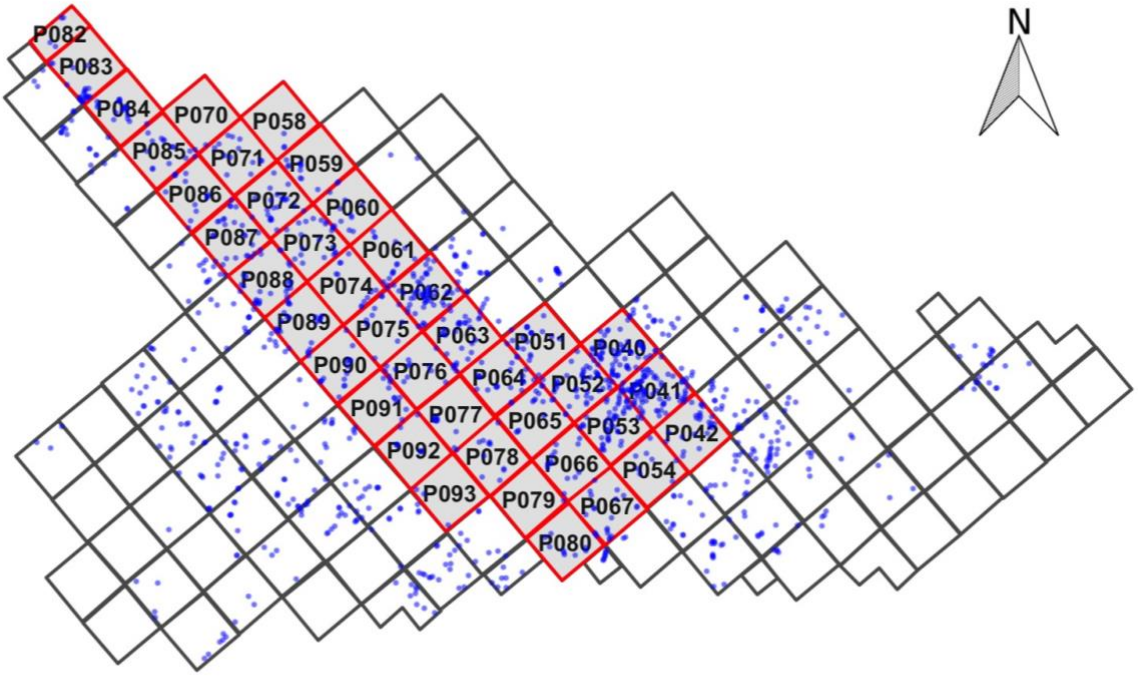


Figure 3.2: Map showing the largest section of excavation areas at Kiwulan, and the distribution of forty squares sampled in this paper presented in red with square ID number. Small dots represent the location of post-holes. Each square is 4 x 4 m

The archaeological record of Kiwulan's upper component shows traces of foreign contact, including Europeans in the 17th century, and waves of Chinese immigrants in the 19th century. Imported ceramics from mainland China, stoneware, and ornaments such as beads have been recovered in the upper component, indicating frequent long-distance trade activities with Europeans and Chinese merchants. Archaeological features such as burials, middens, and post-holes with *in-situ* posts are widespread across the 1-2 m thick deposit of the upper component, and demonstrate that Kiwulan was a continuously occupied large

settlement site (Chen, 2007). To compare different foreign influences, we classified the upper component into three chronological phases: pre-European, European, and Chinese. These phases were identified according to chronologically diagnostic artifacts. Our Bayesian modeling of 11 ages related to the upper component from Chen (2007) shows a consistent result with our artifact-based chronology. However, because the three phases are relatively brief and the number of ages is small, radiocarbon modeling is of limited value to chronology building in this case (more details in Wang and Marwick, 2020). The diagnostic artifacts include blue and white porcelains, light grey glazed jars, and large dark brown glazed stoneware jars commonly used in the 17th century, and bricks and tiles employed by the Chinese in the 19th century (Chen, 2007; Hsieh, 2009; Wang, 2011). We also examined excavation depth measurements and stratigraphic details reported by the excavators (color, texture, disturbance, etc.) to reliably separate the three phases. The deposit exhibited signs of continuous human occupation in each of the three phases with no apparent breaks. More details for the assignment of different phases are in the Online Supplementary Materials (Wang and Marwick, 2020).

The most abundant artifacts in the upper component are locally manufactured ceramics, which are distributed throughout the temporal sequence, and across the study area. More than 550,000 sherds were recovered, and around 1,200 vessels could be completely or partially reconstructed (i.e. complete rim or base). There are two shapes of locally-manufactured vessels; a cooking pot and a steamer made of two cooking pots stacked together with a clay filter between. Those vessel shapes demonstrate suites of standard morphological components. Each has a globular body with a short neck and wide mouth (Figure 3.3). The exterior surface below the neck is decorated with a variety of impressed

geometric motifs. These vessels were likely used for cooking, as indicated by the frequent presence of charred residues and carbon deposits on vessel interiors, and soot on vessel exteriors. Firing resulted in orange and brownish color with a fully oxidized core, or a reduced core with oxidized fringes (Chen, 2007). The vessels were believed to be made with pinching technique according to some hand-shaped traces on vessel interiors, such as finger impressions and seams. This kind of vessel has been widely found at archaeological sites during the late Iron Age and the historical period throughout the Yilan Plain (National Musuem of Taiwan History, 2005).

Petrographic analysis for 34 thin sections presents a high percentage of inclusions (15-50%), including argillite (15-40%), metasandstone (1-10%), sandstone fragments (1-6%), quartz (1-5%), and trace amounts of feldspar and slate. Particle sizes range from 500 to 1300 microns. In general, the vessel fabric presents a mixture of fine, rounded argillite with a small amount of rounded metasandstone and rounded sub-angular monocrystalline quartz. This composition is consistent with the mineralogical composition of local raw materials found in the Yilan Plain (Chen, 2016). There are no significant changes in the inclusions over time, indicating continuity in pottery fabric composition across the three periods ($p = 0.7159$) (Wang and Marwick, 2020).

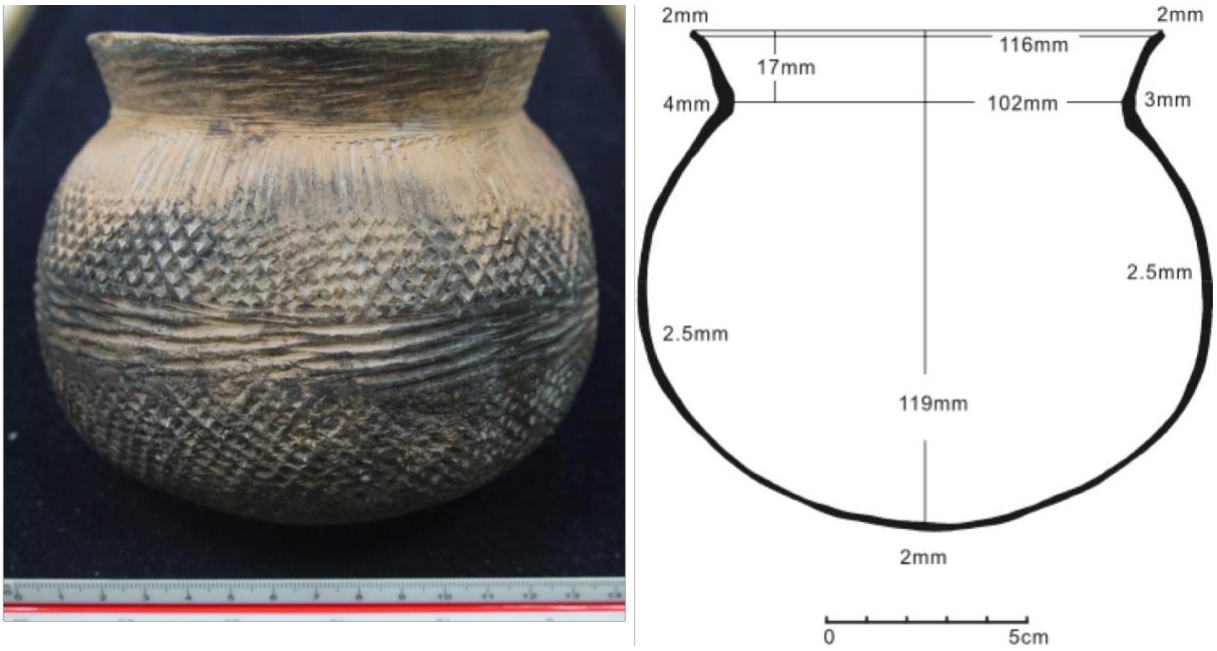


Figure 3.3: A typical pot from Kiwulan (left) and an example of a pottery drawing used for outline analysis (right)

Methods

The sample consists of 73 reconstructed vessels with rim, body and base parts that were securely provenanced to pre-contact (n = 32), post-European (n = 27), and Chinese contact contexts (n = 14).

Digitizing and analyzing by EFA

We used 300 dpi scans of pottery drawings acquired from the Bureau of Cultural Affairs in Yilan (Figure 3.3). All drawings provide a two-dimensional view of vessel cross-sections based on metric measurements. The scanned drawings were imported into Inkscape (http://inkscape.org) for digitization where outlines were manually traced. In those instances where only one side of the cross-section image was available, or small sections were

missing, we interpolated the curves and then mirrored and joined to create a closed outline for each vessel. Analyses were conducted using R software (R Core Team, 2019) with functions from the Momocs package for quantifying and analyzing shapes (Bonhomme et al., 2014). Outlines were converted into a list of successive x and y pixel coordinates for EFA. We analyzed harmonic coefficients by principal component analysis (PCA) for dimensionality reduction to illustrate the diversity of the shape data and identify major patterns of variation.

Statistical analysis

The principal component (PC) scores were analyzed with a multivariate analysis of variance (MANOVA) to test significant differences in shapes between occupation phases. We also computed coefficients of variation values (CVs) for the PCs, treating the PCs as shape variables that are more informative than linear dimensions. The coefficient of variation is a common and widely-used statistical measure of the spread of a set of measurements of a sample. It is defined as the standard deviation divided by the mean:

$$c_v = \frac{\sigma}{\mu}$$

As a standardized measure of the spread of data, coefficients of variation (CV) allows a direct comparison for variation in samples measured with different units or means. This is useful to examine the degree of standardization for archaeological assemblages and enables comparison of variation across different sample sizes (Eerkens and Bettinger, 2001, p. 498). Following Eerkens and Bettinger (2001) and Roux (2003), we take this as our measurement of standardization in vessel shape variables: lower CV values reflect higher standardization,

and thus increased craft specialization in the community. Given that CVs are most informative when computed on either all positive values or all negative values, we normalized PC scores to a range between 1 and 10 for the computation of CV.

To answer the question of whether CV values across our three occupational phases are significantly different or not, we used the modified signed-likelihood ratio (MSLR) test for equality of CVs (Krishnamoorthy and Lee, 2014). While previous work has used the Feltz and Miller (1996)'s asymptotic test for the equality of coefficients of variation from k populations (Eerkens, 2000; Eerkens and Bettinger, 2001; Hoggard, 2017; Lycett and Gowlett, 2008; Okumura and Araujo, 2014), we prefer the MSLR test for shape variables as a more recent development with lower rates of type I error, better performance with uneven sample numbers, and more power across a range of conditions (Krishnamoorthy and Lee, 2014).

To complement our investigation of craft specialization through shape standardization, we investigated spatial patterns of ceramic vessels at Kiwulan. As craft specialization increases, we expect a shift from a pattern of vessels dispersed across the site to a pattern of clusters that reflects the loci of production (Costin, 2001). We used a Monte Carlo test for randomness in spatial locations of ceramics to robustly test whether their distribution is significantly clustered or dispersed.

Reproducibility and open source materials

To enable re-use of materials and improve reproducibility and transparency (Marwick, 2017), the entire R code (R Core Team, 2019) used for all the analysis and visualizations

contained in this paper is openly available online at https://doi.org/10.17605/OSF.IO/ABVGF (Wang and Marwick, 2020). Also in this version-controlled compendium (Marwick et al., 2018) are the raw data for all the visualizations and tests reported here. All of the figures, tables, and statistical test results presented here can be independently reproduced with the code and data in this repository. The code is released under the MIT license, the data as CC-0, and figures as CC-BY, to enable maximum re-use.

Results

Thirteen harmonics captured 99% of the total harmonic power in the elliptic Fourier coefficients of 73 vessels from three phases. Figure 3.4 illustrates differences in vessel shapes using thin-plate spline warping for paired periods, pre- and post-European periods, and post-European and Chinese periods, with the greatest differences evidenced between pre-European and Chinese periods.

The first two principal components (PCs) of the PCA on the elliptic Fourier coefficients explain 74.85% of the total variance, of which 48.32% is explained by the first principal component. With the third component, the first three principal components explain 86.08% of the total variance. PC1 captures the height of the vessels, from tall to short, and the roundness of the body from round to oval-shaped (Figure 3.4). PC2 relates to the neck and mouth constriction, from narrow to wide. PC3 explains a smaller portion of the variance (11.23%), which relates to the degree of the flare in the neck, from a curved to a straight shape. The results reflect a large overlap in shapes from three occupations phases, especially for shapes in the pre-European and post-European periods. However, the spread of shape distribution indicates a wider variation in shapes in the pre-European and post-European

periods compared to those in the Chinese period along both PC1 and PC2 axes. In other words, we find a decrease in shape variance in the Chinese period evidenced in the shorter height and narrower mouth of vessels used in that period.

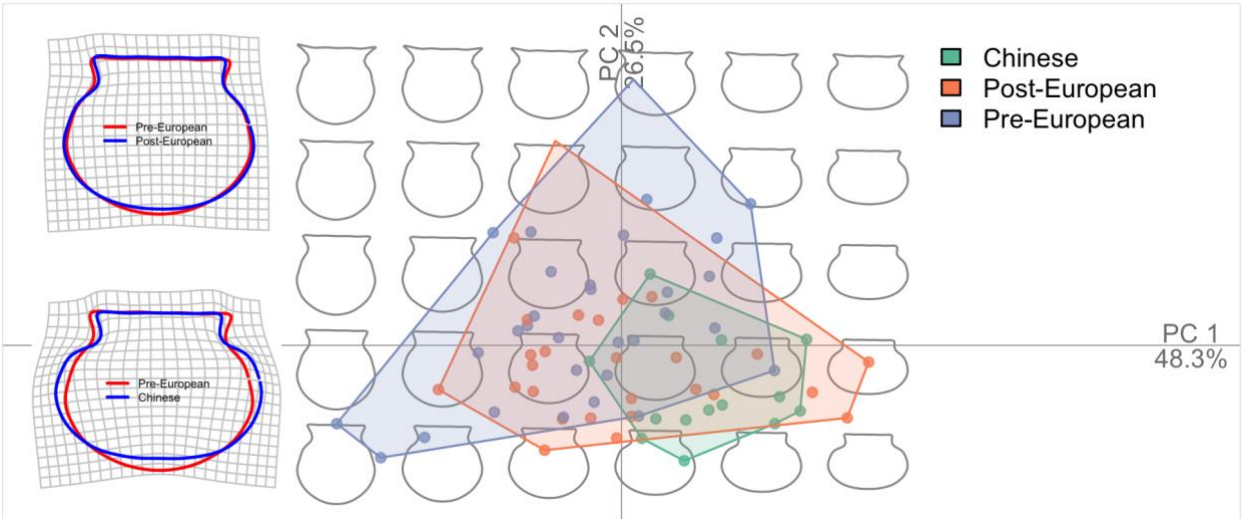


Figure 3.4: Left: Significant differences in average vessel shapes between the Chinese and the post-European period are visible using thin plate splines (TPS), with outline deformations required to pass from an extreme of one morphospace to another. Right: Pottery shape distribution by each occupation phase according to the first two PCs.

Comparison	Pillai's trace	Approximate F value	degrees of freedom	Pr(>F)
Chinese - Post-European	0.3806	1.6202	29	0.1452
Chinese - Pre-European	0.6942	7.0177	34	0.0000
Post-European - Pre-European	0.3491	2.2917	47	0.0243

Table 3.1: Summary statistics for the MANOVA test on the PC scores. Pr(>F) is the p-value associated with the F statistic of the effect and test statistic.

To test for differences in the distributions of shape variables indicated by the PC scores shown in Figure 3.4, we used a multivariate analysis of variance (MANOVA) test to compare pairwise combinations across the three occupation phases. Table 3.1 demonstrates the significant differences in shape between Pre-European and Post-European phases ($p = 0.0243$), and Pre-European and Chinese phases ($p = 0$). These results are consistent with the differences in the visualization of average shapes between the phases (Figure 3.4, see left). Although there is considerable overlap of shape variables between the Pre-European and Post-European phases, their PC scores differ significantly. There is no significant difference in vessel shapes between the Post-European and Chinese contact periods.

To compare pottery shape standardization across the three phases we investigated the distributions of the first three PC scores, taking the PC scores as proxy variables for vessel shape (Figure 3.5). The CVs calculated of the three PC support a general trend toward a more standardized shape over time, especially the shape identified by PC1 that represents vessel height and roundness. PC1 shows a higher variation in the pre-European period and post-European period compared to the Chinese period. That is, a more standardized shape found in the Chinese period. However, PC2 presents a similar diversity in ceramics assemblages across three phases, while PC3 demonstrates a slightly standardized shape in the Chinese period.

To see whether the differences in the distribution of PCs between any two phases are substantive or due to chance, we assessed the equality of CVs for PC1 and PC2 with a

modified signed-likelihood ratio test (Krishnamoorthy and Lee, 2014; Marwick and Krishnamoorthy, 2019). P-values for PC1 show significant differences in shape standardization across periods, between Chinese contact with either pre-European or post-European (Table 3.2). This result supports the observation of a more highly standardized shape in the Chinese period.

