Investigating social change during cultural contact period using geometric morphometry of pottery shapes from Iron Age northeastern Taiwan

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The emergence of ceramic specialization in prehistoric societies is often linked to shifts in the complexity of social structures, because specialized pottery 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 an important method 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. We infer increasing craft specialization and changes in social organization. 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. This study implies that craft specialization can be a deliberate act of resistance to show Indigenous identity and ethnicity in a direct culture contact situation.

# Introduction

The development of craft specialization is sometimes associated with social changes since it reflects changes in production systems that could inform on the social, economic, or political conditions of a society. We define specialization as “differential participation in specific economic activities”, in which a particular good is produced by fewer producers compared to the total population who consume it (Costin, 2001, p. 43, 1991). The effects of the emergence of specialization in past societies on their social structures and social processes is an important question in archaeological investigations of small scale societies in the Late Holocene. Considered through a political lens, craft specialization may be a strategy used by elites to control production systems to maintain their power and authority (Costin, 2001). This relationship between craft specialization and social differentiation has been broadly discussed, and many cases show that increasingly specialized production can be a useful indicator of increasing socio-political complexity (Hirshman et al., 2010; Junker, 1999). That said, a more economic focus considers production, exchange, and consumption as a whole to explain specialization as part of a strategy to accommodate uneven distributions of resources (Arnold and Munns, 1994; Costin, 2001). Craft specialization may appear as a reaction to changes in subsistence practices (Stark, 1995a), or as a result of long-distance trade and inter-regional exchange (Alizadeh et al., 2018). Present-day investigation of ceramic specialization in the Jodhpur region of India suggests that the adoption of standardized products across cultural boundaries is a reaction to a collapse of previous economic system, indicating a correlation with major socio-economic changes (Roux, 2015). However, it is important to note that explanations for the emergence of specialized production in past societies might not be so straightforward or singular. Acabado et al. (2018)’s case study in lowland northern Philippines shows that specialization is not necessarily accompanied with social differentiation based on a low degree of ceramic specialization in Ifugao ranked societies during the time of Spanish occupation. The development of specialization could be dependent on unique historical factors, where the conditions and contexts under which specialists organized must be taken into account when making inferences about changes in social organization (Costin, 2001; Roux, 2015).

The emergence of social inequality in the context of cross-cultural interaction, especially in a colonial situation, has been observed in many parts of the world, for example, when foreign trade goods are introduced to local Indigenous societies. The monopolization of long-distance trade goods has caused substantial transformations of 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 European colonial rule was limited and their conquests were short-lived and unsuccessful, but their colonial activities had economic and political impacts on Indigenous peoples living on the periphery of colonial control (Acabado, 2017; Trabert, 2017). Acabado (2017)’s study of Ifugao society in the Philippines highland suggests economic and political intensification during the Spanish presence as the response of Indigenous peoples to the Spanish cooptation. Indigenous societies might not simply passively accept colonial rule, but instead actively negotiate with the colonist, and accommodate or resist foreign intrusion 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; Torrence and Clarke, 2000). In this paper we present a case study from northeastern Taiwan as an example of these indirect impacts of foreign occupations on local Indigenous societies. Our aim is to investigate if there was increasing ceramic specialization resulting from Indigenous interaction with Europeans in the 17th century or Chinese in the 19th century, two major foreign influences in early historical Taiwan, that might indicate social changes in local Indigenous societies. Previous reports of archaeological evidence in northeastern Taiwan describes increases in the use of prestige goods, such as trade ornaments, and uneven artifact distribution patterns in domestic areas and burial contexts at the time when the Indigenous communities encountered the Spanish and the Dutch in the 17th century. Here we show that in addition to the differential distribution of trade ornaments post-European contact, the locally-made ceramics become highly consistent in their form and shape, compared to other pottery throughout Taiwan. This shift to higher consistency hints at the possibility of craft specialization in pottery manufacture.

To identify craft specialization in the archaeological record, variation in the standardization of a specialized product is often used as an indicator. This is based on the assumption that specialized mass production will lead to uniformity of the product due to routinization, higher skills, and fewer producers involved in production (Costin, 2001, 1991; Stark, 1995b). For investigating ceramic standardization, several measurements have been discussed and used, such as metric, compositional, and technological approaches (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 because of the ease of collecting these data. By comparing variations for sets of data using coefficient of variation coupled with statistical testing, the degree of standardization can be identified according to values (Eerkens and Bettinger, 2001; Roux, 2003; Stark, 1995b). Roux and Karasik (2018)’s ethnographic study in the Jodhpur region of India suggests the number of artisans can be statistically assessed by comparing coefficients of variation of linear dimensions of pots, and differences between artisans can be detected at both intra-individual level and inter-individual level in a region. 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 be relevant to standardization, a method that is sensitive to non-linear aspects of shape variation is necessary. Here we analyze pottery shape using geometric morphometric methods, a new approach for measuring the degree of standardization because it takes a statistical summary of the overall shape as variable for comparison (Slice, 2007). Using geometric morphometry, we study shape and standardization of locally made ceramics at Kiwulan (1350-1950 AD) (Chen, 2007), a large multi-component archaeological site in northeastern Taiwan, to identify changes in ceramic production resulting from cross-cultural interaction contexts.

Our hypothesis is that if foreign influences had impacts on the emergence of social inequality in local Indigenous society due to monopolies of trade arising among a small number of Indigenous people, then we expect to see changes in social organization from a more corporate to a more network organization (Feinman, 2000). We expect this corporate-network shift to manifest as increased specialization pottery manufacture, indicated archaeologically by increased standardization of pottery production at Kiwulan. The emergence of craft specialization, here pottery specialization, is often related to changes in social organization towards a society with increasing status inequality. In this case, if the competition among Indigenous individual for foreign resources and trade partnership with European or Chinese colonizers gradually lead to increasing social inequality, then we expect the local ceramics will show more homogeneous shapes after contact due to the emergence of craft specialization caused by greater economic and social control by a small group of individuals at Kiwulan. Our results are important for understanding the indirect influences of European colonists on local Indigenous societies, which remains unclear in East Asia where colonial power had limited success compared to other places in Southeast Asia. Our findings improve our understanding of the relationship between the use of imported prestige goods, the degree of ceramic specialization, and the influence of foreign colonizers in a pericolonial context (cf. Acabado, 2017).

## Geometric Morphometry

Geometric morphometric methods (GMM) has been increasingly applied in archaeology for shape analysis, which explores morphological variability and similarity of archaeological materials to address the questions of anthropological interest. Geometric morphometrics differs from traditional linear measurements through its use of Cartesian coordinates of morphological structures to define shapes (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 methods: landmark approaches and outline approaches (Adams et al., 2004). Landmark approaches assign a set of landmarks or semilandmarks onto objects as reference points that can be specified on a coordinate system as xy coordinates for two dimensions, or xyz coordinates for three dimensions. In a typical analysis, starting with raw landmarks, a sample of objects are translated to a common centroid, rescaled into the same size, and rotated until the summed squared distances between corresponding landmarks are minimized using generalized Procrustes analysis (GPA) (Bookstein, 1991). GPA is a method that superimposes sets of landmark configurations into a common coordinate system, where superimposed landmark coordinates are used as shape variables for further multivariate statistical analyses (Slice, 2007). Landmark-based morphometrics are widely applied to archaeological objects with obvious morphological features that can provide unambiguous reference points for landmark placement, such as projectile point tips or biological measurements points indicating osteological features (Birch and Martinón-Torres, 2019; Buchanan et al., 2019; Cardillo, 2010; Haruda et al., 2019; Lycett and Cramon-Taubadel, 2013; Meloro et al., 2015).

However, one limitation of landmark approaches is that landmarks may not be able to capture the shape differences of a morphological structure where the curving outlines between landmarks contain crucial variation. Furthermore, landmark points may be unavailable for structures that are mostly or entirely curves. In those cases, outline approaches are more suitable for analyzing the overall shape of an object. One outline approach is the semi-landmarks method, also called sliding landmarks, which assigns points along the curve between two landmarks at defined intervals (Bookstein, 1997; Lawing and Polly, 2010). Those semi-landmarks are allowed to slide along the curve to remove the effect of the arbitrary landmark spacing by minimizing either Procrustes distance or bending energy (Bookstein, 1997; Gunz and Mitteroecker, 2013; Slice, 2007). Another approach that is commonly applied to two-dimensional closed shapes is elliptic Fourier Analysis (EFA), that converts coordinates along a curve into Fourier function coefficients, called harmonic coefficients (Kuhl and Giardina, 1982). 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). The number of harmonics determines the quality and precision of the geometric representation of an object. The harmonic power, a cumulated sum of squared harmonic coefficients, provides a robust rule for determining the desired number of harmonics (Bonhomme et al., 2014).

EFA is suitable for shapes lacking representative landmarks or where curves contain the most meaningful variation. Applications in archaeology include human remains and zooarchaeology to understand biological variation, and more recently on stone artifacts to explore stone tool technology (Fox, 2015; Hoggard et al., 2019; Ioviţă, 2010). Ceramics is another archaeological materials that outline approaches can provide new insights into shape variation to answer anthropological questions related to ceramic specialization. Using semi-landmarks method, Topi et al. (2018) examine 89 photographs of globular jars from the Casas Grandes of northwest Mexico. Their results suggest that some ceramic types from the Medio period (AD 1200-1450), were made by specialists based on highly standardized shapes. Among those highly standardized jars, some were made by specialists attached to elites indicating the presence of social inequality, while others were made by independent specialists according to their spatial distribution patterns. Similarity, Selden Jr (2019) examined 28 Caddo bottles excavated at several sites (AD 500-1700) in northwest Louisiana using semi-landmarks method. The results indicate a significant integration between the different parts of the bottles including rim, neck, body, and base that vary in a coordinated manner. Also, two discrete base and body shapes represented northern and southern differences were identified. For the EFA method, Wilczek et al. (2014) evaluate 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. The results show the variation indicated by EFA and DCT matches the traditional ceramic typology, which supports that claim that outline-based approaches can be efficiently used for studying variations in ceramic shapes. Furthermore, Wilczek et al. (2014)’s EFA results help us understand the level of production standardization over time across the region. Those examples show that outline approaches can distinguish variation in ceramic shapes at high resolutions to understand ceramic production.

Taking the ceramics data from Kiwulan, northeastern Taiwan, we use EFA to evaluate the level of standardization of ceramics in relation to the European presence in the 17th century to get insights into the emergence of ceramic specialization. We use a significance test for the equality of coefficient of variations of shape variables to statistically compare the vessel standardization from different periods. Using pottery shape as a proxy to study craft specialization, we address these questions: Did foreign influence have impacts on Indigenous pottery production that can be detected in the shape of the vessels? Did pottery shape become more homogeneous and standardized after foreign contacts with European colonizers or Chinese immigrants?

# Archaeological background and materials

Ceramics analyzed in this paper come from 40 units (4m by 4m each) sampled from the central, undisturbed area of archaeological excavations at Kiwulan (Figure 1; Figure 2). 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 eastwards the Pacific with high mountains on three other sides. Yilan is an ideal context to study peripheral colonial influence because Indigenous communities there were isolated by natural barriers that limited the frequency of direct contact with the Spanish and the Dutch settlers in northern Taiwan. The chronology of the archaeological deposits at Kiwulan consists of two cultural components, the upper component and the lower component, with a sterile layer in between (Chen, 2007). This paper focuses on the upper component, dated from AD 1350 to AD 1950, covering the late Iron Age and the historical period, which we define as the European occupation in Taiwan in the early 17th century. The Dutch first occupied southern Taiwan in 1624 and then the Spanish occupied northern Taiwan in 1626 (Andrade, 2007). In 1642, the Spanish was expelled by the Dutch in northern Taiwan, who took over their forts at Helping Dau in Keelung, and in Tamsui. Since then, western Taiwan was mostly 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 1: Map showing the location of Kiwulan, and other places in northern Taiwan named in the text. Map data from naturalearthdata.com



Figure 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 contacts, 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 found in the upper component, indicating frequent long-distance trade activities with Europeans and Chinese merchants. In addition to artifacts, 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: the pre-European, European, and Chinese periods. We identified these phases using 32 previously published radiocarbon ages (Chen, 2007), excavation depth measurements, stratigraphic details reported by the excavators (color, texture, disturbance, etc.), and finds of chronologically diagnostic artifacts, such as 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 used by the Chinese in the 19th century (Chen, 2007; Hsieh, 2009; Wang, 2011). The deposit shows signs of continuous human occupation during each of the three phases across the sampling area.