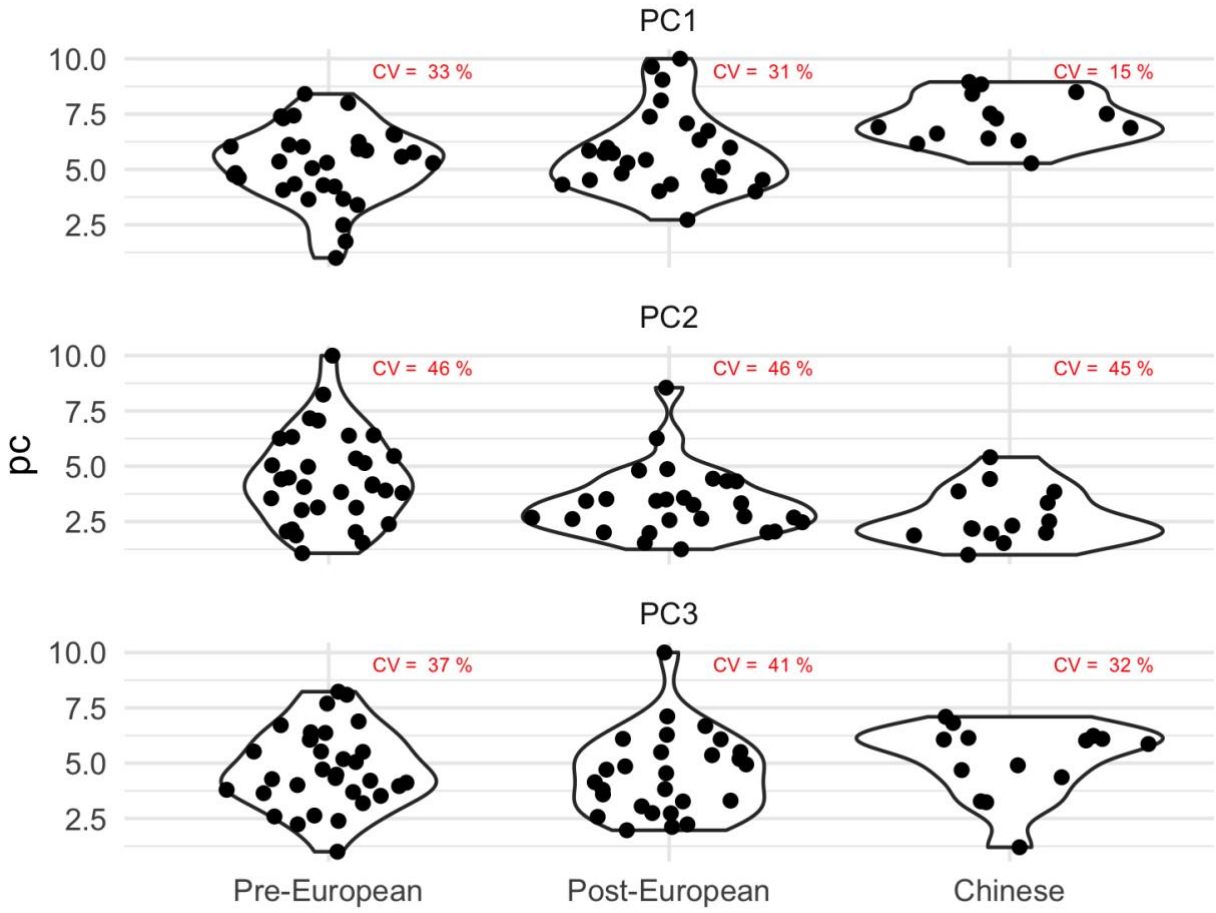


Figure 3.5: The distribution of normalized PC scores by phases. CV values (%) are shown in the upper right of each plot.

PC	MSLRT	p-value	phases
PC1	0.0569	0.8115	Post-European vs Pre-European
PC1	8.2930	0.0040	Chinese Contact vs Pre-European
PC1	6.4299	0.0112	Chinese Contact vs Post-European
PC2	-0.0520	1.0000	Post-European vs Pre-European
PC2	0.0844	0.7714	Chinese Contact vs Pre-European
PC2	-0.0104	1.0000	Chinese Contact vs Post-European

Table 3.2: P-values of the CV equality test of PC1 and PC2 between phases

Vessel size is another important variable for detecting standardization. We used the body diameter of vessels as a proxy of size to examine their variation and relationships with vessel shape. We measured body diameter directly from each physical vessel in the collection, and we focus on this metric because it is available for more vessels than any other metric. The body diameter of vessels from the Chinese period is larger than those from the two earlier periods, and vessels from before European contact have the smallest body diameter on average (Figure 3.6: A). To investigate vessel form standardization, represented by shape and size, we compared CV for PC1 (as a shape variable) in relation to CV for body diameter (as a size variable). The result (Figure 3.6: B) shows a higher standardization in vessel form in the Chinese period, with smaller CV values compared to those from the other two phases. However, there are no obvious differences in form standardization before and after the European presence. To understand the relationship between shape and size, we computed linear regression models for PCs and body diameter (Figure 3.6: C). The results demonstrate that shape and size are positively correlated in all phases, as indicated by

moderate positive relationships ($0.3 \leq r \leq 0.7$) and small p-values (≤ 0.05), except for PC1 in the Chinese period and PC2 in the pre-European period. In general, the shorter vessels are larger in body diameter according to the significant positive correlation. However, vessels from the Chinese period do not show this pattern. For the relationship between PC2 and body diameter, the negative relationship suggests that vessels with a narrower neck and mouth tend to have a larger body diameter.

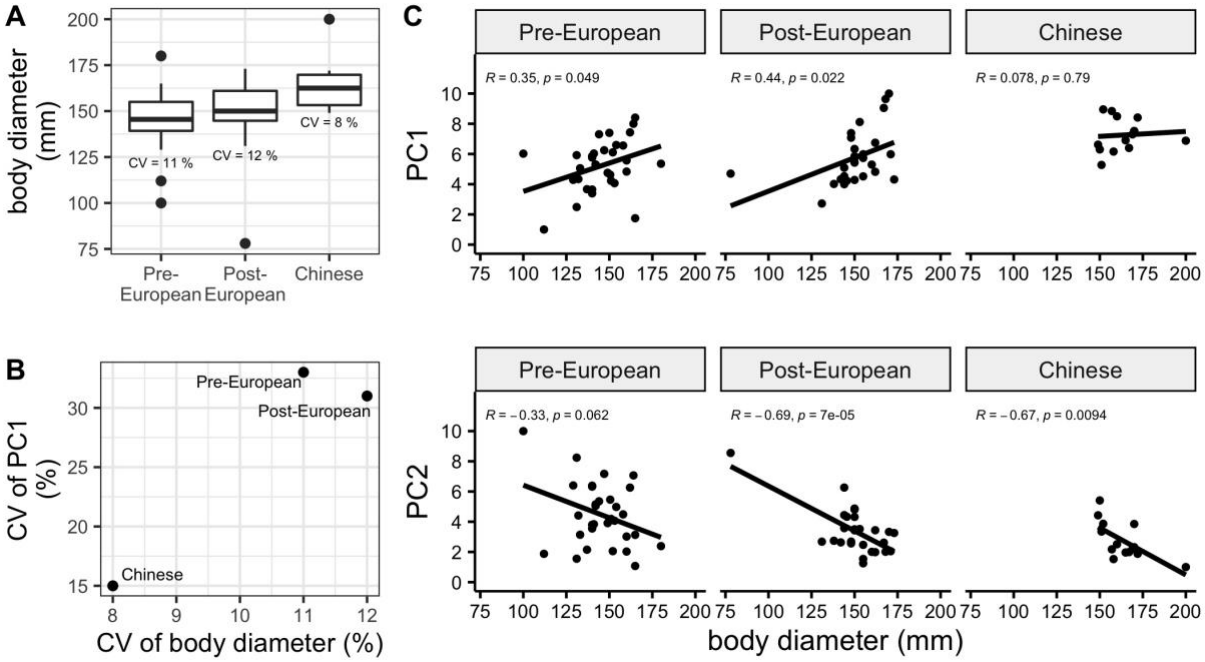


Figure 3.6: A: Distribution of the body diameter of vessels with coefficients of variation by phases. B: Coefficients of variation of vessel shape represented by PC1 in relation to vessel size represented by body diameter, showing more standardization (lower CV values) in vessel form and size in the Chinese period. C: Correlation between shape variables (PC1 and PC2) and body diameter of vessels with Pearson's r and p-values by phases

Discussion

Previous investigations at Kiwulan suggested an unequal distribution of prestige goods with high diversity in types, trade ornaments in particular, following the appearance of Europeans (Cheng, 2008; Wang, 2011). This hinted at the emergence of social inequality within the Indigenous community. To investigate this possible relationship between social inequality and foreign presence, we examined shape standardization of ceramics to measure craft specialization as a proxy for social change (Costin, 2001; Junker, 1999). The result of our MANOVA demonstrates significant differences in shapes between the pre-European and Post-European periods, and pre-European and Chinese periods. The average shape presents as a round body with a wide rim and neck before European contact, which shifts to a more oval-shaped body with narrower rim and neck after the European presence. Such shape is more pronounced in the Chinese period. In general, vessels become oval-shaped with a restricted mouth over time, which corresponds with an increase in body diameter of vessels. The correlation between shape and body diameter suggests that body diameter significantly varies with vessel shape. Oval-shaped vessels with a narrower opening tended to have a larger body diameter, indicative of a change in overall vessel form.

For the degree of shape standardization, our CV tests on PC1 indicate a significant difference between the Chinese period and either pre-European or post-European periods. Analysis of morphological disparity, which measures the positioning of specimens relative to one another in the morphospace (Hopkins and Gerber, 2017), supports our finds of shape differences between Chinese contact and either pre-European ($p = 7.159 \times 10^{-23}$) or post-European periods ($p= 2.065 \times 10^{-25}$) (Wang and Marwick, 2020), suggesting a more

standardized shape after contact with the Chinese. In addition, we found a more homogeneous shape accompanied by a more standardized but also larger size in the Chinese period. Generally, people tend to make mistakes in hand-crafting as the size of an object increases, leading to higher variations in larger artifacts (Eerkens and Bettinger, 2001). However, we found the opposite for ceramics in the Chinese period when using body diameter as our proxy variable of size. This might hint an intentional behavior by Kiwulan potters to achieve a homogeneous form for the larger vessels. Mineral composition shows that the clay pastes are similar throughout three phases, regardless of the increasing standardization of the pottery shape, reflecting continuity in the raw material sources. We can thus rule out changes in clay fabric as a factor in explaining changes in vessel shape. We note that a small sample size in the Chinese period may lead to a more standardized shape. However, this effect can be reduced using CV statistics that scales variation to magnitude, allowing reliable comparison across uneven sample numbers, even for small sample size (Eerkens and Bettinger, 2001). Moreover, the MSLR test for equality of CVs enables a robust test between different sample numbers (Krishnamoorthy and Lee, 2014).

Whether the shape standardization we found results from craft specialization depends partly on the number of producers, which distinguishes mechanical standardization from intentional standardization defined by stylistic and functional attributes (Costin, 2001; Costin and Hagstrum, 1995). Mechanical standardization is related to the appearance of specialized production based on the assumption that increased skills, routinization, and lower diversity of producers will lead to morphological uniformity (Arnold, 2000). In our case, relative changes in the potential number of producers may be inferred from changes in population size at Kiwulan. According to the Dutch census in 1648 (Nakamura, 1938, p. 12),

the population at Kiwulan was large but declined in the Chinese period due to the movement of Indigenous people to the south (Chen, 2007). This change in population corresponds to a decline in ceramic abundance at Kiwulan. Thus, we model CV values as a function of the mass of ceramics using Poisson GLM with a link function. The model suggests that ceramic abundance strongly predicts the CV values ($\beta = 0.06957$, $p = 0$). This indicates that the more standardized vessel shape of the Chinese period may be influenced by a small population, and thus smaller number of pottery producers, if ceramic abundance can be taken to reflect the population size.

However, intentional standardization due to considerations of function or style could also contribute to the shape standardization in our case. To explore this aspect of the relationship between shape standardization and craft specialization, we investigated the function and surface decoration of the vessels. We used geochemical methods to extract and identify lipids trapped in the fabric of potsherds to identify foods that may have contributed residues absorbed into the clay (cf. Kwak and Marwick, 2015). Unfortunately, we did not obtain useful results due to extremely low lipid yields, which were probably due to the very thin, dense, and low porosity fabric of Kiwulan pottery. These physical characteristics of the clay offer limited spaces to trap and protect organic molecules from microbiological degradation (cf. Evershed, 2008, p. 909). To analyse style, we defined surface impressed decorations, usually consisting of multiple bands of geometric motifs, as types of decorations. If two pots shared the same set of motifs but different arrangements of single bands, we considered them two different types. In general, the ceramics in the Chinese period have slightly fewer variations in decoration according to the ratio of distinct types to the total number of pottery from each phase (Chinese = 0.71, post-European = 0.81, pre-European = 0.78) (Wang and

Marwick, 2020). The limited evidence about function, and slight differences in style suggest that intentional standardization may have played only a minor role at Kiwulan, and further evidence is required to completely rule out this factor.

Additional insight into craft specialization at Kiwulan comes from the spatial pattern of ceramics, which provides information about potential production units and production areas (Costin, 2001). Figure 3.7 shows that the pottery samples have a widespread distribution with high densities of pottery at some units during the European presence. Hypothesis testing on spatial randomness indicates a non-randomly dispersed distribution before European contact and a more extreme dispersed distribution after European presence. In contrast, the distribution of pottery is more similar to random distributions during the Chinese period. This is interesting because it contradicts our expectation that a clustered pattern will be observed with an increase in pottery standardization caused by the emergence of specialized groups (Costin and Hagstrum, 1995). The absence of clusters in the Chinese period is notable because this was a time of a historically-documented decline of the Indigenous population (Chen, 2007; Hsieh, 2009). We might expect reduced numbers of potters to result in pottery production shrinking to a few locations in the settlement during this time. However, despite the small number of vessels during the Chinese contact period, Figure 3.7 shows that pottery is distributed randomly across the sampling area without any distinctive clusters during this time. As population across our three occupation phases declines, we see less clustered distributions of pottery, supporting an interpretation of intentional standardization rather than mechanical standardization. The spatial pattern shows that ceramics were mostly household-produced, and no specific facilities of production are evident (Chen, 2007).

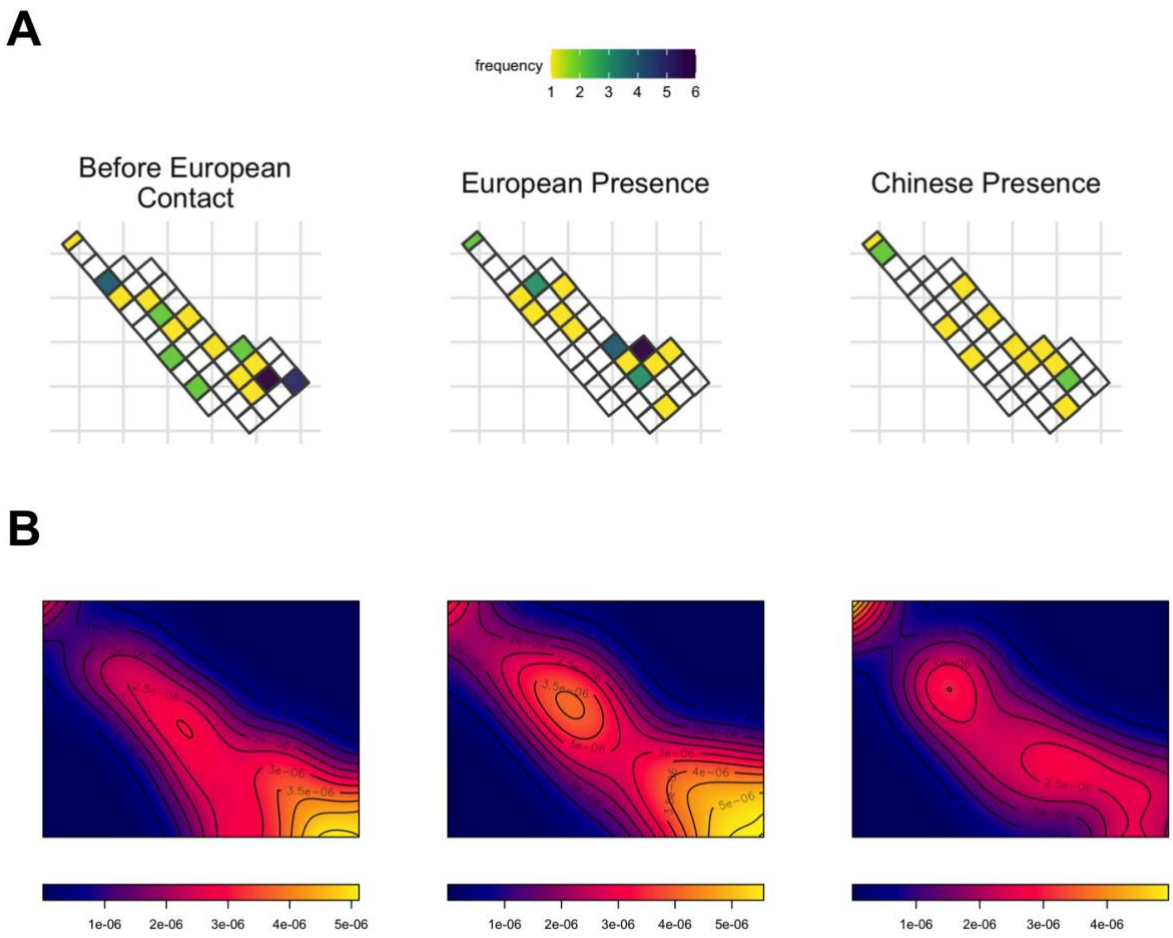
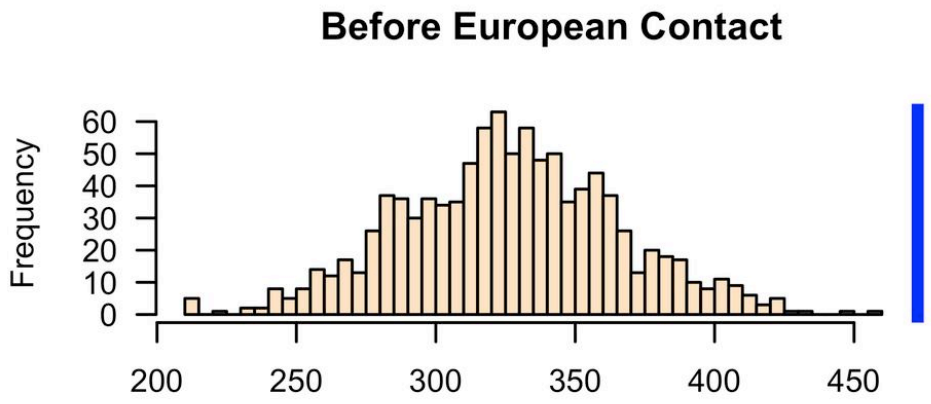
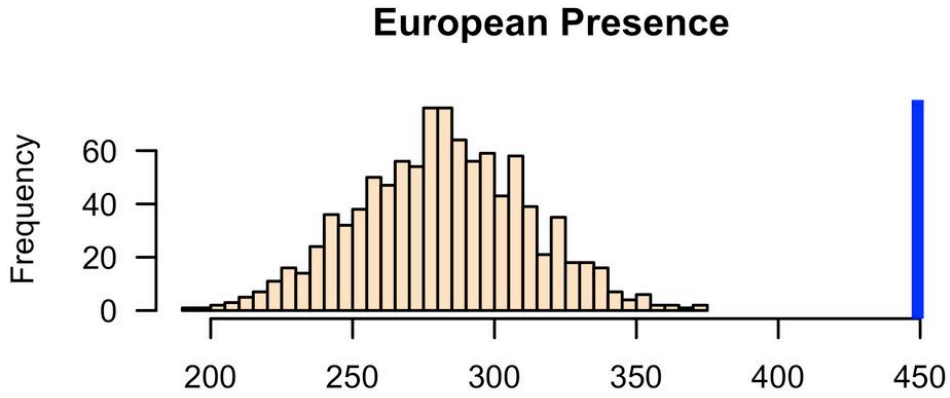


Figure 3.7: A: The spatial distribution of the pottery selected for shape analysis. The quantity is indicated by the color scale. B: Kernel density maps visulize the probability of the density of pottery across space. The maps show a major core area during the pre-European period, multiple core areas during the European period, and a single core during the Chinese period. The bandwidth is based on Silverman (1986)


Before European Contact
Frequency
60
50
40
30
20
10
0
200
250
300
350
400
450


European Presence
Frequency
60
40
20
0
200
250
300
350
400
450

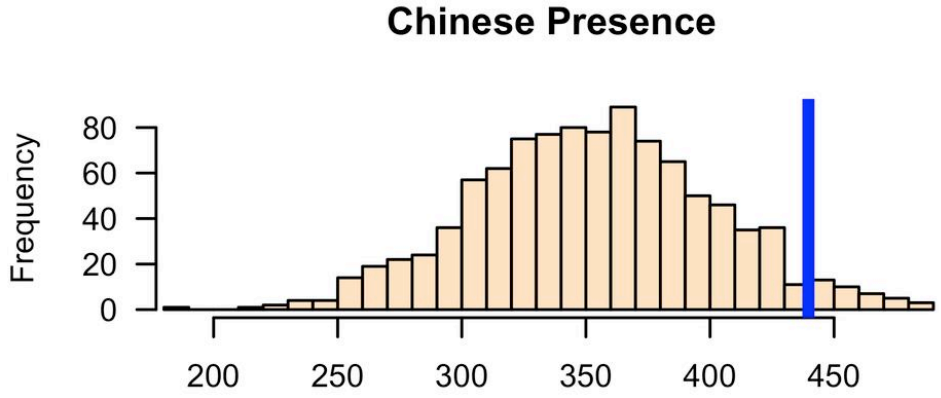

Chinese Presence
Frequency
80
60
40
20
0
200
250
300
350
400
450

Figure 3.8: Histograms of simulated average nearest-neighbour distances (ANN) values from 1000 simulations for three phases. X-axis values based on meteres represent ANN expected value. Each sample distribution presents the null hypothesis with the blue line indicating the observed ANN value

Our results offer tentative support for the hypothesis that foreign presence at Kiwulan influenced the shape of vessels made by the local Indigenous society. We find that vessel shapes were more standardized during the Chinese period than the European period. If increased shape standardization is a reliable indicator of craft specialization, then we may be seeing evidence of a shift from corporate (group-based, distributed, collective, cooperative) to network (individual-based, competitive) organization (Blanton et al., 1996; Feinman, 2010, 2000, 1995; Feinman et al., 2000). However, strong claims for an emergence of social inequality resulting from foreign contact at Kiwulan will need support from multiple and diverse sources of evidence that are beyond the scope of this paper.