The most abundant artifacts in the upper component are locally made ceramics, which are distributed throughout the sequence and across the site. More than 550,000 sherds were excavated, and around 1,200 vessels could be reconstructed. There are only two forms of local vessels, a cooking pot and a steamer made of two cooking pots stacked together with a clay filter layer in between. Those pots forms show high consistency in shape. They have a globular body with a short neck and wide mouth. The exterior surface below the neck is decorated with a wide variety of impressed geometric motifs. These vessels were probably used for cooking, with evidence of charred residues and carbon deposits frequently observed on vessel interiors and soot on their exteriors. Moreover, a lack of evidence of other utilitarian earthenware ceramics suggests these globular pots were mainly used for daily cooking. They are fired to orange to brownish color with a fully oxidized core or a reduced core with oxidized fringes. Finger impressions and seams usually on the interior indicate they were pinched using slabs of clay and shaped by hand. This kind of pot has been widely found at archaeological sites during the late Iron Age and the historical period throughout the Yilan Plain.

Petrographic analysis for 34 thin sections shows 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. The size of the particles ranges from 500 micron to 1300 micron. In general, the globular vessel fabric presents a mixture of fine, rounded argillite with a small part of rounded metasandstone and rounded to sub-angular monocrystalline quartz. The composition matches the mineralogical composition of local raw materials in the Yilan Plain (Chen, 2016). There are no substantial changes in the inclusions over time, indicating continuity in pottery fabric composition across the three periods.

# Methods

A total of 73 largely intact vessels from pre-contact contexts (n = 32), post-European contexts (n = 27), and Chinese contact contexts (n = 14) were selected for elliptic Fourier analysis. Most of them cover every vessel component from rim to bottom. The shape of vessel is the major object analyzed in this paper, however, to fully explore the pottery standardization, we also take the metric measurements into account for comparison. The total of 362 reconstructed pots (pre-European = 153, European = 173, Chinese = 36) were measured. The metric attributes include thickness of rim, neck, and body, and diameter of rim, neck, and body. For each pot, two measurements for thickness and diameter were taken to compute an average value. To obtain information about the pottery shape, we compare the ratio of Rim/Body thickness, and the ratio of Rim/Body diameter. In addition, we use Monte Carlo test for randomness in spatial locations of pots to explore whether their distribution is meaningful, such as clustered or dispersed pattern. As craft specialization increases, pottery distribution might shift from a dispersed pattern to concentrated clusters that reflects the location of production (Costin, 2001).

## Digitising and analysing by EFA

We used scans of pottery drawings acquired from the Bureau of Cultural Affairs in Yilan. All drawings present a two-dimensional view of vessel cross-sections with indications of metric measurements. The scanned drawings were imported into Inkscape (<http://inkscape.org>) where outlines were traced manually. Where only half cross-section images were available, these were duplicated, flipped, and then joined with another one to create a 2D closed outline for each vessel. Geometric morphometric analyses were conducted using the R software (R Core Team, 2019) and the functions included in the Momocs, a R package intended to quantify and analyze shapes, especially for outline analysis (Bonhomme et al., 2014). The digilized outlines were converted into a list of successive xy pixel coordinates for elliptic Fourier analysis (EFA), to investigate morphological differences among pottery shapes from our three occupation phases. The harmonic coefficients generated by EFA were analyzed 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) test to identify 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 in a ratio scale format:

By standardizing standard deviation in each data set, the coefficients of variation (CV) values allows us to directly compare variation in samples measured with different units or means. This is useful to compare the degree of standardization for archaeological assembles since CV scales standard deviation to the mean that enables comparison of variation across different sample sizes (Eerkens and Bettinger, 2001, p. 498). 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 CV is robust for positive values due to the representation by ratio, we normalized PC scores to a range between 0 and 1 before computation of CV.

To answer the question of whether CV values for vessel samples 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) 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).

# 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>. 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

To investigate the effect of the historically-documented decline of Indigenous population in the Chinese period (Chen, 2007; Hsieh, 2009) on pottery production we examined the spatial distribution of pots in our sample in each period. Our concern is that the smaller population size during the Chinese period could confound our investigations into craft specialization because of reduced numbers of potters and pottery production shrinking a few locations in the settlement during this time. Although the overall number of vessels is smaller during the Chinese contact period, Figure 3 shows that pottery is distributed randomly across the sampling area without any distinctive clusters. This suggests that differences in population across our three occupation phases are probably not driving variation in craft specialization.