Compared to other regions in Taiwan, European colonial influence was weak in Yilan due to isolation by the surrounding mountains, and the economic focus of the Spanish and Dutch who preferred northern and northwest Taiwan as their trading base (cf. Berrocal et al., 2020). Indigenous communities in Yilan experienced indirect influence from European trade networks and their colonial activities in a pericolonial context (cf. Acabado, 2017). In contrast to the Indigenous-European interactions at Kiwulan, interaction between Indigenous people and Chinese immigrants in the 19th century appears to have been more intense and direct. Historical records indicate that Chinese groups settled in Yilan and lived closely with Kiwulan Indigenous societies (Chen, 1963; Ke, 1993). This direct influence is reflected by the archaeological evidence of large amounts of Chinese porcelain and distinctive Chinese

architectural bricks and tiles (Hsieh, 2009). Similarly, burials at Kiwulan in this later phase show the adoption of coffins in mortuary practices, which Chiu (2004) interprets as the adoption of a symbol of ethnic Chinese.

The shape variation reported here is subtle and invites consideration of another possible scenario, namely that the absence of major changes in vessel shape at Kiwulan may have been an act to show ethnic identity when experiencing foreign influences (cf. Torrence and A. Clarke, 2000b). Ceramic morphology could be a signal for communication between potters, such that repeating the same shape or slight modifications may have occurred in a non-deterministic way (Kubler, 1962). As the only type of locally made pottery throughout 600 years, the homogeneous and even more standardized shape in the Chinese period might convey some meaningful information about community identity. We recognize the decline in population may lead to a standardized shape, however, the evidence of ceramic spatial distribution shows a dispersed or random pattern across the whole area throughout three phases. This indicates manufacturing activities may be limited to the household scale and reflect a common, shared practice in the community. The standardization in vessel shape over time draws our attention to the endurance of traditional pottery production practices amid intrusions from Europeans and Chinese. In a culture contact situation, we speculate that social identity might have be expressed through material practices as a means of expressing cultural homogeneity and distinction from other groups (Voss, 2005).

It is also important to recognize that social identity might be more complicated in a colonial context, and maybe representative of more than a colonized–colonizer or local/foreign dichotomy (Voss, 2008, 2005). For example, the Shamaoshan cemetery (BC 250 to 55 AD) in Southwest China suggests that the process of the incorporation of Southwest China into

the Han Empire involved a century of conflicts, resistance, and acceptance among social groups with different identities, especially in the historical context of Han immigrants (Wu et al., 2019). At the Oconee Valley (AD 1540 to 1670) in the Southeastern United States, Indigenous endurance and resilience are indicated by the long-term persistence of mound use lasting for 130 years after the initial contact with European colonizers (Holland-Lulewicz et al., 2020). A similar dynamic may have occurred at Kiwulan, with vessel shape indicating both acceptance of foreign influence through increased shape standardization, and resistance through the overall continuity in vessel shape. Vessel shape may be viewed as a symbolic expression of Indigenous identity and social boundaries because shape is a highly visible trait compared with other features of pottery (cf. Roux, 2015). Although there is an increase in number of imported ceramics through time at Kiwulan, production of the same type of local ceramics was continuous, and increasingly standardized. This might imply not only the utilitarian function, but an intentional and increased emphasis on the local ceramic tradition, their cultural custom, as a response to intensified foreign contact (cf. Acabado, 2017). However, additional lines of evidence are necessary from Kiwulan to confirm this speculation.

Conclusion

This study demonstrated the first use of EFA on ceramic shapes to explore the emergence of ceramic specialization as indicative of foreign influences. Here, EFA is combined with significance tests for the equality of CVs of shape variables to provide a robust method for assessing differences in shape standardization. The direct relationship between foreign influences and standardization of ceramic shape was tested on ceramics from Kiwulan, a

large Iron Age Indigenous settlement in northeastern Taiwan. Much lower variation in ceramic shape was identified during the period of Chinese presence. Our findings help to expand upon those factors that may lead to the standardization of ceramic production in a pericolonial interaction context. More homogeneous vessel shapes and sizes during the Chinese period, without any substantial changes in clay paste composition, production technique, and spatial distribution, suggest that shape standardization emerges from a combination of mechanical and intentional factors. Discrete groups of producers are not evident, favoring the role of intentional factors in this case. The distribution of ceramics in the Chinese period does not support clustered patterns of manufacturing locations, such as workshops. Instead, ceramic production is likely to have occurred in households. We speculate that the relatively homogeneous appearance of the vessels may suggest an expression of social identity or cultural boundaries in Indigenous societies through highly visible vessel qualities, such as shape. The symbolic value of these shapes may be heightened during periods of foreign contact in pericolonial contexts. Our analysis, with its openly available methods and data, is readily extensible to other pottery assemblages in the region to further explore related questions about craft specialization and standardization in ceramic assemblages. This study also broadens the GMM field by focusing on ceramic technologies, which may motivate more ceramic studies and become a promising branch parallel to current applications to lithic typology and bone morphology.

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Chapter 4

A Bayesian networks approach to infer social changes in burials in northeastern Taiwan during the European colonization period

Note: A shorter version of this chapter has been adapted for submission for publication to the *Journal of Archaeological Science* in March 2021 and is under peer review at the time of writing (March 2021). An open access pre-print is online at https://osf.io/preprints/socarxiv/3vfea. The research compendium containing data and R code for reproducing the published results is at http://doi.org/10.17605/OSF.IO/XGA6N. Supplementary materials discussed in this chapter can be found in appendix B.

Abstract

Burials provide valuable information to study social structures based on the assumption that burials and associated grave goods can represent social roles and relations in a society. To study social relationships, network analysis has been increasingly applied to archaeological data to infer interactions and relationships between entities. Statistical approaches to network analysis, such as exponential random graph models (ERGMs), provide a way to test hypotheses about dynamic processes of network formation. However, computational

difficulties and sensitivity to uncertainties limit the application of ERGMs. In this paper, we introduce a Bayesian framework on ERGMs that enables an efficient computational process, effective quantification of uncertainty, and robust model evaluation of network properties. We tested a hypothesis of social change relative to the arrival of Europeans by studying burial data from Kiwulan, an Iron Age site in northeastern Taiwan. The results indicate a transition among the burials from network ties based on ritual objects to wealth objects, and a more centralized structure with increased social differentiation after the European presence was established in the 17th century. Our case study demonstrates the effectiveness of Bayesian network analysis for archaeological data, and expands the use of burials in understanding the impacts of colonial presence on Indigenous groups in a pericolonial context.

Introduction

Network analysis has been increasingly used by archaeologists to understand past relationships, interactions, and structures of observed phenomena by visualizing and analyzing relational data (Brandes et al., 2013; Mills, 2017; Peeples, 2019). Recent developments in modeling approaches enable hypothesis testing for the intercorrelations between individual elements and overall structures in networks (Brughmans, 2013; Brughmans and Peeples, 2018; Freeman, 2004; Salvini, 2010). By comparing hypothesized networks with the observed network, statistical network modeling can answer anthropological questions related to exchange (Crabtree, 2015; Gjesfjeld and Phillips, 2013), diffusion (Östborn and Gerding, 2015), or social transformation (Mills et al., 2013) in a statistical way. Among network modeling methods, exponential random graph models

(ERGMs) are stochastic models for investigating the process of network formation through dependence assumptions for relationships and simulations for network patterns (Ghafouri and Khasteh, 2020; Handcock et al., 2008; Harris, 2013). ERGMs are promising for evaluating the dynamic social processes behind observed archaeological networks (Brughmans et al., 2014). However, computational difficulties, sensitivities to uncertainties, and ambiguities in interpretation limit the practical applications of ERGMs (Caimo and Friel, 2014).

In this paper, we go beyond ERGMs with a novel Bayesian approach that alleviates the computational issues and other limitations of ERGMs to enable clearer and more robust interpretations of the processes of network formation. Using burial data from an Iron Age site in northeastern Taiwan as a case study, we explore social changes by investigating the formation of material connections between burials. Social changes in Indigenous societies, when faced with colonial powers, are commonly observed in many parts of the world, especially European colonies where Indigenous economic, cultural, or socio-political aspects were substantially impacted (Dietler, 2005; Silliman, 2005; Voss, 2005). Recent studies demonstrate that the indirect effects of colonialism, or involvement in long-distance trade, may also have impacted Indigenous societies, this is known as a pericolonial context (Acabado, 2017; Trabert, 2017; Wang and Marwick, 2020). Burials are important for understanding past societies because material culture and biological records of burial behaviors can represent the social ranking of the deceased, and social relations between them (Binford, 1971; Drennan et al., 2010; Saxe, 1970). Burial treatments can further indicate social complexity or inequality where foreign goods from long-distance trade were used by Indigenous people to express status (Carter, 2015; Dolfini, 2019).

Burial studies are usually based on characterizing each physical trace or burial variable, such as biological records, grave forms and goods, or ritual behaviors, and finally combining and comparing those individual observations to infer the organization of past societies (Byrd and Monahan, 1995; Seikel, 2011). Here we treat burials as a complex network based on the assumption that a network is a patterned aggregation that includes individual elements (i.e. individual burials), pair-wise relationships (the dyads, for example burials with similar types and amounts of grave goods), and an overall structure showing social patterns represented in the data (Brandes et al., 2013). Our case study illustrates how a Bayesian approach to network modeling provides new insights into the formation of archaeological networks and allows testing of anthropological models to better understand dynamic social processes.

Review of network analysis and archaeological applications

Drawing largely on network science and graph theory, a key assumption in the construction of archaeological networks is that a phenomenon can be conceptualized as a network through abstraction and representation (Brandes et al., 2013; Collar et al., 2015; Mills, 2017; Peeples, 2019). A social network is generally visualized as a graph consisting of a set of socially-relevant nodes/actors, connected by edges/ties representing one or more relations, such as friendship, collaborations, information flow, trade ties, or any other forms of connection of interest (Marin and Wellman, 2011; Wasserman et al., 1994). The ties can be classified into four major types, including similarities, social relations, interactions, and flows (Borgatti et al., 2009). In archaeology, actors can be people, groups, objects, places, or events, with ties built on similarity, proximity, or co-presence of material culture to create

patterns reflecting influence, geographical distance, or affiliations in social groups (Brughmans and Peeples, 2018; Mills, 2017; Peeples, 2019). For example, past trade can be conceptualized as a network of individual entities connected by shared similar objects or elements, such as the flow of goods, to represent their interactions (Collar et al., 2015, p. 4). This concept can be applied to burial contexts where each burial is an actor linked by similar elements, such as burial goods. Burial goods, especially high value goods, can reflect social practices in broader cultural contexts to represent personal wealth or social status from which we can infer social differentiation or complexity (Gamble and Zepeda, 2002; Janes, 2013). This enables the exploration of the structure of the past social organization through the identification of the relationships among burials.

Network analysis has been increasingly applied by archaeologists in recent years to deal with past interactions and explore the underlying mechanisms. There are two common approaches to characterize network properties at two distinct scales: node/edge level and graph level (Peeples, 2019). Node level focuses on node properties in a network, such as centrality, representing the individual influence or social prominence in a group, while graph level assesses the whole network attributes, such as density, clustering in a network, to generalize relationship patterns (Mills, 2017; Peeples, 2019). By quantifying those network properties, archaeologists can answer a wide range of research questions.

Examples include exploring the political centralization in the Kofun period in Japan through the hierarchical communication network constructed by prestige goods (Mizoguchi, 2013), and the investigation of long term inter-site relationships from the Epipalaeolithic to the early Neolithic in the Near East according to trade items (Coward, 2013). Regarding burials, Sosna et al. (2013) examined spatial patterns of burials from the Early Bronze Age in

Rebesovice with two hypothesized networks constructed according to cultural and chronological similarity between burials. Recently, complex network modeling has been used to evaluate networks at both node and graph level through simulations of particular processes and statistically tests of the formation of network properties (Brughmans, 2013; Brughmans and Peeples, 2018; Freeman, 2004; Salvini, 2010). Such applications include simulations and testing of food exchange modes for Ancestral Pueblos on the aggregation of households in the American Southwest (Crabtree, 2015), and exploring the diffusion of fired bricks across Hellenistic Europe by comparing similarity networks of sites with random networks (Östborn and Gerding, 2015). Another example is the assessment of hunter-gatherer exchange networks structure across the Kuril Islands using bootstrap simulation based on ceramic composition (Gjesfjeld, 2015).

Current approaches to network analysis used by archaeologists are mostly restricted to a single rational structure without consideration of interaction between network variables. Our use of Bayesian inference on ERGMs is the first application to archaeological data that can bring new insights to understand past social structures by characterizing network properties as a whole. ERGMs are an important family of statistical models for networks that allows direct modeling for the formation of edges, or ties, between nodes (Robins et al., 2007). The assumption is that possible ties in a network are random variables and dependent on actor variables or the presence or absence of other ties (Robins et al., 2007). In other words, networks in ERGMs are viewed as dependent variables, where network dependencies and the attributes of nodes/edges can influence the formation of a tie (Snijders, 2011). For example, nodes with similar attributes are more likely to have a relationship, such as friendship between people with the same hobby. Ties form a small structure in a network

called a graph configuration, that describes the form of dependence, such as reciprocity (relationship between two actors), transitivity or clustering (relationship between two actors through a shared third actor), homophily (relationship between actors with a similar attribute), and popularity (actors have many relationships with others) (Morris et al., 2008; Robins et al., 2007; Snijders et al., 2006). Those configurations represent the structure or the property of a network and can be expressed by network statistics.

By modeling those network statistics as direct functions of ties by specifying the forms of configurations, we can generate a distribution of random networks that represent our hypothesis-based model (Morris et al., 2008; Robins et al., 2007). Such a distribution consists of a large number of possible networks that enables statistical inference and comparison with an observed network (Robins et al., 2007). ERGMs helps us understand whether an observed network shows significantly more or less of a property of interest than the random networks generated from our model assumptions.

Exponential random graph models in a Bayesian framework

Exponential random graph models (ERGMs) first appeared in archaeology with Brughmans et al. (2014), who studied Iron age settlement patterns in Southern Spain by modeling inter-settlement visibility networks and visual control at 159 sites. By fitting models with the observed network of archaeological data, they proposed that ERGMs are a promising approach for exploration and hypothesis testing of social processes. Similarly, Amati et al. (2019) modeled three networks consisting of 15 sites (AD 100 to 400) in the Caribbean to explore interaction mechanisms, including proximity, inter-cultural items, and pottery types. By comparing hypothesized networks with the observed sites, they found that the presence

of hub sites can be efficiently explained by multiple interdependent mechanisms instead of only one variable exclusively.

However, those studies also illustrate some limitations of ERGMs, such as sensitivity to missing data and limited ability to incorporate and represent uncertainty. Also, it is difficult in ERGMs to estimate model parameters and interpret the results due to intractable likelihood normalizing constants and model degeneracy (Caimo and Friel, 2014; Jin et al., 2013). A normalizing constant is a function of the model parameter for making probability distributions integrate to one, which becomes harder to compute with a larger set of networks (Caimo and Gollini, 2017). This is also termed "doubly intractable" since both the likelihood normalizing constant and the marginal likelihood (the evidence of the posterior) are hard to derive (Caimo and Friel, 2013; Lyne et al., 2015). Model degeneracy is another issue where probability models tend to overestimate a small number of extreme graphs by assigning too much weight, e.g., in extreme cases such as empty (all nodes unconnected) or complete graphs (all nodes connected) (Caimo and Friel, 2014; Schweinberger, 2011). One solution to these limitations is to implement ERGMs in a Bayesian framework.

Bayesian approaches to ERGMs are effective tools for network modeling by incorporating prior information about the network configurations (details in Supplementary Online Materials) to better understand dependencies of network variables and overcome computational issues of ERGMs (Caimo et al., 2017; Lehmann et al., 2020). Prior information is derived from previous data or assumptions derived from the context of our data. An important advantage that Bayesian modeling has over traditional ERGMs is the application of Markov chain Monte Carlo (MCMC) simulation using the approximate exchange algorithm (Caimo and Friel, 2011). With the exchange algorithm, Bayesian

ERGMs avoid doubly-intractable computations by directly sampling from the not normalized part of the posterior, which alleviates the computational problems and gives better convergence results. This enables us to deal with complicated dependence patterns with ease, providing better estimations for complex social network models with heterogeneous data (Caimo et al., 2017; Snijders et al., 2006). By fitting an ERGM with the approximate exchange algorithm, a Bayesian approach generates posterior probabilities that incorporate our sample data and prior information to estimate the effect of each ERGM parameter in our models (Caimo and Lomi, 2015; Nemmers et al., 2019). This allows robust and interpretable uncertainty quantification by examining the posterior mean and 95% credible intervals (Caimo and Gollini, 2017). In addition, Bayesian approaches are useful to deal with missing data, which is often a problem leading to misinterpretation of networks, especially for archaeological studies. Koskinen et al. (2010) shows that the effect of missing data can be reduced with Bayesian modeling that can accurately predict, on average, 80% of the ties when a third of data is missing.

Background

A Case Study from Northeastern Taiwan

We use a Bayesian ERGM to study social changes in a pericolonial context at Kiwulan, an Iron Age site in northeastern Taiwan (Figure 4.1), which was occupied from the 14th to 19th centuries. This occupation period includes the time before the European arrival, the presence of the Spanish and the Dutch in the 17th century, and finally a large wave of Han Chinese in the 19th century (Chen, 2007). Our anthropological model proposes that the influence of a

colonial power, combined with high local values attached to imported goods, led to increased social inequality due to competition among individuals (Brumfiel, 1994; Clark and Blake, 1994). Increased social inequality associated with the use of foreign prestige goods is recognized as a 'network' strategy for gaining power (Blanton et al., 1996; Feinman, 2000). Network-based societies are identified in some places in Asia with involvement in long-distance trade (Carter, 2015; Liu and Chen, 2006; Ueda et al., 2016). The observed uneven distribution of burial goods at Kiwulan may be explained as a result of unequal access to trade goods when Indigenous societies became more involved in the complex trade network stimulated by Europeans.

The features of network-based societies include the accumulation of prestige goods, wealth differentiation, and trade monopolization through individual networks (Blanton et al., 1996; Feinman, 2000). These may be contrasted with corporate-based societies that stress communal ritual elements, shared power, and where wealth differentiation, if any, would be associated with corporate groups, such as age groups, rather than individuals (Siegel, 1999). Using the theoretical framework of corporate-network strategies, we test a hypothesis that changes from a corporate mode (a structure showing more subgroups with less wealth differentiation) to a network mode (a centralized structure with more wealth differentiation) can be observed in the Kiwulan burial network after European arrival. We ask: (1) did European colonial activities result in increased social inequality in Indigenous society in ways that can be detected by analysis of burial networks? and if so, (2) what are the major variables affecting or forming unequal social positions that might hint at social heterogeneity? By answering these questions, this case study helps to expand our understanding of European colonial effects on Indigenous groups in a pericolonial context.

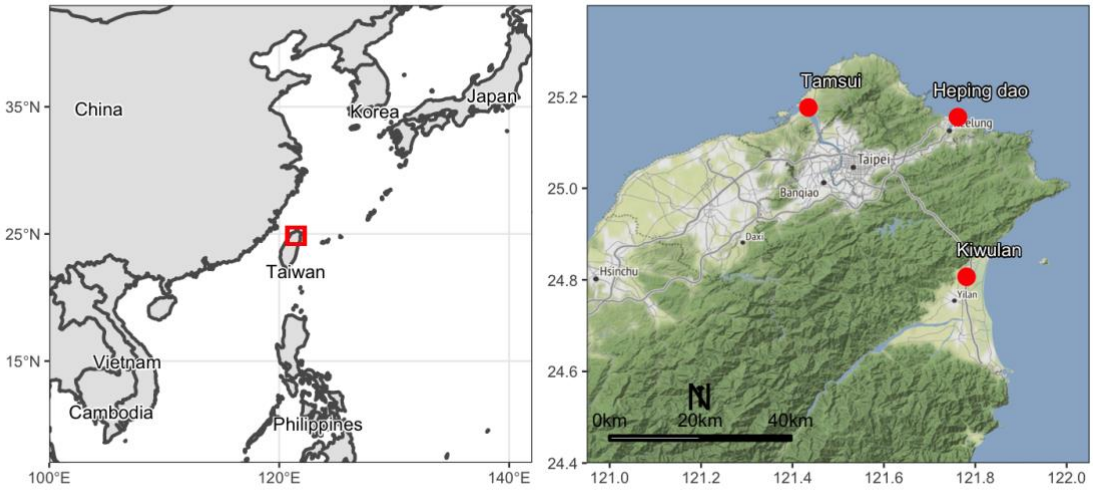


Figure 4.1: The location of Kiwulan and the European forts at Heping dao and Tamsui in northern Taiwan (modified from Wang and Marwick, 2020). Map data from naturalearthdata.com.

Materials

We analyzed burial data collected from the excavation reports, and the original fieldwork notes for the upper component of Kiwulan (1350-1850 AD) (Chen, 2007). A total of 90 burials were unearthed from adjacent excavation squares that provide continuous stratigraphic sections suitable for temporal comparison (Figure 4.2). The preservation of human remains at Kiwulan was generally poor, so we have incomplete age and sex data (details in Supplementary Online Materials) and lack health status data. Burials are oriented in an east-west direction on the north side of the residential area, which is indicated by post-holes and *in-situ* wooden posts, suggesting a well-organized spatial arrangement of houses. Previous studies report an uneven distribution of prestige goods across burials without agreement about whether this uneven distribution hints at vertical social differences. For

example, Cheng (2008) interpreted the unequal distribution of glass beads, especially the gold-foil beads between burials, as evidence for hierarchy, indicating a stratified society. However, Hsieh (2012) suggested a relatively egalitarian structure based on a comparative analysis of the frequencies of all burial goods. She found that the burials with rare prestige goods were usually associated with elders, which might indicate achieved, rather than inherited, status. One important limitation of these previous studies is that they did not use analytical units suitable for comparing behaviors before and after European arrival. Here, we adopt a new chronological framework for the burials to test if network configurations differ from the pre-European period (before European colonization) to the post-European period (during and after European colonization until arrival of Han Chinese immigrants).

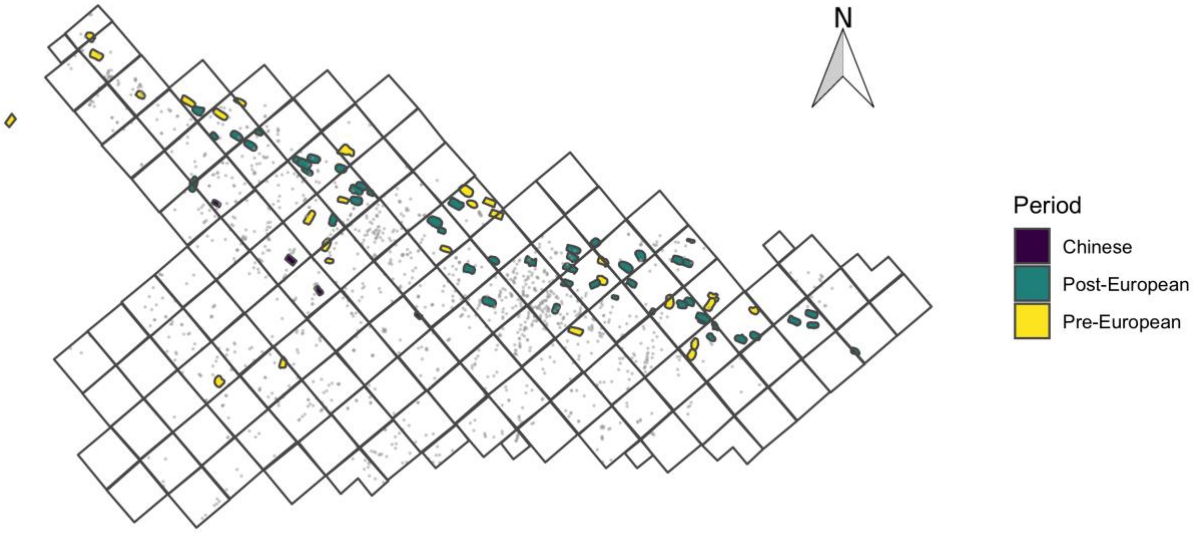


Figure 4.2: Map illustrating the location of burials by periods at the central excavation area of Kiwulan (each square is 4 X 4 meters). The gray dots are post holes.

To compare burial networks, we assigned burials to the pre-European period (n = 29), European and post-European period (n = 49). Our assignments are based on an established fine-grained chronology that was reexamined and cross-validated by diagnostic materials, stratigraphic data, depth, and radiocarbon ages (for more details see Wang and Marwick, 2020). We excluded burials from the Chinese phase (n = 4) due to the smaller sample size. We also excluded 8 burials that were heavily disturbed by modern construction which prevented accurate determination of their chronology.

Based on the assumption that social status and associated relations can be represented by sharing similar prestige goods (cf. Coward, 2013, p. 252), we built networks where burials (nodes in the network) that are linked when they have the same prestige goods in common. The prestige goods we identified include gold-foil beads, carnelian beads, glass beads, Chinese porcelains, stonewares, gold foils, and fish-shaped ornaments. These items are considered as high-value across different archaeological contexts throughout Taiwan based on their rarity and descriptions in historical records (Cheng, 2008; Hsieh, 2012, 2009; Wang, 2011). European historical accounts mentioned that those items were treated as prestige goods in Indigenous culture (Borao, 2009; Li and Wu, 2006). For example, a Spanish priest described a Spanish soldier exchanging carnelian beads for natural resources with local Indigenous people, because of the beads' high value in Indigenous culture (Li and Wu, 2006). In addition, Spanish visitors observed that Indigenous people possessing more imported goods were recognized as having higher status in their community (Li and Wu, 2006).

Methods

Hypothesis and construction of networks

Our social change hypothesis is that differential access to foreign prestige goods after the European presence led to increased social inequality at Kiwulan, where the social structure changed from a more corporate strategy to a more network strategy (Blanton et al., 1996; Drennan et al., 2010; Feinman, 2000). This would be reflected by the pattern of intercorrelations of foreign prestige goods in burial networks. If social inequality gradually increased as we hypothesize, then we expect to observe a network structure with higher centralization (or popularity) and less transitivity (or clustering), along with network ties determined by wealth, indicative of a network-based society. In contrast, we predict the network before European arrival will show low centralization and high transitivity, and network ties associated with ritual elements, indicative of a corporate-based society. To test this hypothesis, we use Bayesian ERGMs to model the formation of network ties and the underlying mechanisms that shaped relationships between people at Kiwulan. By comparing networks from the pre-European period and the post-European period we can examine the effects of foreign contact on community relationships at Kiwulan.

Trade beads are commonly found across burials with substantial differences in quantities, so we described each burial as having one of four levels, high, upper-middle, lower-middle, and low, according to their distributions across all burials (Figure 4.3). Gold-foil beads are in levels of high (>3), upper-middle (3), lower-middle (2), and low (1); carnelian beads are in levels of high (>6), upper-middle (4-6), lower-middle (3), and low (1-2); glass beads are in levels of high (>6), upper-middle (3-6), lower-middle (2), and low (1). If burial 1 and

burial 2 both have high quantities of agate beads, then there will be a tie connecting them. For less frequent prestige goods, including imported ceramics, gold foils, and fish-shaped ornaments, we linked two burials when they both possess each type of goods (i.e. presence or absence).

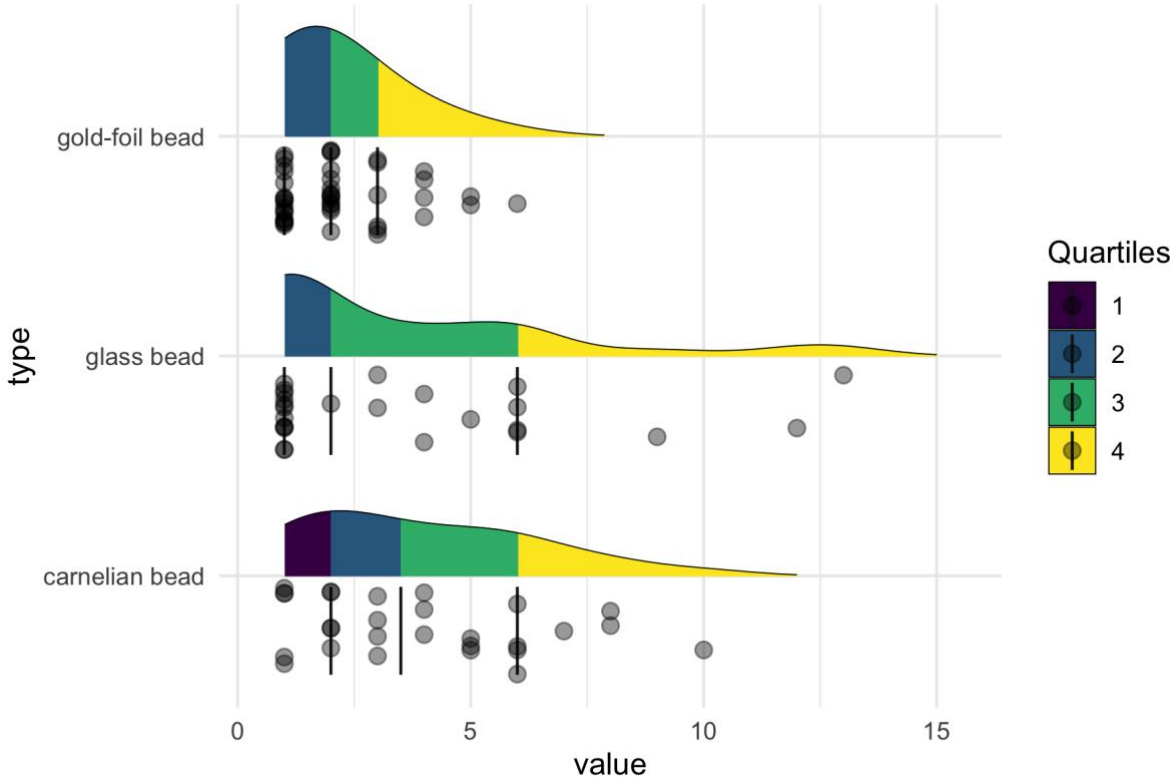


Figure 4.3: The distributions of different types of trade beads across burials analyzed in this paper.

Node attributes here include osteological data, such as age and sex, and cultural data, such as ritual pottery, and a burial value index. We have three groups for the age attribute, 0-12, 12-20, and above 20; two groups for the sex attribute, male and female; and four groups for

the burial value that are specified in the main paper document. Table 1 shows the number of burials, of which sex and age can be determined. Ritual pottery was identified as locally-made ceramics placed above an individual. These pots mostly have sooty vessel exteriors and charred residues on interiors that are interpreted as vessels used for funeral feasting (Hsieh, 2009). We calculated our burial value by summing values of all types of prestige goods in each burial context. For example, for gold-foil beads, we take the total number of burials (90) and divide by number of burials with gold-foil beads (46), to give a value of 90/46 = 1.96. We repeat this for each type of prestige item. For each burial we sum these values of each type of prestige item to get a burial value (Jorgensen, 1991).

age	pre-European			post-European		
	male	female	unknown	male	female	unknown
0-12	0	0	1	0	0	9
12-20	0	0	1	0	0	1
+20	4	7	4	8	6	7
unknown	2	2	8	0	4	14

Table 4.1: The number of burials with identification of age and sex at Kiwulan. The unknown means no sufficient skeletal remains for determination of age or sex

We then assigned the burials into three ranks according to breaks in the distribution of burial values, high (>24.7, top 10 percent), above average (16-24.7), and below average (<16), as

an index of wealth (details in Supplementary Online Materials). Since burials tend to have multiple prestige goods in common, the network ties are weighted instead of binary (the value 1 represents a tie and the value 0 otherwise) (Snijders, 2011). For example, if two burials have both low quantity of glass beads and porcelain in common, the tie is given a value of 2. Our networks are non-directed, which means a mutual relationship where the tie between any two actors is bidirectional. The networks constructed based on these principles show that the network after the European presence has more node connectivity in general with some nodes having a larger number of connections (Figure 4.4).

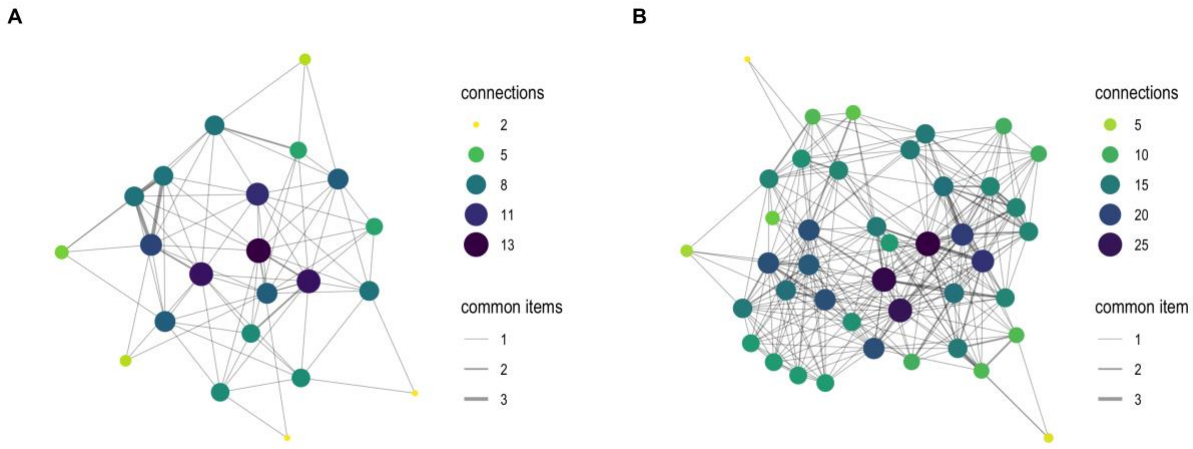


Figure 4.4: A: Burial network before the European arrival, B: Burial network after the European arrival. The size of each node is proportional to node degrees or the number of connections to a node. The thickness of ties represents the number of goods in common between two nodes.

Model specification in a Bayesian framework

We quantify the relations among burials and test our hypothesis of social change using the R programming language (R Core Team, 2019) with the bergm package (Caimo and Friel, 2014). Table 2 lists the network parameters we used for dependence assumptions that define our models (Morris et al., 2008). Every parameter in an ERGM has an associated algorithm for computing the probability of observing relations between two burials. Based on our hypothesis, we model a network with increased social inequality to be represented by endogenous network effects: low transitivity and high centralization. We include burial-specific attributes as covariate effects for homophily, such as age, sex, ritual activity, and the degree of wealth, to explore the importance of these variables in tie forming. For example, if age-homophily is important here, then people of the same age should have the same burial goods. We also include the physical distance between burials as an indicator of a kinship-based relations since the deceased from the same family were buried nearby (Li and Wu, 2006). Our model may reveal the emergence of social inequality via the presence of a few individuals as network centers, having more relations with others, with more wealth differentiation after the European arrival.

Network variable	Configuration (ERGM term)	Archaeological Interpretation
Density/inter-relation	Edges (edges)	constituent element of the network
Age-homophily	Uniform homophily (nodematch)	burials in the same age tend to have similar goods
Sex-homophily	Uniform homophily (nodematch)	burials in the same sex tend to have similar goods

Ritual-homophily	Uniform homophily (nodematch)	burials having ritual practice tend to have similar goods
Wealth-homophily	Uniform homophily (nodematch)	burials in the same wealth rank tend to have similar goods
Transitivity/clustering	Geometrically weighted edgewise shared partner (gwesp)	burials being connected with a third burial
Centralization/popularity	Geometrically weighted degree distribution (gwdegree)	burials being connected with multiple partners
Physical distance	Dyadic covariate (dyadcov)	burials close to each other tend to have similar goods

Table 4.2: Network parameters in ERGMs used for model specifications with associated archaeological interpretation for burial relations. ERGM terminology is from the R package statnet (Handcock, 2008; Morris, 2008)

Choice of prior values to evaluate our anthropological model

Normal distributions for the priors are typical in network analysis studies that assume networks to have low density and high transitivity, as are commonly found in the real world (Caimo et al., 2017). Thus, we specified the prior of the edge density parameter to low for both network models, following a normal distribution with mean at -3, and standard deviations at 3 (i.e (N(-3, 3))). For covariates about biological features, such as age, sex, we specified a vague prior (N(0, 5)) for both models to explore their effects. For physical

distance between burials, we also set a vague prior (N(0, 1)) to explore whether there is kinship-based proximity, e.g. stronger correlations for shorter distances. To evaluate our anthropological model of increased social inequality over time based on assumptions of corporate-network strategies (Drennan et al., 2010; Feinman, 2000), we incorporated different prior information for the network variables that are meaningful for social inequality, especially for transitivity and centralization. We set the priors to higher transitivity (N(2, 2)), lower centralization (N(-2, 3)), and higher covariate effect of ritual activity (N(1, 5)) for the network before European contact to indicate less social differentiation and emphasize the ritual element shared in corporate groups. Conversely, we set the priors for the network after European arrival to lower transitivity (N(1, 3)), higher centralization (N(2, 3)), and a higher covariate effect for burial values (N(2, 3)) to model an increased social differentiation after European contact.