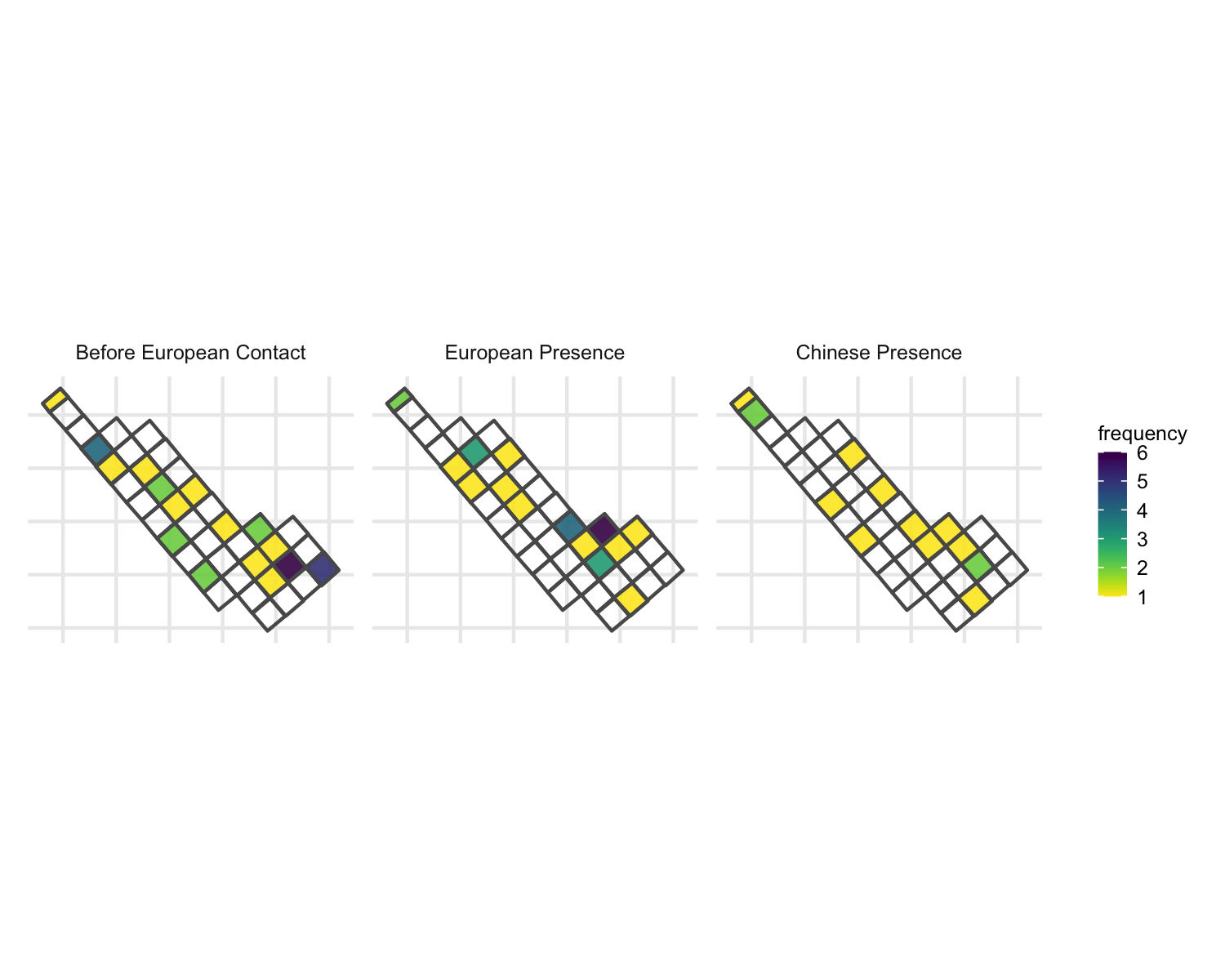


Figure 3: The spatial distribution of the pottery selected for shape analysis. The quantity is indicated by the color scale.

The elliptic Fourier coefficients of 73 pottery from three phases were calculated. Reliable pottery outlines were captured by 13 harmonics that gather 99% of the total harmonic power. Figure 4 shows the shape changes described using thin-plate spline warping for paired periods, pre- and post-European periods, and post-European and Chinese periods. The average shape of vessels from each phase was visualized and it shows more obvious differences between post-European and Chinese periods.

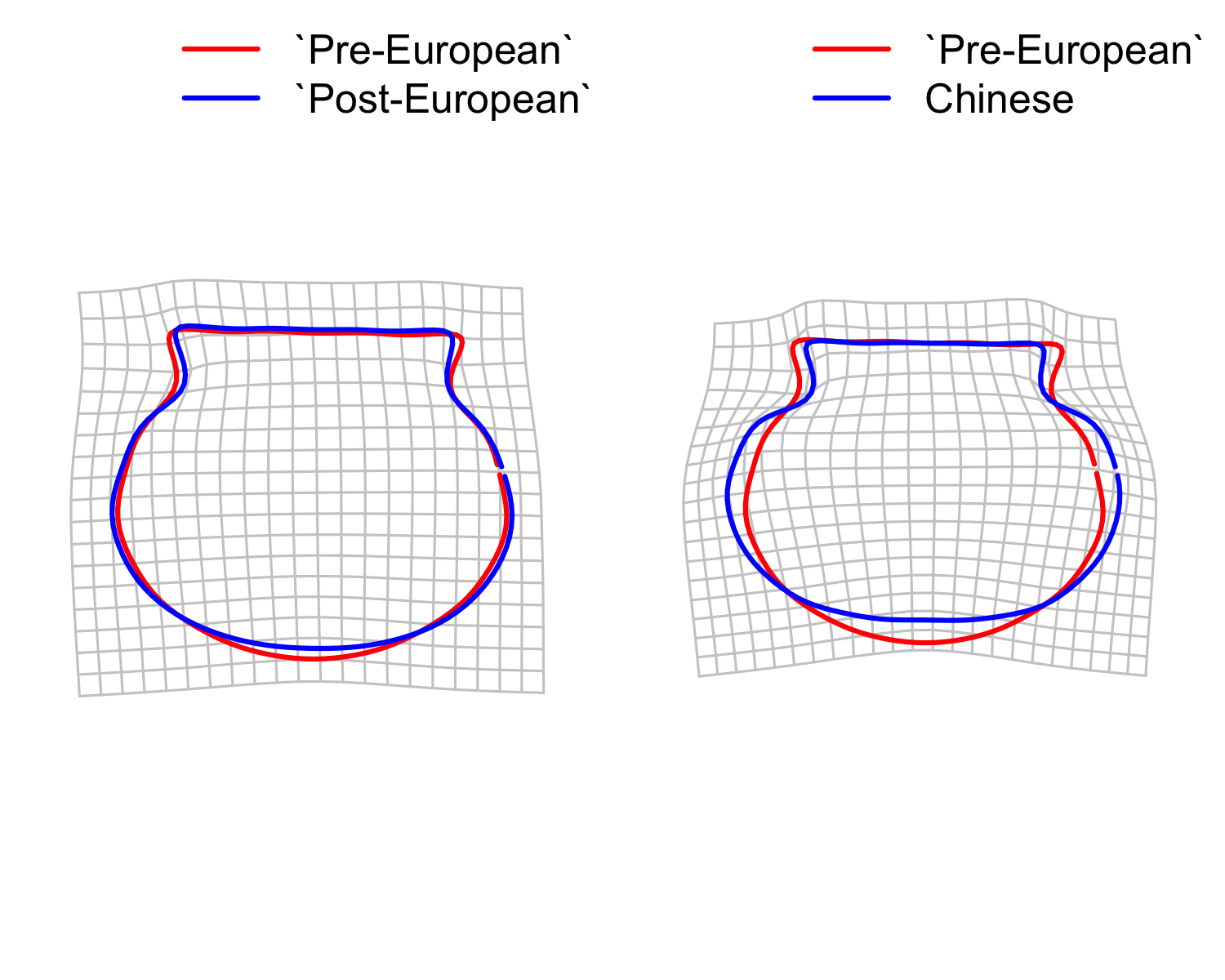


Figure 4: Compare the average shapes across phases using thin plate splines (TPS) with outline deformations required to pass from an extreme of the morphospace to the other.