Modeling fitting

After we set our model parameters, we simulated networks in a Bayesian framework using a Markov chain Monte Carlo (MCMC) algorithm. MCMC algorithms allow estimation of posterior distributions through direct random sampling the posterior without assuming the prior comes from any specific distribution (Hamra et al., 2013). We can obtain a posterior distribution by constructing a Markov chain that describes a sequence of moves from current state to the next state following probabilistic rules based on the approximate exchange algorithm (Caimo and Friel, 2011). This enables a random or stochastic simulation in a long run where each move does not depend on the previous move. More chains ensures a more desirable posterior distribution that is close to the target distribution under study, or convergence. In Bayesian ERGMs, MCMC first selects a set of edges (or a set of empty

pairs of actors) with equal probability, and then switches to a pair of actors at random within the chosen set (Caimo and Friel, 2011). In our case, we set the number of chains to six. For each chain, the number of burn-in iterations was 100 and the number of iterations after the burn-in was 1000. We set the number of iterations used to simulate a network y' at each iteration to 4000.

Reproducibility and open source materials

The entire R code (R Core Team, 2019) used for all the analysis and visualizations contained in this paper is included in the Supplementary Online Materials at http://doi.org/10.17605/OSF.IO/XGA6N to enable re-use of materials and improve reproducibility and transparency (Marwick, 2017). Also in this version-controlled compendium (Marwick et al., 2018) are the raw data for all the visualizations and tests reported here and additional details of definition of our approach to tie formation, model fitting, assessment of MCMC output and goodness-of-fit diagnostics for our models. All of the figures, tables, and statistical test results presented here can be independently reproduced with the code and data in this repository. The code is released under the MIT license, the data as CC-0, and figures as CC-BY, to enable maximum re-use.

Results

We examine the estimates from the posterior distributions to compare their differences in structure of the simulated networks (Table 4.3; Figure 4.5). For nodal covariates in the pre-European model, the ritual element represented by pots (ritual-homophily) has a significant

effect on the formation of relations between burials, while the wealth rank represented by burial values (wealth-homophily) has a negative effect but not significant since its confidence intervals include zero. This demonstrates that burials with ritual pottery tend to form relations, but burials in the same wealth level tend not to. Despite positive mean for some covariates, such as age (age-homophily) and sex (sex-homophily), they do not show a significant tendency. Similarly, the dyadic covariate, physical distance, shows no significant effect, indicating that physical proximity between burials does not reflect similarity in burial treatment. For the endogenous network effects, transitivity presents a significant positive effect, while centralization demonstrates a negative effect. The high positive value for transitivity suggests a tendency of burials with similar burial goods to be clustered as connected communities, indicative of the presence of multiple corporate groups sharing burial goods in common. In contrast, the strong negative centralization shows there is a tendency toward decentralization that reflects most burials having a similar number of ties without any prominent burials. This might imply that individuals have equal access to trade goods in terms of the flow of goods.

parameter	pre-European				post-European			
	mean	median	2.5%	97.5%	mean	median	2.5%	97.5%
density	-24.63	-24.65	-25.64	-23.35	-14.60	-14.59	-15.06	-14.16
age-homophily	0.34	0.36	-0.23	0.89	0.14	0.15	-0.22	0.48
sex-homophily	0.27	0.30	-0.41	0.81	-0.12	-0.12	-0.45	0.19
ritual-homophily	1.87	1.90	0.63	2.68	-0.01	-0.01	-0.41	0.35

parameter	pre-European				post-European			
	mean	median	2.5%	97.5%	mean	median	2.5%	97.5%
wealth-homophily	-0.06	-0.06	-0.57	0.44	0.54	0.55	0.06	0.93
transitivity	13.81	13.87	12.94	14.47	3.63	3.63	3.45	3.81
centralization	-17.75	-17.89	-18.69	-16.15	4.95	4.94	4.43	5.48
physical distance	0.03	0.03	-0.01	0.07	0.01	0.01	-0.01	0.02

Table 4.3: Estimated posterior means, medians, and 95% confidence intervals for each network parameter of two models. Confidence intervals that do not include zero indicate significant effects of parameters (Caimo, 2017). Posterior means are generally close to posterior medians.

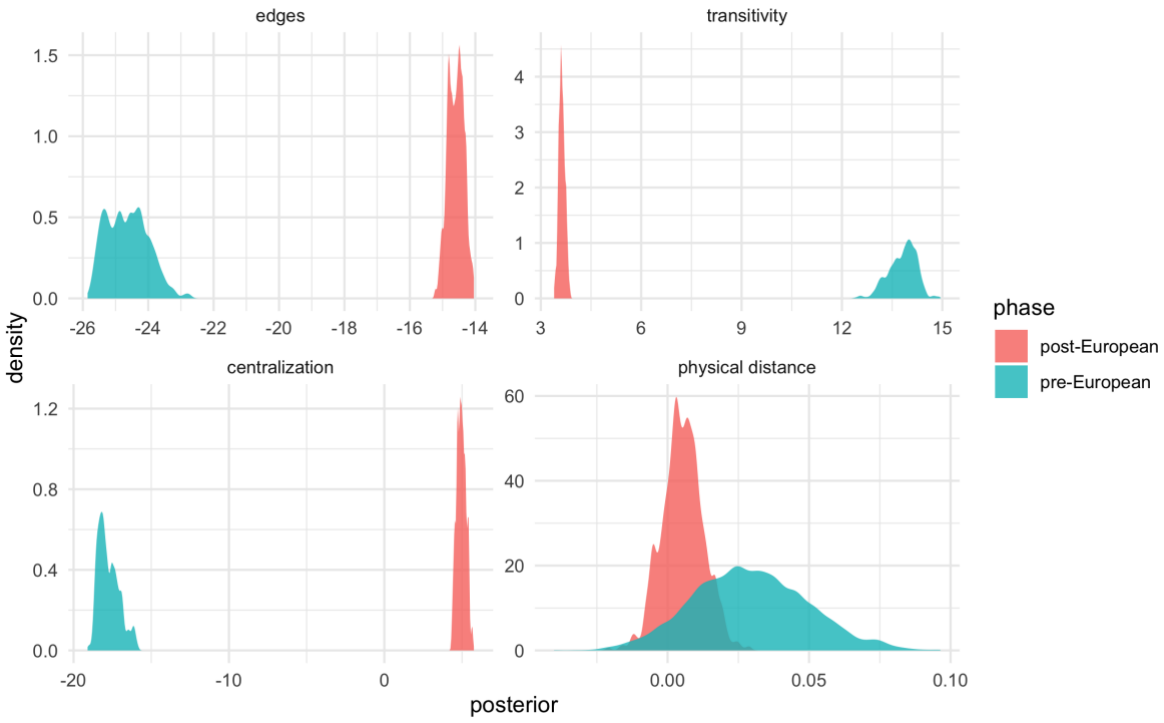


Figure 4.5: Posterior density estimates for the parameters associated with edges, transitivity, centralization, and physical distance by phases. The pre-European group presents remarkably larger values for the transitivity, but lower values for the edges and centralization parameters compared to the post-European group. The distance parameters overlap between two groups. Both posterior estimates present generally symmetric distributions.

For the post-European network model, the nodal covariate of wealth rank shows significant positive effects. This indicates the burials in the same wealth level tend to have relations. Despite negative effects for the ritual and sex variables, they are not significant. Also, there are no significant effects for the variables of age and physical distance. Similar to the pre-European network, transitivity demonstrates a significant positive effect, but much weaker than the effect of the pre-European network. In contrast, centralization has a significantly higher positive effect than the effect of the pre-European network. This means there is a tendency toward centralization, reflecting a limited number of burials having many more ties than others. This implies that the presence of better access to trade goods and the behavior of wealth accumulation and display in burial events. In general, the post-European network model has a smaller transitivity effect and a positive centralization effect than the pre-European network model. This may suggest a reduced tendency toward clustering but high tendency toward centralization after the European presence.

One key difference between the pre-European and post-European networks is their size, with 29 burials compared to 49 burials. To understand the robustness of comparison between two

networks, we used a vertex bootstrap technique to cross-validate the results of our Bayesian ERGMs. The vertex bootstrap is a non-parametric method that conducts resampling for all vertices (i.e. node) to quantify standard errors and estimate sampling variability in the network statistics of interest (Chen et al., 2019; Roberts et al., 2021; Snijders and Borgatti, 1999). This enables the evaluation of uncertainty for networks and tests the difference between multiple networks of different sizes by examining their confidence intervals for the network population. We used the vertex bootstrap to compute endogenous network statistics, including density, centralization, and transitivity for our two networks. We explored the sample size effect by removing nodes at certain percentages (5-40%) for both networks and comparing their confidence intervals. The results demonstrate a consistent difference between the two networks up to 30% node removals (Figure 4.6). This indicates that the network variables under investigation are robust to the different network size of our sample. Figure 4.6 also shows consistency with our earlier finding of negative centralization in the pre-European period and positive centralization in the post-European period, over several conditions of node removal. Similarly consistent with our earlier result, the vertex bootstrap shows no significant difference on density and transitivity.

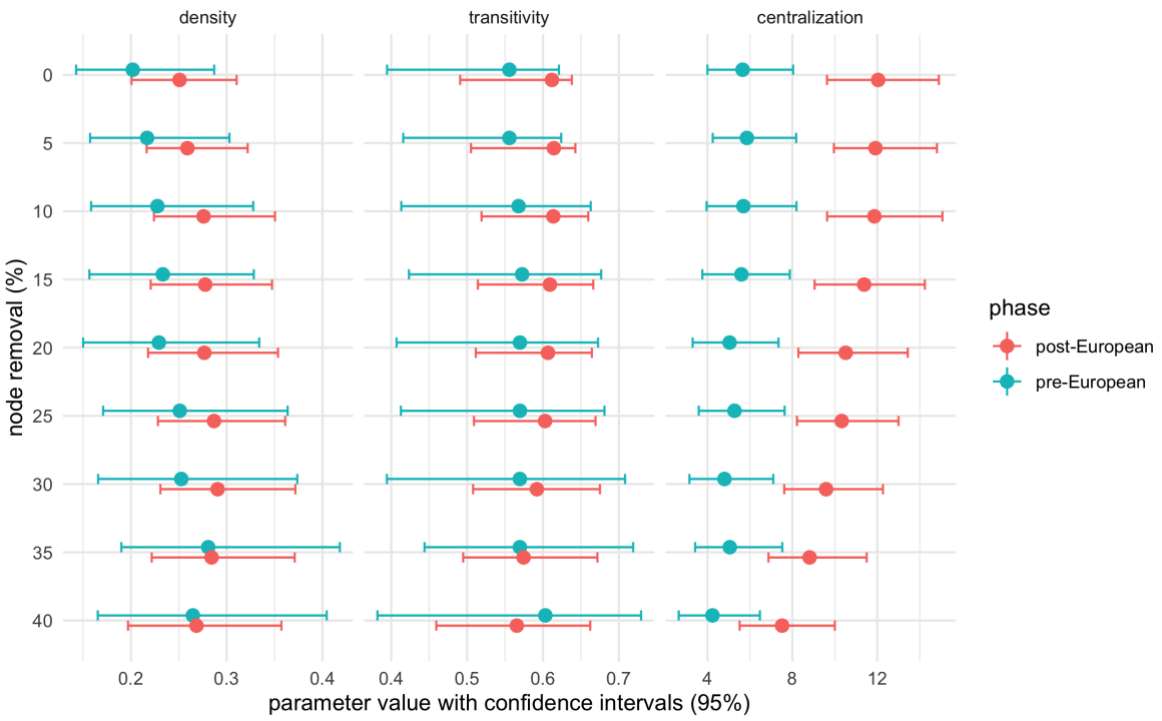
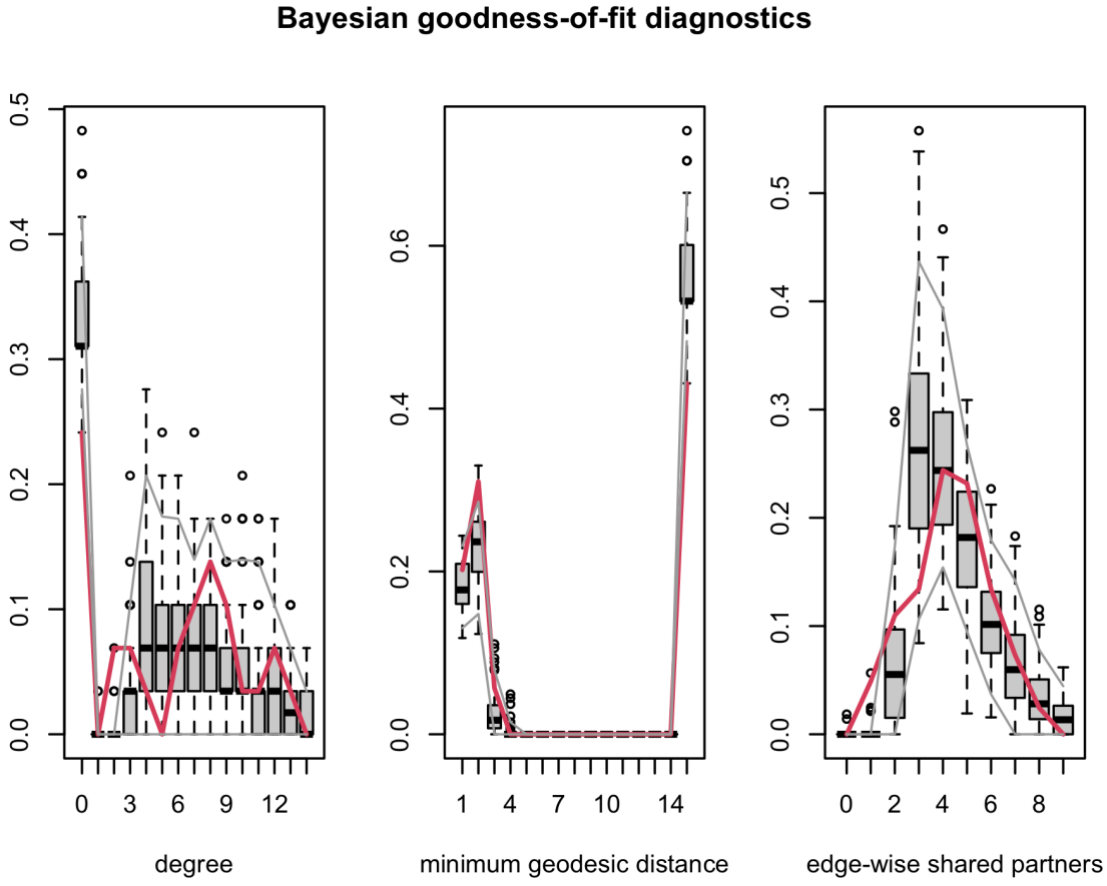


Figure 4.6: Results of the vertex bootstrap analysis by three network variables, showing the 95% bootstrap confidence intervals for the bootstrapped (n = 1000) networks, for each category of node removal. The 0% node removal category is the original data for the two phases. Networks with nonoverlapping confidence intervals indicate a significant difference between the two phases for that network variable.


Bayesian goodness-of-fit diagnostics
0.0
0.1
0.2
0.3
0.4
0.5
0 3 6 9 12
degree
0.0
0.2
0.4
0.6
1 4 7 10 14
minimum geodesic distance
0.0
0.1
0.2
0.3
0.4
0.5
0 2 4 6 8
edge-wise shared partners

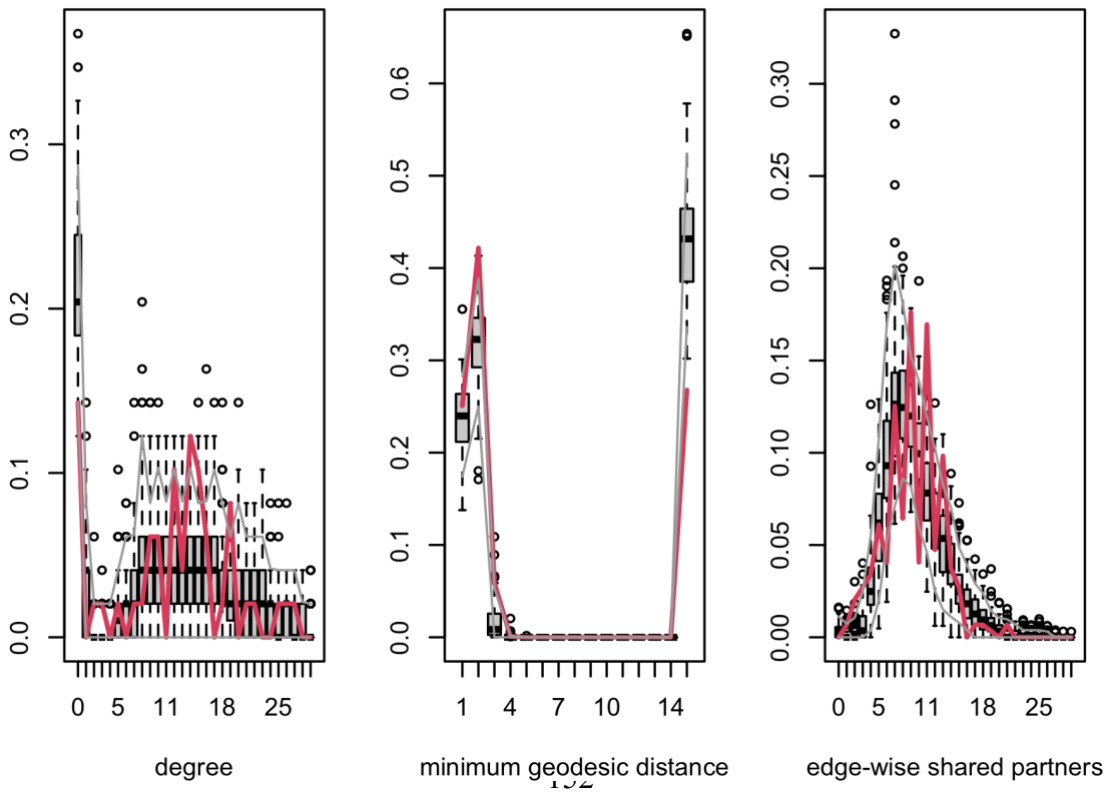

Bayesian goodness-of-fit diagnostics
0.0
0.1
0.2
0.3
0 5 11 18 25
degree
0.0
0.1
0.2
0.3
0.4
0.5
0.6
1 4 7 10 14
minimum geodesic distance
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0 5 11 18 25
edge-wise shared partners

Figure 4.7: Goodness-of-fit diagnostics for the pre-European model (top) and the post-European model (below). Boxplots represent distributions calculated on 100 network graphs simulated from the estimated posterior distribution. Red lines represent distributions of observed networks, and gray lines show the 95% intervals.

Our computational models reproduce networks that resemble the structural features of our observed networks. Bayesian goodness of fit diagnostics plots (Figure 4.7; details in Supplementary Online Materials) demonstrate that both models fit the observed networks very well for the minimum geodesic distance distribution (i.e. the number of edges between node pairs in a shortest path, Hunter et al. (2008)) and the degree distribution. For edgewise shared partner distribution, despite some observations falling outside the 95% interval, the fit is generally good with most observations within it. We also compared the first three distribution moments of each observed distribution and their corresponding simulated distributions, represented by means. Figure 4.8 shows that modeled values from the pre-European network are slightly closer to the observed values for the mean and the variance of distributions, compared to the values from the post-European network. In general, this demonstrates a slightly better fit between model and data for the pre-European network.

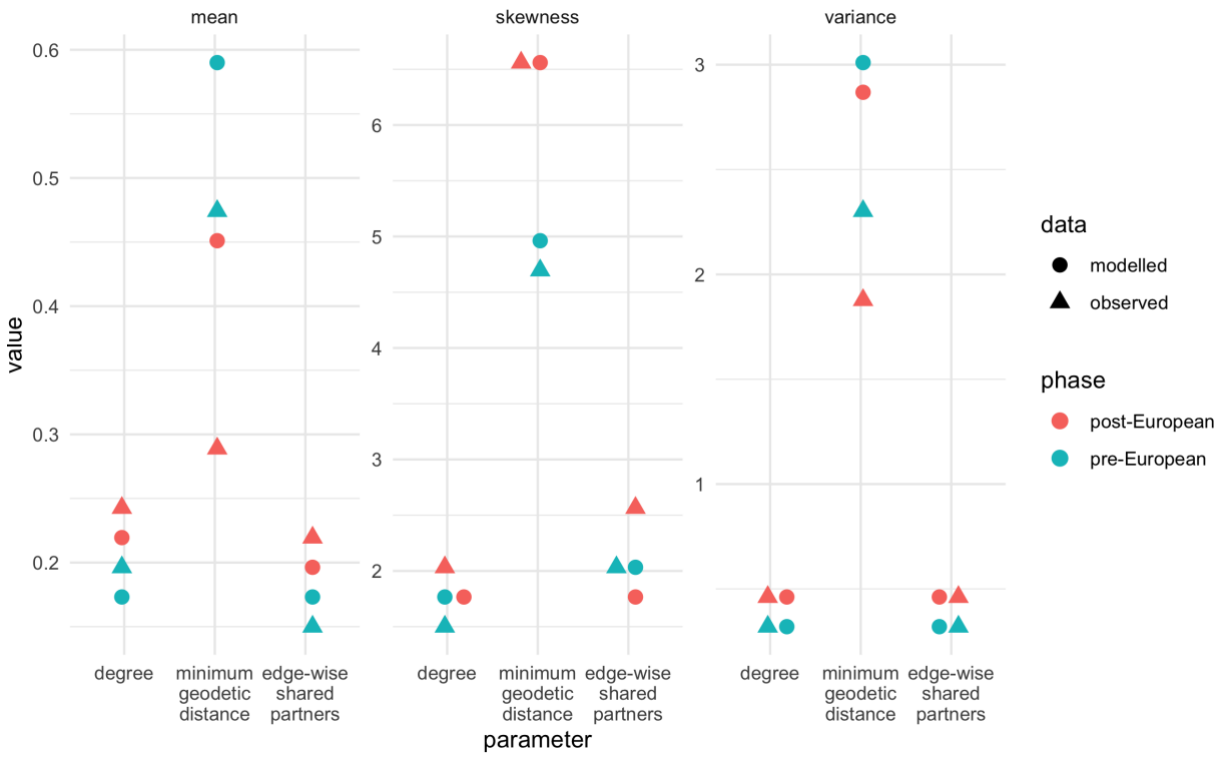


Figure 4.8: Distribution moments (mean, skewness, and variance) calculated on the observed data and simulated distributions for the pre- and post-European models.

Discussion

A striking finding in our results is the change in network properties of Kiwulan burials from a more cohesive network with multiple subgroups toward a more centralized network with concentration of connections among fewer burials after the European arrival in the 17th century. This supports our pericolonial impact model that Kiwulan changed from a more corporate-based to a more networked-based society, as indicated in the grave goods and

burial attributes. A corporate-based society, as we interpret the pre-European situation at Kiwulan, stresses shared power between individuals, communal rituals, and social inequality, if any, would be associated with groups (Drennan et al., 2010; Feinman, 2000; Feinman et al., 2000). In contrast, a network-based society, as we interpret the post-European data from Kiwulan, presents wealth accumulation through individual networks, prestige goods manipulation, and trade monopolization (Blanton et al., 1996). It should be noted that the corporate-network continuum represents a dynamic process with different degrees of hierarchical complexity instead of static ideal-type stages (Feinman, 2000).

Network covariates give insights into the socio-cultural factors that were associated with the acquisition and distribution of foreign prestige goods. Our results indicate that the major factor contributing to burial networks for the pre-European network was ritual, and for the post-European network was wealth. We interpret these results as illustrating different social and economic mechanisms influencing relations between burials for the two periods. Before European arrival, ritual behaviors were important factors that structured the interconnections of prestige goods in the burial contexts. This might imply that ritual could be a status indicator at the time before many foreign goods were introduced to Indigenous societies. After the European presence was established, status indicators shifted from ritual to wealth differences. Geographical proximity of burials, implying kinship association, has no effect on sharing similar prestige items between burials for both phases. This may suggest that the use of prestige items is more individual-oriented instead of kinship-based. Demographic information, such as age and sex, do not have any effects on network formation for both networks. We also note that no effects could be due to the unavailability of age (30 out of 78 burials) and sex (52 out of 78 burials) values in our sample.

We used burial data as a proxy to explore social relations reflected by interconnections of prestige goods based on assumptions that burials can represent social structures (Binford, 1971; Saxe, 1970), and individuals with similar prestige goods reflect similar access to trade, exchange, and gifting networks (eg. Coward, 2013, p. 252). We argue that the social relations at Kiwulan changed because of contact with European colonial powers and associated foreign trade. This argument is supported by changes in burial network structures through time. It should be noted that manipulation of burial rituals by the living can cause a disconnect between a person's status in life and their status represented by burial contexts (Hodder, 1980; Pearson, 1982). However, this issue can be reduced by comparing the results with evidence from other archaeological contexts, such as residential areas (Chapman, 2003). Previous studies of trade ornaments from the residential area of Kiwulan suggests an uneven spatial distribution when the Europeans were active in northern Taiwan that hints at an increased social differentiation (Wang and Marwick, 2020). This is consistent with the result of a more centralized burial network after the presence of Europeans, that supports a connection between a burial and the social role of the living person. Also, ethnographic records support our interpretation of burial goods as prestige goods or status items in the local Indigenous culture (Borao, 2009; Li and Wu, 2006), so the interrelations represented by the flow of these goods observed in the burial data likely reflect social contexts of the living people at Kiwulan.

Conclusion

We presented a novel approach for studying burials to interpret social structures using ERGMs within a Bayesian framework. This case study demonstrates the methodological benefits of Bayesian inference on ERGMs to inform and enhance studies of relational data in archaeology. A Bayesian framework can reduce the effects of small sample size or missing data commonly present in archaeological data and incorporating prior information and MCMC estimations to quantify uncertainty and provide interpretable output. An important feature of Bayesian network modeling is the ability to set prior values to evaluate competing anthropological models, enabling a comparison of anthropologically-relevant models, rather than testing a hypothesis of no difference or randomness. Bayesian network modeling can be applied to a wide range of archaeological data to examine the formation of relationships using robust probabilistic inference. This enables insights into the dynamic processes of relationship formation and the underlying factors of historical trajectories of socio-cultural phenomena.

Our case study examined social changes in a European pericolonial context in northeastern Taiwan. We tested a hypothesis of changes in burial networks at Kiwulan with the evaluation of both endogenous and exogenous network effects. The results support our model that the relationship between burials changed after the European colonization period in the 17th century. Before the arrival of Europeans, the burial network has a tendency of more clustered subgroups with pottery as ritual practice as the key formation mechanism. After European arrival, the network has a tendency of centralization relative to the rarity of goods. We interpret the changes in formation mechanisms of networks, observed as a

change from ties formed by ritual to wealth, as an increase in wealth accumulation behaviors, stimulated by the European presence and its associated long-distance trade network. This aligns with changes in horizontal hierarchy represented by corporate-network societies, that demonstrates different degrees of social inequality in relation to different strategies for achieving power (Feinman, 2000). Using burial data with historical documents, we can better understand indirect European impacts in understudied pericolonial contexts of East Asia (e.g. Acabado, 2017; Trabert, 2017).

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Chapter 5

Conclusion

The archaeology of encounters between Europeans and Indigenous people is important for understanding colonial and cross-cultural experiences in different parts of the world. Archaeology has a special role here because although many of these encounters involved colonizing groups that kept documentary accounts, the Indigenous groups involved in these encounters often did not record written texts, so the archaeological record is an important witness of their experiences (Given, 2004; Lightfoot, 1995; Lyons and Papadopoulos, 2002; Silliman, 2010). Archaeologists are increasingly aware of this special role they have in documenting the experience of Indigenous peoples in colonial contexts, which is also an important goal of historical archaeology, to interrogate and challenge the history written by colonists (Little, 2016). My work in this project has been focused on the experience of Indigenous people of northern Taiwan during the time of the first European colonial activity in that region. The aim of this dissertation has been to explore whether social complexity occurring in Late Iron Age northeastern Taiwan was associated with the pericolonial context of the European presence in Taiwan in the 17th century. I defined a pericolonial situation as one where direct colonial dominance is generally weak, but long-distance trade activities are active and frequent (Acabado, 2017; Prentiss, 2017; Trabert, 2017).

This dissertation sought to explain social changes by using models based on a corporate-network conceptual framework (Feinman, 2000) to detect power strategies at Kiwulan, and observe how they change over time. My specific focus was on changes in three elements of the archaeological record: (1) trade ornaments, (2) locally made ceramics, and (3) burials. Through a focus on these elements, I have explored changes in the use of prestige goods, economic activities, and social relations at Kiwulan. Taking a long-term perspective, I examined materials from the pre-European phase, the post-European phase that includes the European presence, and afterwards, including a latter phase indicated by a large wave of Chinese immigrants, to understand reactions of the Indigenous society at Kiwulan to different foreign presences. In this final chapter I will first synthesize and discuss the results from the previous three chapters in relation to the models introduced in chapter one. After that, I will highlight the novel approach of doing archaeology that unites and runs through the three core studies of this dissertation. Then I will review the broader contributions and implications of this study. Lastly, I will conclude with a brief discussion of the limitations of this research and sketch out some productive directions for future work.

Evaluating the Social Change Model and the Social Continuity Model

In this section I synthesize the results according to the two models I outlined in my first chapter: social change and social continuity. The results I presented in chapter two (ornaments) and chapter four (burials) show evidence consistent with increased social differentiation after the European presence in the 17th century and before the Han Chinese presence in the 19th century, which supports the model of social change. These results hint

at a change in power strategies from a more corporate mode society to a more network mode society. This might have been caused by the emergence of aggrandizers competing with each other for foreign resources through direct trading with Europeans or indirect trading with other Indigenous groups for the same resources.

Chapter two focused on the spatial distribution of trade ornaments, viewed as prestige goods in local culture, across the residential area of Kiwulan. I found a significantly uneven distribution of trade ornaments represented by a few clusters after the European presence, where the clusters might correspond to different house structures according to orientations and arrangements of post holes (Chen, 2007). This clustered pattern may be caused by the accumulation of prestige goods and differential access to sources, indicating a competition for foreign resources. A greater variety and a larger number of trade ornaments at the same time indicate frequent trade activities. I interpret these differential distributions in the residential area of Kiwulan as increased social inequality, supporting the model of social change. As mentioned in chapter one, inequality emerges when the difference is preferred or tolerated, such as one owning more trade ornaments than others.

Chapter three, with its focus on the production of locally-made ceramics, found no changes after the European presence, but a significantly more standardized shape across the residential area after the Han Chinese presence. Contrary to the ornament data, the ceramic data support the model of social continuity in response to the European presence. I interpret the ceramic vessels as reflecting economic aspects of a society, where the more homogeneous shape of ceramics indicates mass production or the presence of specialized production (Blackman et al., 1993). The emergence of specialized potters is an indicator of craft specialization, when ceramic production exceeds household scale. This could reflect a

social division or control of production by a small group of people, such as specialists (Costin, 1991; Costin and Hagstrum, 1995; Topi et al., 2018). The locally-made ceramics at Kiwulan suggest a continuity in social organization before and during the European presence. This evidence is inconsistent with my findings from the ornaments and burial evidence. I explore some of the implications of this inconsistency below, in the following section.

Chapter four focused on burial data as a proxy to explore social structure using Bayesian network modeling. The construction of the network connections was based on burials containing the same prestige goods, reflecting social relations at Kiwulan. The results support the model of social change with the establishment of European presence. I found that the burial network before the European arrival shows a structure consisting of multiple tied subgroups without any extent of centralization. Moreover, the network ties are associated with ritual behaviors, indicated by the use of local ceramics in mortuary practices. I interpret this as related to feasting practices often observed in many Indigenous societies in Southeast Asia (Hayden, 2016; Hsieh, 2012; Junker, 1999). I found that the burial network after the European presence becomes established showed a different pattern, with a significantly higher centralization, but less tied subgroups. During the European period, burial relationships were defined by wealth differences, as represented by the total number of foreign goods. I interpret the network structure of the later period as indicating the emergence of a few prominent centers, suggesting a network mode society. The burial network structure may also suggest a social change where tied subgroups, representing corporate groups, are gradually weakened and less important after the emergence of

competitive individuals when Kiwulan was more involved in the long-distance trade network stimulated by the European colonial activities in northern Taiwan.

Based on two lines of evidence, trade ornaments and burial data, showing consistent results of an increase in social inequality, I conclude that the social change model is the best explanation for the evidence observed before and after the European presence. I find that the corporate-network concept is a useful framework to understand the shift in power strategies in a pericolonial context.

Speculation on Resistance and Expression of Social Identity at Kiwulan

Although the ornament and burial data support the model of social change, the ceramic data from Kiwulan support the model of social continuity. How can we explain this tension and inconsistency in the archaeological evidence? Here I explore one possibility, namely that the Kiwulan ceramics were a locus of resistance and expression of social identity. The ceramics studied for this project are the major type of cookware found throughout Iron Age sites in northeastern Taiwan, considered by local archaeologists as a local ceramic tradition (Chen, 2007; Li and Chiu, 2014; Taiwan History, 2005). I interpret my finding of a significantly more homogeneous vessel shape only in the period of Chinese presence as indicating that the shape of local ceramics was used as a symbol to demonstrate social identity when facing a large number of Chinese immigrants in the 19th century (eg. Roux, 2015).

Compared to the low-intensity and sporadic interactions between the Indigenous occupants of Kiwulan and the Europeans, the interaction between Indigenous people and the Chinese

was direct and intense because the Chinese settled down in large numbers in northeastern Taiwan. As a response, a large number of Kavalan people, the Indigenous people who originally lived in Yilan, moved southwards to Hualien especially in the 19th century due to increased conflicts and competition for land with the new immigrants (Hsieh and Huang, 2007; Zhan, 1995). A more homogeneous ceramic shape could reflect the shared identity of the people at Kiwulan, serving to distinguish them from Han Chinese (eg. Peelo, 2011). The practice of ceramic making may thus be viewed as a behavior of resistance to the spread of cultural elements introduced by the Chinese. The inhabitants of Kiwulan may have consolidated their ceramic making practices as an act of resistance against the influence from direct and intensive contact with Han Chinese ceramic traditions.

Further support for this resistance scenario comes from finds of foreign materials in the 19th century at Kiwulan, such as a wide variety of porcelains, iron knives and cookwares, bricks, and tiles that were recognized as Chinese tradition. Those materials are mostly associated with cutlery or house structures, reflecting their use in mundane life. Although there are a large number of Chinese cookwares and utensils found at Kiwulan, local ceramics are still continuously found throughout six hundred years until the abandonment of Kiwulan at 1850 AD, according to radiocarbon dates (Chen, 2007). This pattern of a continuation of local ceramics among the introduction of foreign materials indicates that local ceramics were an important cultural item, showing resistance to replacement by other similar ones brought by the Chinese. This resistance may be part of a practice of affirming and consolidating a shared identity in the face of threats of dilution or overwhelming cultural influence from other groups. Or, the access to Chinese goods may be costly that made them not economically viable for utilitarian items that could be made locally. Both interrelations

could be possible in the situation where foreign goods and local items coexisted in Indigenous societies.

Transparency and Reproducibility in Archaeological Science

In addition to sharing a common focus on the archaeology of social inequality at Kiwulan, the three papers at the heart of this project also demonstrate a consistent and novel approach to scholarly communication in archaeological science. Each of the three papers was conceived and produced to ensure that the scientific results are fully reproducible by other researchers. Reproducibility means one can obtain the exact results using the same data, code, and analytic procedures provided by the original authors (Marwick et al., 2020). Reproducible research is a key practice in open science approaches across many fields of research. Open science practices value the accessibility of all stages in scientific research for everyone, including data analysis, computational processes, and publication, to foster sharing and collaboration with active engagement (Beck and Neylon, 2012). This is important because reproducible research can enhance scientific credibility, research transparency, and accessibility of knowledge by incorporating practices of open data, open methods, and open access into our research (Marwick et al., 2017). Reproducible research fosters progress in scientific development by sharing materials from which other research can be efficiently built upon. Open science practices have long been demonstrated by researchers in many disciplines, such as biology, but only applied to archaeology in recent years. At the start of work on each paper I made a major commitment to ensure that future readers can inspect every detail of my analytical process, and each of my decision points in the statistical analyses are visible to the reader.

Traditionally in archaeology, a typical research process involves data analysis, visualization, and writing done separately, in different software. The author copies and pastes content between the different software programs to create their paper, which they submit for publication. The disconnected nature of this process, and the availability of only the final product to the reader in publication, mean that transparency of the research process to the reader is very limited. The reader of a traditional publication cannot trace a published result, such as a figure, table or statistical output, back through the analytical processes that generated the result from the raw data. This means the research is not transparent to the reader, and the reader cannot inspect the decisions made by the researcher, but has to simply trust that the researcher has made good analytical choices. While this is the normal prevailing practice in archaeology, I do not believe it is good practice, because it is contrary to the ideals of science, which are 'show me,' not 'trust me' (Stark, 2018).

In order to show the reader that my results are reliable, and document my analyses with maximum transparency and integrity, each chapter in this dissertation is written with R markdown. R Markdown is a document format where plain text and R code for statistical analysis are combined in a single document, avoiding copy-pasting between multiple programs (Xie et al., 2018). The results produced by an R Markdown document can be reproduced with minimal effort by other researchers.R is a free and open source programming language, used here as my primary tool for data analysis and visualization (R Core Team, 2019). For each paper, I have also organized my R code and raw archaeological data into a research compendium (Marwick et al., 2018). I have deposited these research compendia on a trustworthy data repository (the Open Science Framework) for long-term availability to any future researcher, with no restrictions. Furthermore, although my papers

have been published in paywalled journals that are only accessible by subscription, I have posted open access pre-prints for each of the three papers on the SocArxiv pre-print service so anyone can freely access the full text of each paper at any time.

These practices of open and reproducible research that my work embodies are a novel way of doing archaeology that is strikingly different from current norms. By working in this way for my dissertation, my hope is to introduce and promote reproducible research, especially for historical and East Asian archaeology, by providing examples showing a practical workflow applicable to many types of archaeological research. While some scholars have adopted this way of working in other areas of archaeology (Schmidt and Marwick, 2020), to date historical archaeologists have paid little attention to data sharing and the reproducibility of their research. Similarly, in East Asian archaeology these practices are almost completely unknown. My publications are the first from this region to demonstrate this commitment to reproducible, open and transparent archaeological research. One of my goals with this dissertation is to provide an example to inspire future researchers to improve the openness and reproducibility of historical archaeology in East Asia.