The elliptic Fourier coefficients were examined by Principal Components Analysis to explore the shape variations across three phases. The first two principal components (PCs) explain 74.85% of the total variances, of which 48.32% is explained by the first principle component. With the third component, the first three principal components explain 86.08% of the total variance. According to Figure 5, PC1 captures the height of the vessels, from tall to short, and the roundness of the body from round to oval-shaped. 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 of the neck, from curved to straight shape. The first two components account for most of the variance in relation to three phases. 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 that is evident in the shorter height and narrower mouth of vessels used in that period.

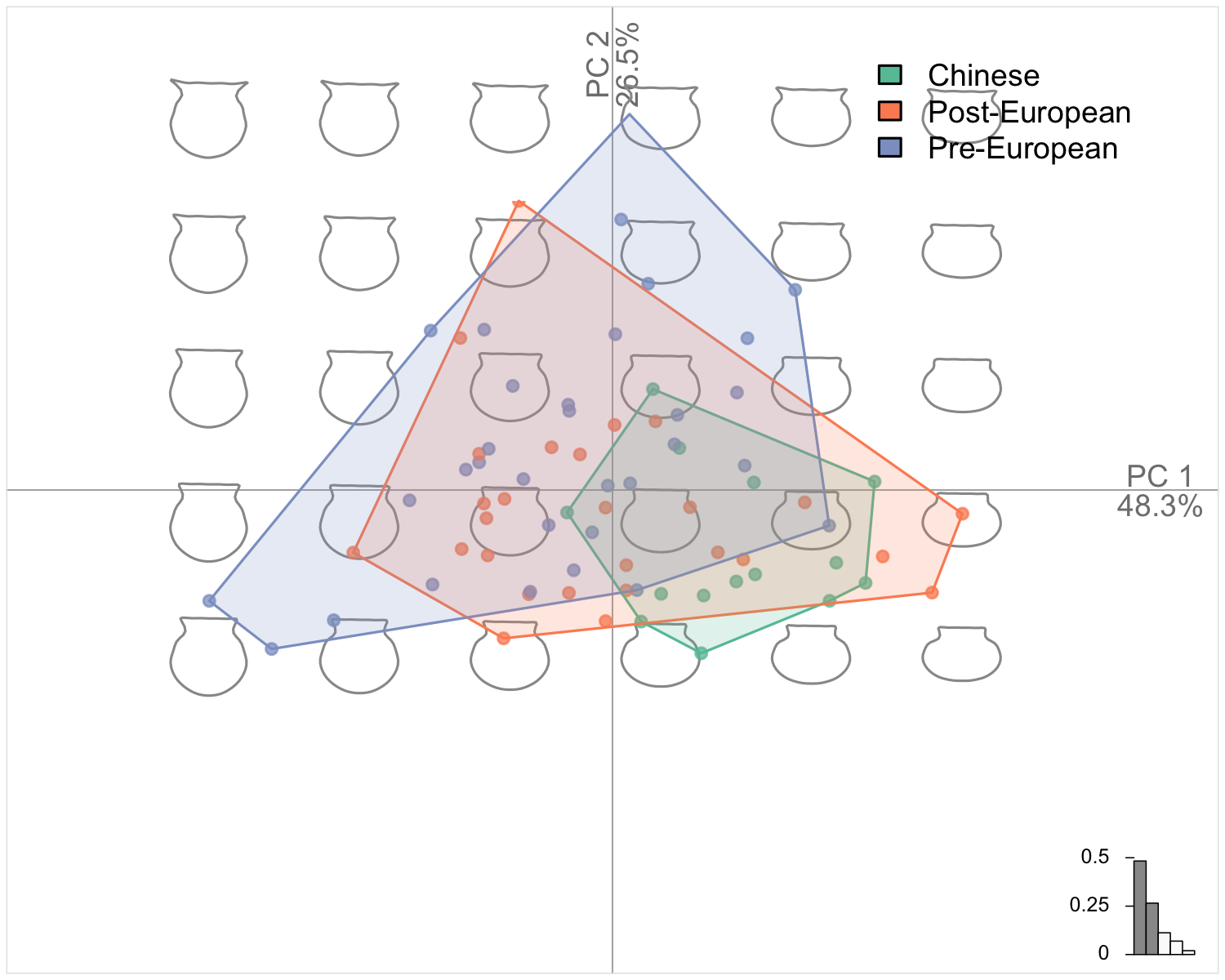


Figure 5: Pottery shape distribution by each occupation phase according to the first two PCs

Table 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.

|  |  |  |  |
| --- | --- | --- | --- |
| Pillai’s trace | Approximate F value | degrees of freedom | Pr(>F) |
| 0.3806 | 1.6202 | 29 | 0.1452 |
| 0.6942 | 7.0177 | 34 | 0.0000 |
| 0.3491 | 2.2917 | 47 | 0.0243 |

To test for differences in the distributions of shape variables indicated by the PC scores shown in Figure 5, we used a multivariate analysis of variance (MANOVA) test to compare pairwise combinations across our three occupation phases. Table 1 shows significant differences in shape between Pre-European and Post-European phases (p = ), and Pre-European and Chinese phases (p = ). Although there is considerable overlap of shape variables between the Pre-European and Post-European phases, their PC scores are significantly different from each other. There is little difference between vessel shapes in the Post-European and Chinese contact periods.

To compare pottery shape standardization across the three phases we investigate the distributions of the first three PC scores, taking the PC scores as proxy variables for vessel shape (Figure 6). The first PC, vessel height, shows higher variation in the pre-European period compared to the Chinese period. That indicates that shape standardization was higher in the Chinese period compared to the pre-European period. The second PC also presents a similar pattern of higher shape standardization in the Chinese period compared to the other two phases. To see whether the differences in the distribution of PCs between any two phases are substantive or due to chance, we used a modified signed-likelihood ratio test to assess the equality of CVs. P-values for this significance test of CVs for PC1 and PC2 show significant differences in the standardization of vessel shapes across periods, especially between Chinese contact with either pre-European or post-European (Figure ??, Table 2). A significant difference is also detected between the pre-European and post-European periods.

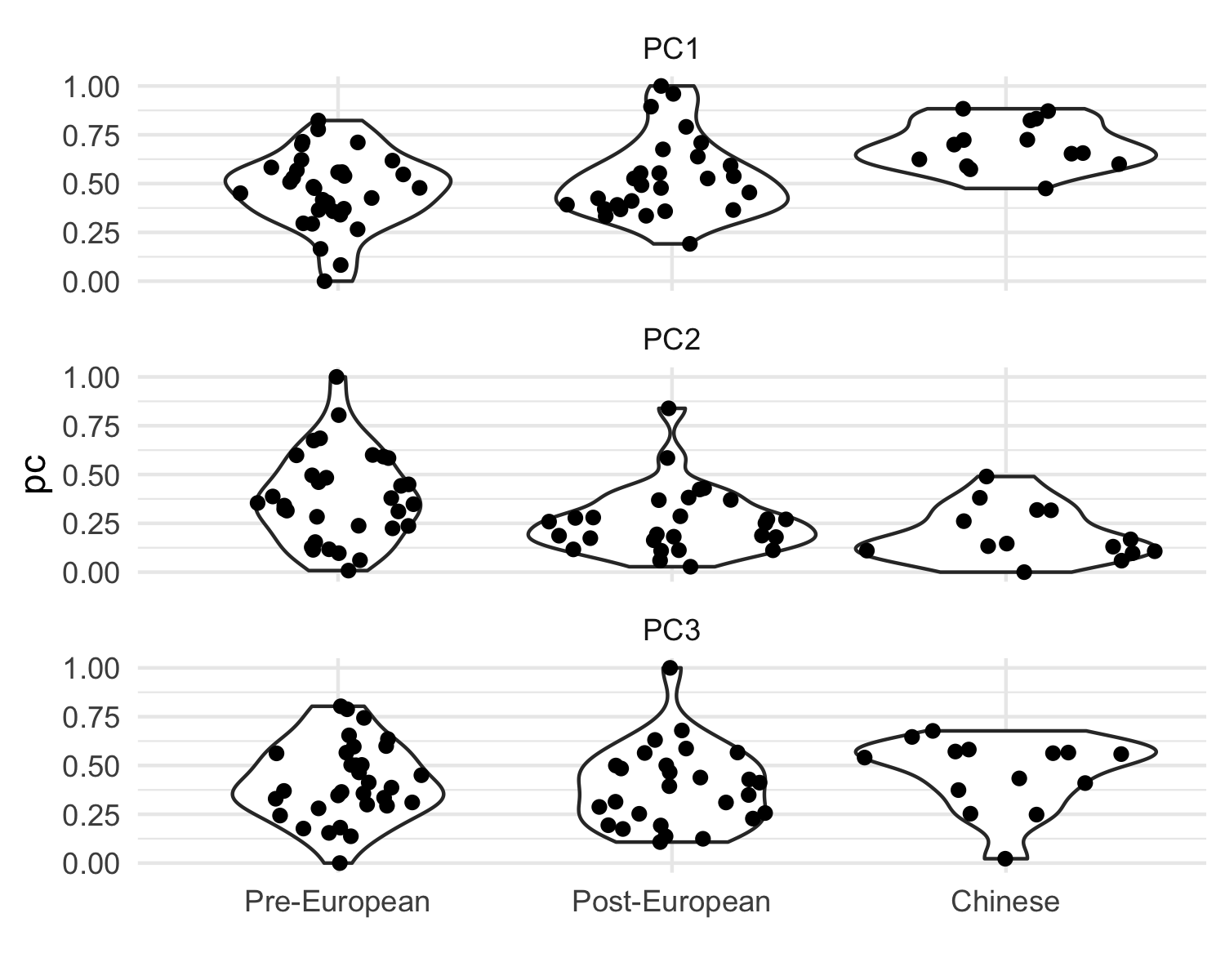


Figure 6: The distribution of PC scores by phases

Table 2: P-values of the CV equality test of PC1 and PC2 between phases

|  |  |  |  |
| --- | --- | --- | --- |
| PC | MSLRT | p\_value | phases |
| PC1 | 0.0781 | 0.7799 | Post-European vs Pre-European |
| PC1 | 9.0612 | 0.0026 | Chinese Contact vs Pre-European |
| PC1 | 6.7882 | 0.0092 | Chinese Contact vs Post-European |
| PC2 | 0.1288 | 0.7196 | Post-European vs Pre-European |
| PC2 | 0.2442 | 0.6212 | Chinese Contact vs Pre-European |
| PC2 | 0.0585 | 0.8089 | Chinese Contact vs Post-European |

# Discussion

Previous investigations at Kiwulan have suggested an unequal distribution of prestige goods, trade ornaments specifically, following the appearance of Europeans (Cheng, 2008; Wang, 2011), hinting at the emergence of social inequality in the Indigenous community. Here we have examined ceramic vessel shape standardization to measure craft specialization as a proxy for social differentiation, such as elite control (Costin, 2001; Junker, 1999). Our results indicate that differences in pottery shape can be detected using EFA. The result of our MANOVA test shows there is a significant difference in shapes between the pre-European and Post-European periods, and between the pre-European and the Chinese periods. The average shape presents a round body with a wider rim and neck before European contact, and turns to a more oval-shaped body with narrower rim and neck after the European presence. These changes even more pronounced during the Chinese contact period. In general, pottery vessels become shorter in height over time, leading to an oval-shaped body.