My practice of reproducible research also has an ethical motivation. The theme of European colonization woven throughout this project connects to an ethical concern in contemporary archaeological science, "scientific colonialism." This occurs when scientists, such as archaeologists, hold knowledge generated from data collected from local communities without sharing it back to those communities from whom it was taken (Hollowell, 2006). Ethical practice in archaeology involves making research data and results available to the communities and other researchers. Responses to a recent survey for revising the Principles of Archaeological Ethics of the Society for American Archaeology reinforce the importance

of this issue. Many respondents to this survey call for data sharing between archaeologists as a necessity for ethical archaeological practice (Marwick et al., 2021; Pruski et al., 2021). With my openly available research compendia, other researchers and members of relevant communities in northeastern Taiwan have unrestricted access to all my research materials to examine my scientific claims. This dissertation demonstrates how we can align the ideals of archaeology for the public good with actual practices to increase transparency and openness in archaeology (Marwick and Wang, 2021).

Broader Implications and Impacts of this Research

In this section I explore some of the broader implications of my findings for the wider region and for archaeology in general.

1. Indirect impacts of colonial power could be relevant to understanding changes in social complexity in many places

Colonial activity in Asia has distinctive historical and cultural contexts due to the variety of colonial forces involved through time, including the Dutch, Spanish, English, Portuguese, Chinese, and Japanese. It is difficult to generalize about the East Asian situation from colonial experiences in other parts of the world, especially from the British settler colonialism of the US and Commonwealth countries that dominate the literature. My research offers a novel local perspective from East Asia for discussing the variety of forms and effects of colonization around the globe. An important contribution of this project is the local view from a peripheral area of major European colonies. Peripheral locations such as Kiwulan tend to be ignored in the scholarly literature, and indirect impacts are rarely

discussed. This research stresses the active involvement and vivid role of Indigenous people, who tell their own stories through archaeological evidence, rather than as a people without history (Wolf, 2010). My results invite questions about colonial influences for other places close to European colonies in Asia, where colonial power was much less pronounced but still impacted Indigenous societies in various ways. Many current discussions about European colonization, with their foci on British settler colonialism (Lester, 2002; Veracini, 2011), suffer from kind of colonial logic of its own, by homogenizing the colonial experience and neglecting the diversities of peripheral experiences, such as what I have documented at Kiwulan. With this dissertation I argue for a turn to study the complex and various situations at the peripheries of colonial activities, where Indigenous people were involved at different levels.

2. Corporate/network societies as a more suitable framework to discuss social structure in northeastern Taiwan

The corporate and network modes I used in this project provide a productive conceptual framework to understand the situation at Kiwulan. I expect they will be similarly useful for understanding social changes among many other Indigenous societies in this region. For current-day Indigenous societies, such as the Kavalan, we see groups for making decisions regarding the whole tribe, normally middle-aged males. In those societies, power is shared in a certain group and decisions are made together in the group, accompanied by communal ceremonies or ritual activities to strengthen social cohesion, suggesting a corporate mode society (Feinman, 2000). Focusing on changes in power strategies provides flexible and relevant concepts to describe societies showing some level of social inequality but lacking centralized institutions. I have shown how a focus on power strategies, using the

corporate/network modes, can contribute to the debate of whether Kiwulan society was egalitarian or stratified society. Given this productive result, I believe this approach will also be effective at explaining other settlement sites with similar evidence of social complexity in Iron Age Taiwan.

3. Responses to foreign presence could vary due to different forms of interactions

My research at Kiwulan presents a local view from a long-term perspective of a community facing a foreign presence. This demonstrates the variety of reactions of Indigenous people to a foreign presence due to different forms of foreign power, and the extent of involvement of Indigenous people in the interaction with foreign presence (eg. Torrence and Clarke, 2000). As colonists, Europeans often exerted power over Indigenous people due to military hardware and frequent use of force. This often created asymmetrical relationships between Indigenous groups and Europeans (Panich, 2013; Silliman, 2005). However, when this colonial power is indirect and weak, and to some extent relies on local Indigenous assistance to achieve economic goals, as we can see at Kiwulan, this kind of colonial presence may lead to the emergence of aggrandized individuals. In this situation, local people may have more flexibility to manipulate colonial power by taking advantage of the benefits, such as prestige goods and symbols of colonial power, obtained from the interaction with the Europeans or accessing long-distance trade to build their personal networks. This could gradually drive changes in power strategies in the local society. In contrast, despite the Han Chinese immigrants consisting of commoners not having strong economic or political influence over Indigenous people, the cultural impact of the Han migration and occupation of Indigenous lands appears to have stimulated a subtle form of Indigenous resistance among the residents of Kiwulan. This concept of a resistance response may also be useful

elsewhere in East Asia for explaining Indigenous interactions with population movements that are not part of state-sponsored colonizing processes.

4. Application of novel empirical methods to historical and East Asia archaeology

An important technical contribution of this research is the use of novel reproducible quantitative methodologies with statistical testing. These push the boundaries of typical studies of trade ornaments, ceramics, and burial data, especially for historical archaeology and East Asian archaeology. For the study of trade ornaments, I have introduced simulation with hypothesis testing on the randomness of spatial distributions of ornaments to provide a robust way to examine spatial patterns. For the study of ceramics I have introduced geometric morphometric analysis of pottery vessel shape outlines. This is very useful for capturing shape variation for artifacts that lack distinctive reference points, such as the vessels from Kiwulan. Finally, for burial data, I have introduced network modeling using a Bayesian framework to show the potential of this method for further applications to other archaeological materials and contexts. My work has demonstrated several new methods, all united by a strong commitment to reproducibility and transparency. My hope is these methods will be more widely used, and will motivate more reproducible research in these fields, especially for historical archaeology and East Asian archaeology.

5. Broader impacts related to contemporary societies

This research provides broader impacts on many different aspects related to contemporary society. First, the results provide explanations for Indigenous social structures in Taiwan that had previously been simply characterized as egalitarian or stratified societies without considering variations in societies. Many Iron Age sites are closely related to current-day

Indigenous peoples of Taiwan. This means that a detailed examination of archaeological evidence in addition to historical records can provide an important opportunity for Taiwanese to trace back the history of this land, from Formosa, Taiyuan, to Taiwan. Second, the results of this research will help to challenge the Taiwanese-centered viewpoint that has been a dominating voice for hundreds of years. Furthermore, the language of Kavalan is one of the most endangered Austronesian languages in Taiwan today (Hsieh and Huang, 2007; Lee, 2009), and urgent action is required to support both Indigenous tangible and intangible heritage. Archaeological work here offers a great way to provide this support by arousing public awareness about protection of minorities and reinforce the value of Indigenous heritage and cultural diversity. Third, the emergence of inequality is highly relevant to our contemporary societies since it has increasingly become a concern in many places. Studying the mechanisms behind it could help us to explain, reflect on, and manage the issues of inequality at different scales in our lives.

Limitations of the Research

For a project focused on social changes, and including a study of burials, it is no doubt surprising to the reader that I have not directly studied the human remains at Kiwulan. One important indicator of social inequality is skeletal remains, such as bones or teeth, which can provide demographic information and show traces of disease and diet from which we can infer their social status (Le Huray and Schutkowski, 2005; Robb et al., 2001). However, I chose to exclude human remains from this project to limit the scope of this research so that it could be completed in a reasonable time. Furthermore, the weathered fragmentary nature of the remains suggested to me that a detailed analysis may not be highly insightful. I was able

to incorporate some demographic information such as age and sex of some of the burials, collected by previous researchers. These data are not available for all burials because of poor preservation of skeletal materials.

Preservation conditions were a major source of limitations for this project. In addition to degrading the human skeletal material, many other types of organic archaeological evidence were not feasible to include in my study. I originally intended to study foodways and culinary practices as another element of the archaeological record to get insights into social inequality. I planned to study organic molecules preserved in the fabric of the ceramic cooking vessels since it is directly related to diet. Despite my intensive efforts to extract these biomolecules from the pottery, and my experimentation with numerous different laboratory protocols to reduce contaminants, I was unable to produce a yield suitable for further analysis. Poor organic preservation at Kiwulan has imposed substantial limitations on the types of analysis possible for my project.

Another potentially informative category of evidence that I excluded for reasons of time is architectural traces. The spatial layout of Kiwulan may also be another line of evidence to understand social changes (Lightfoot et al., 1998). The house arrangements in a settlement and its association with spatial patterns of artifacts and middens may offer another opportunity to investigate social inequality. At Kiwulan a general pattern of house structures can be identified in the distribution of post-holes sampling area. However, further work into the exact boundary of each house and spaces in each house are needed that can serve as a unit for analysis both in a settlement and household scale.

Future Research

There is considerable potential for future research at Kiwulan, particularly with emerging archaeological science techniques that are becoming increasingly accessible and affordable. Future research could incorporate stable isotope analysis of teeth and bones to understand dietary patterns that may reflect social inequality and health conditions during individuals' lifetimes. In addition, ancient DNA analysis of human remains in the burials can be also incorporated to examine kin relationships among the burials, and see how kin relations intersect with wealth and cultural relations indicated by the artefacts in the burials.

Although Kiwulan is the largest Iron Age settlement that had been systematically excavated in Yilan, there are more than thirty Iron Age settlements in this region. A logical extension of this project is thus a multi-site investigation of changes in social complexity around the time of the establishment of European presence. This will be a major undertaking, with new excavations necessary to obtain ceramics, ornaments, architectural features, and other elements of the archaeological record. This work will be important to establish if Kiwulan is unique in the changes it experienced, or if the responses observed at Kiwulan reflect regional transformations towards increased social complexity. With data from several Iron Age sites, the Bayesian network modelling I applied to burials at Kiwulan could be applied at a regional scale, for example where each settlement is a node in the network. This will help to reveal the relationships between settlements, and how these relationships changed over time.

Excavations at other Iron Age sites in northeastern Taiwan will also help to explore the importance of geographical variations in site settings, for example, close to the coast or to

the mountains. These different geographical contexts may have influenced different cultural trajectories due to differential access and exposure to foreign contacts. In addition, it may also be interesting to examine Indigenous settlements in the area near colonist sites or directly under colonial control to further understand the reaction of Indigenous people to different modes and levels of colonization. Future projects will also be done with close consultation and collaboration with Indigenous decent communities to include their voices and interpretations, and outreach programs or school education programs to involve local children in the research to maximize local participation. By increasing community involvement, we could help Kavalan people to revitalize their culture.

Concluding Remarks on Social Changes in a Pericolonial Context

Exploring the emergence of social inequality in past societies is one primary task for archaeologists to understand mechanisms that drive changes in social organizations. Broadly speaking, it is critical to improve our understanding of varying forms of human societies with distinct cultural and environmental conditions across time and space. This dissertation pursued this topic with the specific aim to answer the question: Did the European presence in the 17th century stimulate social changes in Late Iron Age northeastern Taiwan? The answer to this question is that an indirect impact by the European presence led to increased social inequality at Kiwulan. I found that society changed from a more corporate mode to a more network mode due to competition among individuals. This finding was supported by an uneven spatial distribution of prestige goods across the residential area, and a centralized pattern of burial networks that demonstrates an increased social inequality after the

European presence. However, a standardized ceramic shape after the Chinese presence, instead of the European presence, does not correspond to the ornament and burial data. I interpret this apparent inconsistency as a result of the household scale of ceramic production with the asserting social identity and resisting cultural change during the influx of Han Chinese settlers. Further work is necessary to explore this scenario of resistance.

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Appendix A

Notes on constructing a chronology for artifacts recovered from archaeological excavations at Kiwulan, Taiwan.

This document provides guidance for reading spreadsheets included in the Supplementary Online Materials for the chapter 2, "Ornaments as indicators of social changes in northeastern Taiwan before and after the European colonial period", and the chapter 3, “Standardization of ceramic shape: A case study from the Iron Age pottery from northeastern Taiwan”. The purpose is to provide details about the methods used for assigning artifacts into one of three phases: pre-European period, 17th century European presence, and 19th century Chinese period. We have included four spreadsheets that provide detailed information about the stratigraphic data, soil color, layer depth, diagnostic artifacts, radiocarbon dates, descriptive observations for artifacts in general, judgements for assigning, and the final decision for the chronology of each excavation unit. The information assembled here was collected from the original field notes and excavation report. This document and all the files relating to the publication are openly available online at http://doi.org/10.17605/OSF.IO/R8YGA

KWL_excavation_depth.xlsx provides the depth in centimeters for each layer. L1 means first layer and so forth. The depth was recorded based on the sea level. Some units are recorded based on sections A, B, C, D, these are 2x2 m subunits in each 4x4 m unit.

KWL_soil_color.xls provides.xlsx provides the soil color we identified from original field notes for each layer. L1 means first layer and so forth. The color was recorded according to Mansell color chart. Some units are recorded based on sections A, B, C, D, these are 2x2 m subunits in each 4x4 m unit.

KWL_layer_assign_details.xlsx provides detailed information of the archaeological contents of each unit that we used for assigning chronology. L1 means first layer and so forth. We listed the diagnostic items, including pipes, jars (An-ping jars), stonewares for the European period, and tiles, bricks for the Chinese period for the enclosing layer. The European period indicators are indicated with number after * to present their frequency.

The column, “radiocarbon dates (tree rings)”, includes the layers where charcoals were collected for radiocarbon dating. The original radiocarbon dates were corrected by the original excavators using tree rings data, these are represented in the parenthesis. Some charcoals were collected from features: H represents middens and M represents burials.

The column, “stratigraphic analysis based on field note”, describes the changes in soil color and distribution of potsherds. Those two variables are highly correlated to the depth between 20 cm to -20 cm that is around 17th century.

The column, “assessment (1: excellent, 2: good, 3: fair)”, is our assessment for the overall reliability of our chronological determination of the unit.

The column, “observations on artifacts & features based on field notes”, presents our judgment of possible post-depositional issues based on the description in the original field notes.

The column, “previous studies indicating 17th layer” and “previous studies indicating 19th layer” are based on the chronology used by previous studies on Kiwulan site, Hsieh (2009) and Wang (2011).

The column, “assigning the layer indicating the start of European phase” is our judgment for the European period. First, we determined the artificial layer (mostly 10 cm) based on the higher frequency of time indicators. Second, we identified the archaeological context (normally consists of 2-3 layers) where the layer belongs to according to the description of soil color, soil texture, and the distribution of potsherds and charcoals using original stratigraphic data. Third, we checked if there are radiocarbon ages associated with the context as a cross validation. Since we noted that the radiocarbon ages normally represent long time ranges, the ages are not considered if they cannot provide useful information. Fourth, we examined the original fieldwork notes to identify any post-depositional issues that might affect the deposition of time indicators to ensure an appropriate assignment. Fifth, we cross evaluated all adjacent squares to confirm a consistent, and continuous context

between them. Sixth, we compared our chronology with six analytic units classified by previous studies to make a final decision.

The column, “assigning the layer indicating the start of Chinese phase” is our judgment for the Chinese period. First, we determined the layer based on the presence of time indicators. Second, we identified the complete context (normally consists of 2-3 layers) where the layer belongs to according to the description of soil color and texture. Third, we checked if there are any post-depositional issues or disturbance based on original field notes. Forth, we cross evaluated all adjacent squares to confirm a consistent, and continuous context between them. Fifth, we compared our chronology with six analytic units classified by previous studies to make a final decision.

The columns, “The start of European phase (17th)” and “The start of Chinese phase (19th)”, are our final decision for the layer that represents start of each contact period.

KWL_reassigned_chronology.xlsx provides our final assignment of three phases. L1 means first layer and so forth. Some units are recorded based on sections A, B, C, D, these are 2x2 m subunits in each 4x4 m unit.

Radiocarbon Age Modeling for Kiwulan Chronology

This section provides information about radiocarbon dates calibration and chronology modeling for the upper component of Kiwulan. The data and code are openly available online at https://doi.org/10.17605/OSF.IO/ABVGF. There are 17 radiocarbon dates in total from the upper component according to the excavation report (Chen 2007). We calibrated 11 radiocarbon dates after removing 6 dates that are not informative due to their long time ranges without standard deviation (< 200 yr). The 11 radiocarbon dates are from different contexts, including artifact-bearing deposit, burials, and middens, at Kiwulan. They are calibrated using oxcAAR package, which executes OxCal v4.4.1 with radiocarbon calibration curve IntCal20 (Reimer et al. 2020).

We then modeled two phases related to the European influence, pre- and post- European periods. Our purpose is to answer whether the radiocarbon dates support a time range that corresponds to our artifact-based chronology in terms of the presence of Europeans in Taiwan.

Chronological model

We constructed a Bayesian radiocarbon calibration model for the 11 dates to obtain the range of the pre-European and the post-European periods we examined. We assume that those two phases are in a time sequence with the arrival of the Europeans in 1624 as a break (Andrade 2007). The end of the post-European period is identified by the start of the Chinese migration to Yilan in 1780s (Chen 2007).

The results (Figure A1; Table A1) suggest that the pre-European period started between 998–1386 cal AD at a 95.4% probability range and ended between 1496–1656 cal AD at a

95.4% probability range. The start date of the post-European period is the same as the end date of the pre-European period (1496–1656 cal AD). The end date of the post-European period is 1524-1770 cal AD at a 93.4% probability range. In general, the overall model for radiocarbon age relative to the European contact is consistent with our artifact-based chronology.

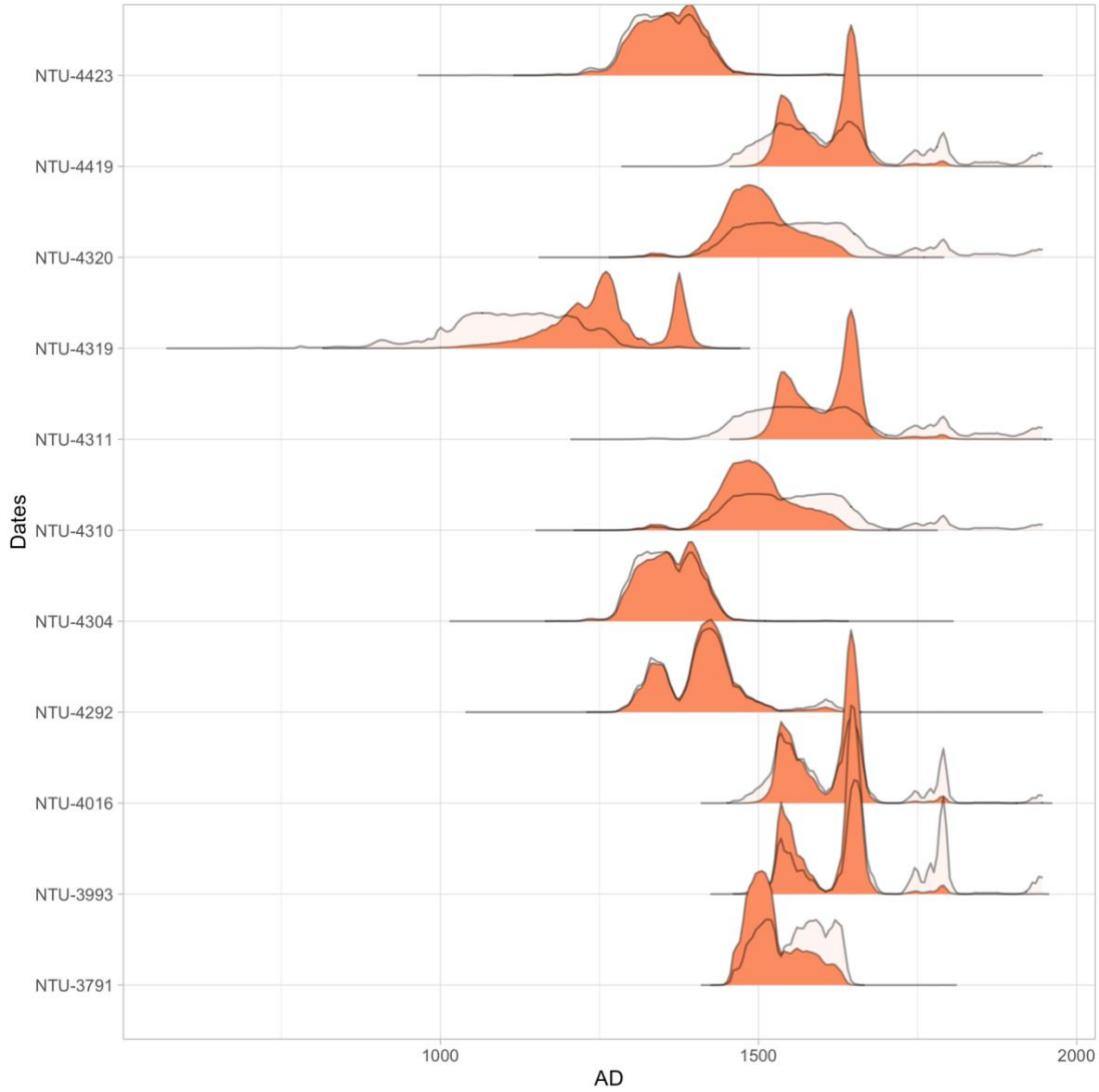

Figure A1: Calibrated probability distribution of radiocarbon dates from the upper component of Kiwulan by periods.