Our CV tests indicate that there are significant differences in shape standardization between the pre-European period and post-European period, and between the Chinese contact and either pre-European or post-European periods. This suggests pottery shape became more homogeneous and standardized after foreign contacts with European colonizers and even more so after contact with Chinese immigrants. Compositional analysis shows that the clay pastes are similar, 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. To determine if shape changes might be related to changes in the function of pots at Kiwulan, 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 is 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).

We compare the result of shape variable with the result of metric data for six measurements and two ratio values using CV test (Table 3). Metric measurements show there is a significant difference (p-value less than 0.01) between CV values for two metric measurements across phases, the rim diameter and the neck diameter before and after the European presence. After the arrival of the Chinese, there is only one metric attribute, the rim diameter, showing significant difference compared with post-European period (p-value less than 0.05). Although these results show the differences between different contact phases that corresponds to part of the results of shape variable, elliptic Fourier analysis captures more subtle differences in a substantial way reflected by overall shapes of pottery, not only limited to diameter variables. In addition, the result of spatial analysis (Figure 7) for pottery shape samples presents multiple clusters with high density of pottery during the European presence. However, the hypothesis testing on spatial randomness indicates a non-randomly dispersed distribution before European contact and more extreme dispersed after European presence. In contrast, the distribution of pottery is more similar to the random distributions during the Chinese period. This contradicts our expectation that clustered pattern will be observed with an increase in pottery standardization since the emergence of specialized groups. Or, this may indicate that there are other factors lead to pottery shape standardization instead of a small number of artisans.

Table 3: Coefficient of Variation for metric attributes by three phases using Asymptotic test (Feltz and Miller, 1996). The first set of P-value represents the comparison between before European and European periods, while the second represents the comparison between European and Chinese periods

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| variable | before European | European | Chinese | D\_AD-1 | P value-1 | D\_AD-2 | P value-2 |
| Rim thickness (mm) | 23.0893 | 26.3245 | 21.8166 | 2.3423 | 0.1259 | 1.5072 | 0.2196 |
| Neck thickness (mm) | 17.3862 | 20.3716 | 19.8610 | 3.6038 | 0.0576 | 0.0329 | 0.8561 |
| Body thickness (mm) | 25.9332 | 28.6251 | 24.1887 | 1.3382 | 0.2473 | 1.2724 | 0.2593 |
| Ratio of Rim/Body thickness | 31.9633 | 30.7785 | 30.0600 | 0.1812 | 0.6703 | 0.0252 | 0.8738 |
| Rim diameter (mm) | 6.8355 | 9.6082 | 6.9300 | 17.0602 | 0.0000 | 4.6128 | 0.0317 |
| Neck diameter (mm) | 10.6207 | 7.7212 | 7.0658 | 15.3071 | 0.0001 | 0.4012 | 0.5265 |
| Body diameter (mm) | 9.2486 | 8.8551 | 6.5620 | 0.2684 | 0.6044 | 3.3958 | 0.0654 |
| Ratio of Rim/Body diameter | 6.6892 | 7.2115 | 7.0293 | 0.7686 | 0.3806 | 0.0280 | 0.8671 |

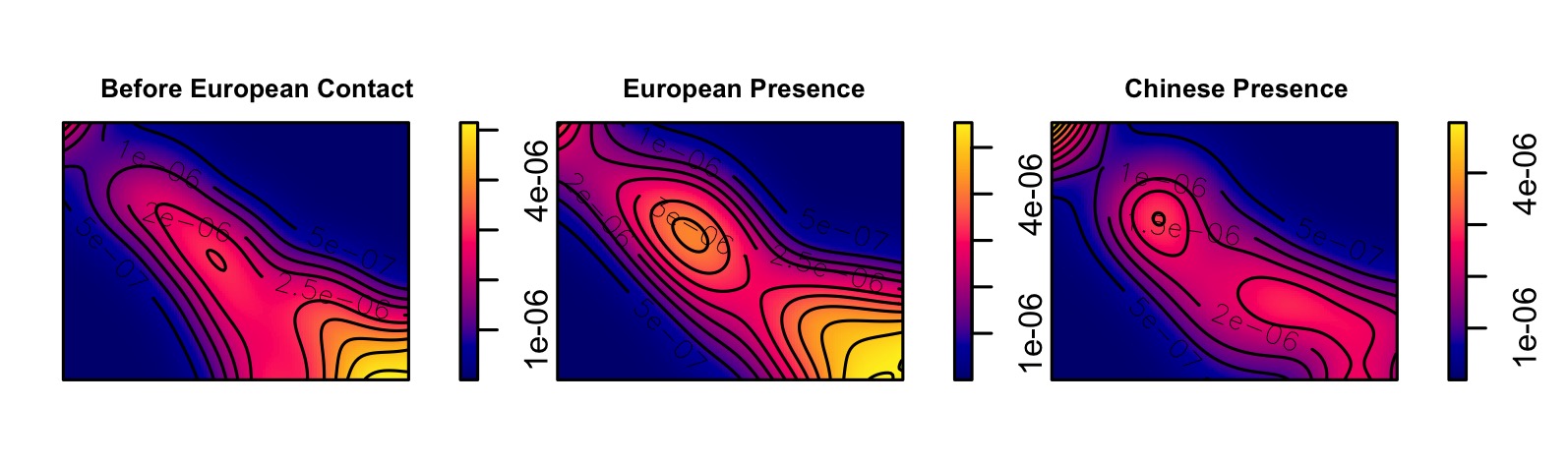


Figure 7: Kernel density map visulizes the probability of the density of pottery across space. The map shows major core area during the pre-European period, multiple core areas during the European period, and a single core during the Chinese period. Used the bandwidth based on Silverman (1986)’s rule of thumb