Boundary: Start of Pre-European	
posterior:	
one sigma	1126 AD - 1292 AD (62%)
	1342 AD - 1368 AD (6.27%)
two sigma	1003 AD - 1390 AD (95.45%)
three sigma	746 AD - 1414 AD (99.73%)
R_Date: NTU-3791	
BP = 340, std = 30	
unmodelled:	posterior:
one sigma 1494 AD - 1526 AD (21.86%) 1558 AD - 1602 AD (31.26%) 1610 AD - 1632 AD (15.14%)	one sigma 1462 AD - 1534 AD (65.64%) 1556 AD - 1563 AD (2.63%)
two sigma 1474 AD - 1638 AD (95.45%)	two sigma 1458 AD - 1618 AD (95.45%)
three sigma 1454 AD - 1647 AD (99.73%)	three sigma 1450 AD - 1640 AD (99.73%)
R_Date: NTU-4292	
BP = 510, std = 75	
unmodelled:	posterior:
one sigma 1321 AD - 1359 AD (19.35%) 1390 AD - 1458 AD (48.92%)	one sigma 1326 AD - 1356 AD (15.32%) 1392 AD - 1456 AD (52.94%)
two sigma 1292 AD - 1516 AD (92.19%) 1590 AD - 1620 AD (3.26%)	two sigma 1296 AD - 1512 AD (95.45%)
three sigma 1279 AD - 1638 AD (99.73%)	three sigma 1279 AD - 1534 AD (97.28%)

	1540 AD - 1626 AD (2.45%)
R_Date: NTU-4310	
BP = 360, std = 100	
unmodelled:	posterior:
one sigma 1454 AD - 1636 AD (68.27%)	one sigma 1430 AD - 1539 AD (68.27%)
two sigma 1328 AD - 1340 AD (0.41%) 1396 AD - 1691 AD (87.14%) 1728 AD - 1809 AD (6.35%) 1922 AD - NA (1.55%)	two sigma 1400 AD - 1632 AD (95.45%)
three sigma 1306 AD - 1365 AD (1.44%) 1384 AD - NA (98.29%)	three sigma 1303 AD - 1650 AD (99.73%)
R_Date: NTU-4320	
BP = 340, std = 100	
unmodelled:	posterior:
one sigma 1456 AD - 1645 AD (68.27%)	one sigma 1436 AD - 1544 AD (68.27%)
two sigma 1404 AD - 1695 AD (83.89%) 1726 AD - 1812 AD (8.69%) 1840 AD - 1844 AD (0.15%) 1863 AD - 1867 AD (0.15%) 1872 AD - 1877 AD (0.17%) 1916 AD - NA (2.38%)	two sigma 1408 AD - 1630 AD (95.45%)
three sigma 1317 AD - 1360 AD (0.75%)	three sigma 1306 AD - 1368 AD (1.68%)

1388 AD - NA (98.98%)	1380 AD - 1652 AD (98.05%)
R_Date: NTU-4304	
BP = 600, std = 75	
unmodelled:	posterior:
one sigma 1456 AD - 1645 AD (68.27%)	one sigma 1314 AD - 1410 AD (68.27%)
two sigma 1278 AD - 1438 AD (95.45%)	two sigma 1280 AD - 1440 AD (95.45%)
three sigma 1217 AD - 1498 AD (99.73%)	three sigma 1224 AD - 1485 AD (99.73%)
R_Date: NTU-4423	
BP = 610, std = 90	
unmodelled:	posterior:
one sigma 1298 AD - 1406 AD (68.27%)	one sigma 1309 AD - 1412 AD (68.27%)
two sigma 1230 AD - 1244 AD (1.13%) 1256 AD - 1454 AD (94.32%)	two sigma 1266 AD - 1454 AD (95.45%)
three sigma 1160 AD - 1525 AD (99.2%) 1560 AD - 1632 AD (0.53%)	three sigma 1176 AD - 1525 AD (99.6%) 1592 AD - 1616 AD (0.13%)
R_Date: NTU-4319	
BP = 920, std = 105	
unmodelled:	posterior:
one sigma 1032 AD - 1217 AD (68.27%)	one sigma 1190 AD - 1286 AD (52.07%) 1362 AD - 1390 AD (16.2%)

two sigma 896 AD - 926 AD (2.36%) 950 AD - 1281 AD (93.09%)	two sigma 1094 AD - 1326 AD (74.19%) 1340 AD - 1405 AD (21.26%)
three sigma 772 AD - 1324 AD (99.34%) 1355 AD - 1394 AD (0.39%)	three sigma 996 AD - 1428 AD (99.73%)
Interval: Duration of Pre-European	
posterior:	
one sigma	242 AD - 494 AD (68.27%)
two sigma	124 AD - 618 AD (95.45%)
three sigma	80 AD - 873 AD (99.73%)
Phase:	
Boundary: Pre-European - Post-European	
posterior:	
one sigma	1508 AD - 1554 AD (36.89%)
	1612 AD - 1651 AD (31.37%)
two sigma	1496 AD - 1656 AD (95.45%)
three sigma	1460 AD - 1671 AD (99.32%)
	1753 AD - 1794 AD (0.41%)
R_Date: NTU-3993	
BP = 250, std = 40	
unmodelled:	posterior:
one sigma 1526 AD - 1558 AD (14.79%) 1632 AD - 1674 AD (36.36%) 1768 AD - 1800 AD (17.12%)	one sigma 1528 AD - 1554 AD (22.1%) 1633 AD - 1665 AD (46.17%)
two sigma	two sigma

1508 AD - 1594 AD (24.45%) 1618 AD - 1686 AD (41.42%) 1732 AD - 1806 AD (26.06%) 1927 AD - NA (3.53%)	1516 AD - 1596 AD (39.19%) 1616 AD - 1680 AD (55.59%) 1785 AD - 1792 AD (0.67%)
three sigma 1474 AD - 1699 AD (68.52%) 1722 AD - 1815 AD (26.65%) 1836 AD - 1884 AD (0.57%) 1910 AD - NA (3.99%)	three sigma 1498 AD - 1690 AD (97.21%) 1734 AD - 1802 AD (2.52%)
R_Date: NTU-4016	
BP = 270, std = 45	
unmodelled:	posterior:
one sigma 1521 AD - 1580 AD (33.29%) 1624 AD - 1666 AD (29.4%) 1784 AD - 1796 AD (5.58%)	one sigma 1528 AD - 1558 AD (23.91%) 1629 AD - 1664 AD (44.36%)
two sigma 1481 AD - 1681 AD (82.92%) 1740 AD - 1754 AD (1.52%) 1762 AD - 1800 AD (10.15%) 1940 AD - NA (0.86%)	two sigma 1516 AD - 1602 AD (42.2%) 1610 AD - 1673 AD (53.25%)
three sigma 1454 AD - 1696 AD (84.32%) 1724 AD - 1813 AD (13.33%) 1838 AD - 1878 AD (0.24%) 1916 AD - NA (1.84%)	three sigma 1492 AD - 1690 AD (97.93%) 1736 AD - 1802 AD (1.8%)
R_Date: NTU-4311	
BP = 310, std = 100	

unmodelled:	posterior:
one sigma 1458 AD - 1664 AD (66.94%) 1787 AD - 1792 AD (1.33%)	one sigma 1526 AD - 1570 AD (27.11%) 1620 AD - 1665 AD (41.15%)
two sigma 1424 AD - 1698 AD (75.55%) 1722 AD - 1814 AD (12.83%) 1836 AD - 1884 AD (3.04%) 1910 AD - NA (4.03%)	two sigma 1507 AD - 1683 AD (95.45%)
three sigma 1328 AD - 1348 AD (0.19%) 1396 AD - NA (99.54%)	three sigma 1478 AD - 1817 AD (99.73%)
R_Date: NTU-4419	
BP = 280, std = 70	
unmodelled:	posterior:
one sigma 1496 AD - 1602 AD (41.31%) 1611 AD - 1667 AD (22.68%) 1783 AD - 1796 AD (4.28%)	one sigma 1526 AD - 1566 AD (26.43%) 1623 AD - 1665 AD (41.84%)
two sigma 1449 AD - 1694 AD (76.98%) 1726 AD - 1812 AD (14.79%) 1917 AD - NA (3.69%)	two sigma 1510 AD - 1680 AD (95.45%)
NA	three sigma 1483 AD - 1710 AD (97.48%) 1720 AD - 1810 AD (2.25%)
Interval: Duration of Post-European	
posterior:	

one sigma	0 - 78 AD (68.27%)
two sigma	0 - 229 AD (95.45%)
three sigma	0 - 492 AD (99.73%)
Phase:	
Boundary: End of Post-European	
posterior:	
one sigma	1536 AD - 1581 AD (21.56%)
	1638 AD - 1690 AD (46.71%)
two sigma	1524 AD - 1762 AD (93.13%) 1770 AD - 1774 AD (0.25%)
	1784 AD - 1814 AD (2.07%)
three sigma	1502 AD - 2058 AD (99.73%)
Sequence: Upper Layer	

Table A1: List of calibrated dates from the upper component of Kiwulan. The dates are calibrated based on atmospheric data from Reimer et al (2020)

Appendix A References

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Appendix B

Assessment of MCMC output and Goodness-of-fit diagnostics for our models

As an informal way to diagnose model convergence, we first evaluated three diagnostic visual summaries of our MCMC output, including density plots, trace plots, and autocorrelation plots for both models (Figure B1 and Figure B2) (Hamra et al., 2013). In general, models with informative priors have a better convergence of the MCMC. We can see that the diagnostic plots show stationary distributions and a trend of decreased autocorrelation. Then we summarize output from our two models by goodness-of-fit (GOF) diagnostics in the Bayesian framework, where the observed network is compared with the set of networks simulated from the estimated posterior distributions of the parameters of each model (Caimo et al., 2017; Caimo and Friel, 2011). We set 10^4 network graphs simulated from the estimated posterior distribution in ERGMs.

Our Bayesian GOF diagnostics, shown in the main text, summarized three distributions, including degree, minimum geodesic distance, and edgewise shared partner distributions. This provides a statistical approach to check how well the estimated posterior parameter distribution, based on our hypotheses, can reproduce networks with similar general structural features of the observed networks. We then compared the distribution of our observed networks, the networks before and after the arrival of Europeans, with the distribution of our hypothesized models. We expect to see the models fit with our hypotheses, indicative of an increased social inequality after the foreign contact. In addition,

the covariates can give some more clues for the underlying mechanisms for the formations of each network, such as the relative importance of age and sex.

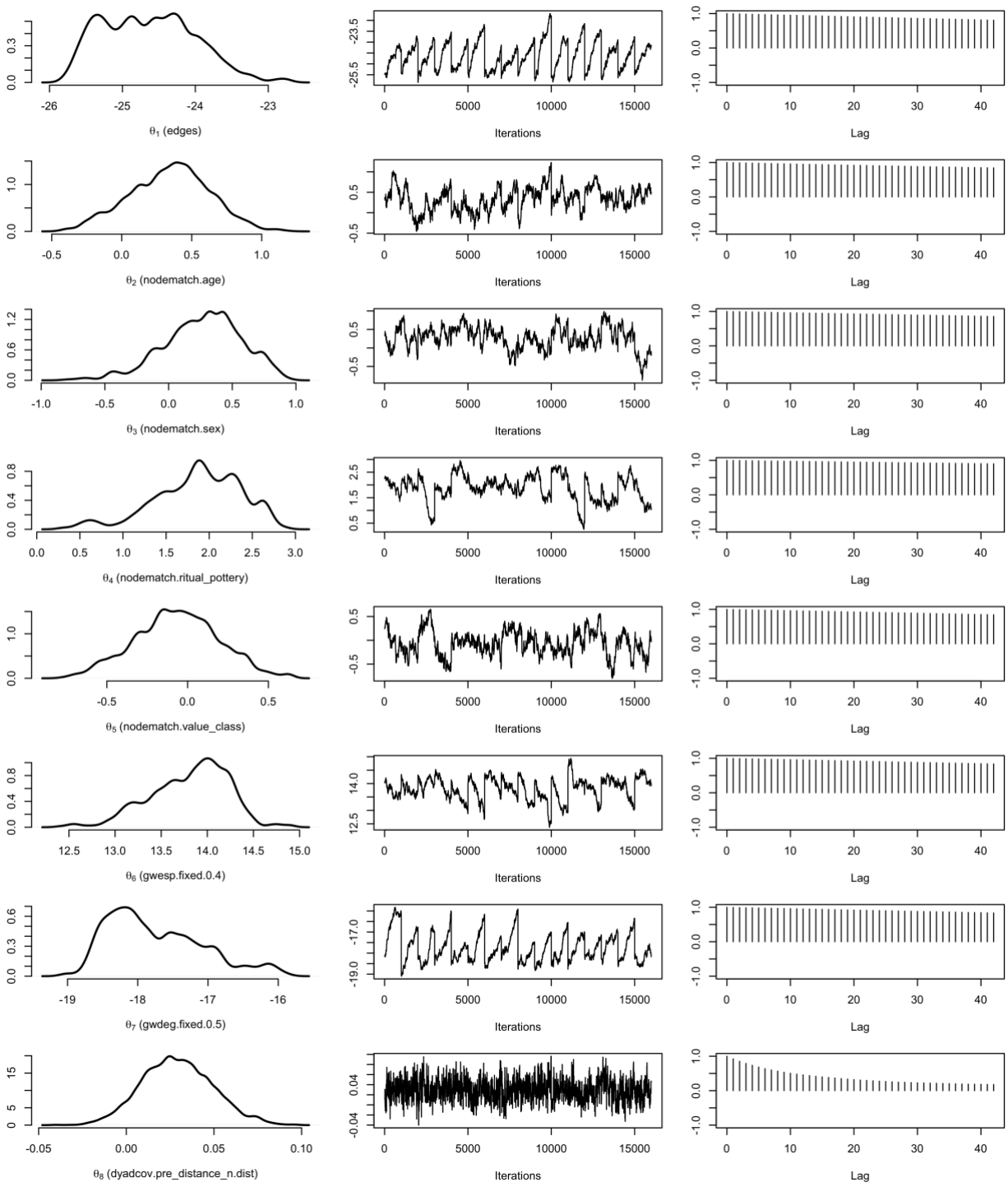

Figure B1: MCMC output of the pre-European model. In the order of edges, nodematch-age, nodematch-sex, nodematch-ritual, nodematch-value, gwesp, gwdeg, and dyadcov.distance.

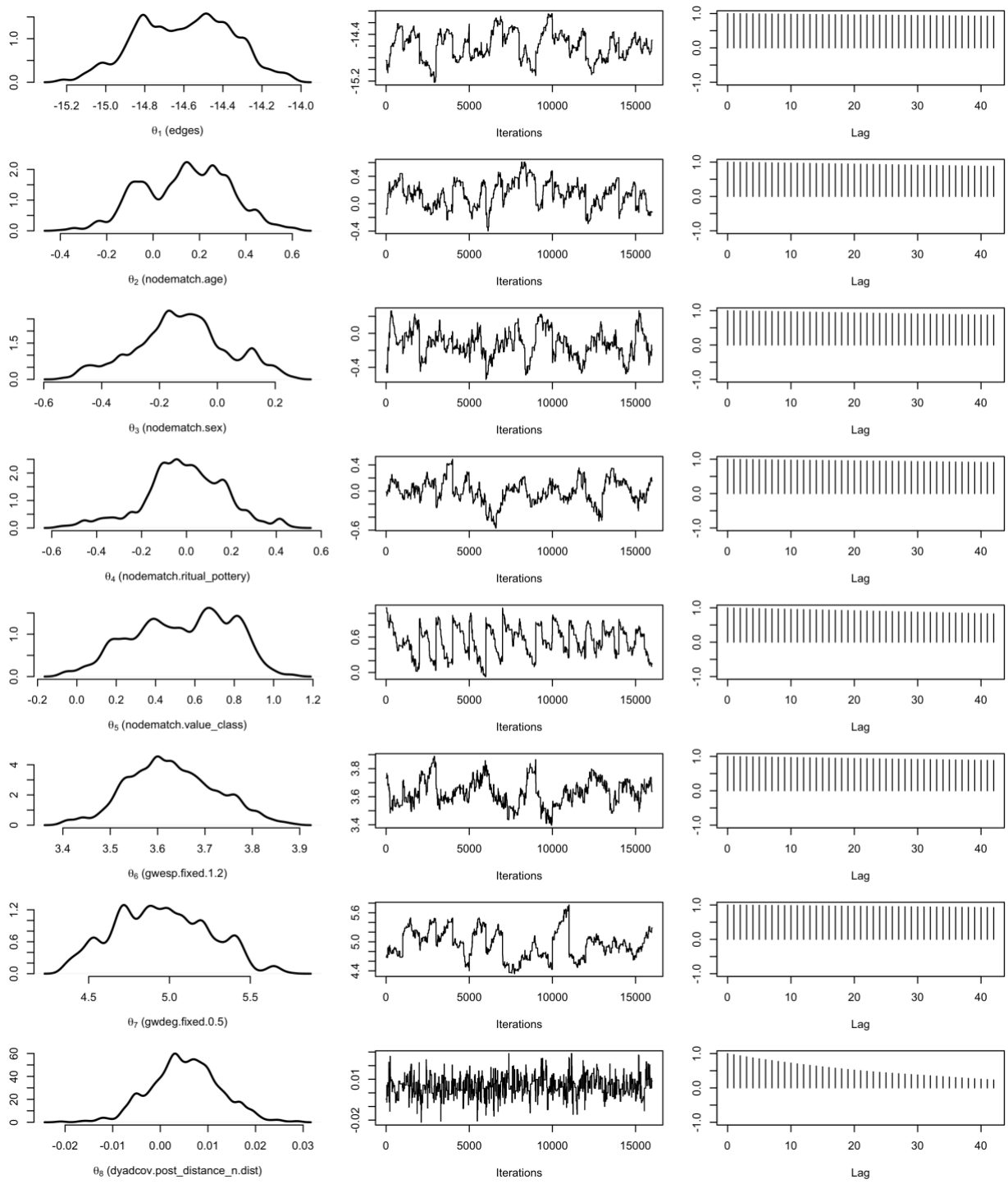

Figure B2: MCMC output of the post-European model. In the order of edges, nodematch-age, nodematch-sex, nodematch-ritual, nodematch-value, gwesp, gwdeg, and dyadcov.distance.

Appendix B References

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