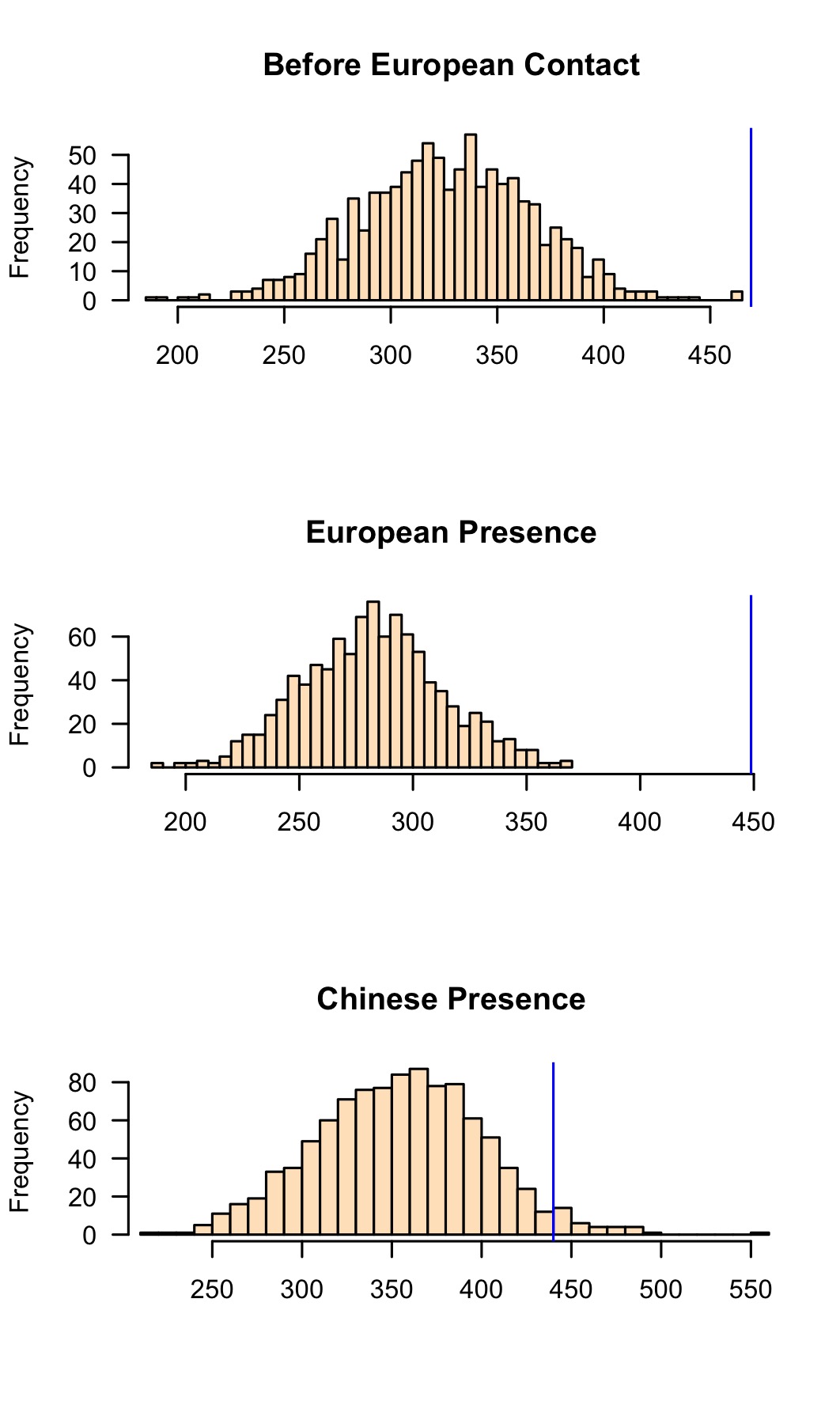


Figure 8: Histograms of simulated average nearest-neighbour distances (ANN) values from 1000 simulations for three phases. X-axis values based on meteres represent ANN expected value. Each sample distribution presents the null hypothesis with the blue line indicating the observed ANN value

Our results offer tentative support for the hypothesis that foreign influences at Kiwulan influenced emergence of social inequality in the local Indigenous society. If increased shape standardization is a reliable indicator of craft specialization, then we may be seeing evidence of a shift from corporate to network organization (Feinman, 2000). However, strong claims for an emergence of social complexity resulting from foreign contact at Kiwulan will need support from multiple and diverse sources of evidence. This should include the other two main datasets at Kiwulan, the ornaments assemblages, and the burial goods. We find vessel shapes were more standardized in the Chinese period than the European period, contrary to previous work that has downplayed the effect of Chinese settlement in Yilan (Wang, 2011). Compared to other regions in Taiwan, European colonial influence was weak in Yilan due to the isolated of the surrounding mountains and the economic focus of the Spanish and Dutch who preferred northern Taiwan as their trading base. Indigenous communities 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, the interaction between Indigenous people and Chinese in the 19th century appears to have been more intense and direct. Historical records indicate that Chinese immigrants 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 porcelains and distinctive architectural bricks and tiles used by Chinese (Hsieh, 2009). Similarly, burials at Kiwulan in this later phase show the adoption of coffins in mortuary practices, which Chen (2007) interprets as the adoption of a symbol of ethnic Chinese.

We recognize that the shape variation reported here is subtle, and this invites consideration of the possibility that the absence of major changes in vessel shape at Kiwulan may have been an act of resistance to foreign influence. Continuities 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, social identity may be expressed through material practices to show 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 may be more than a colonized–colonizer or local/foreign dichotomy (Voss, 2008, 2005). Shamaoshan cemetery (3BC- 4AD) in Southwest China shows 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). 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 can be viewed as a symbol as an expression the 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 over time at Kiwulan, the production of the local pottery continued and became more standardized. This might imply not only a utilitarian function of the local vessels, but a deliberate action to emphasize the local pottery tradition as their cultural custom as foreign contact intensified.

# Conclusion

This study demonstrates an application of elliptic Fourier analysis on ceramic shapes to explore the emergence of ceramic specialization as indicative of foreign influences. Here, EFA is combined with a significance test for the equality of CVs of shape variables to provide a robust way to identify and statistically assess differences in shape standardization. The direct relationship between foreign influences and standardization of ceramic shape was tested on pottery from Kiwulan, and large Iron Age Indigenous settlement in northeastern Taiwan. Lower variation in ceramic shape was identified after European presence began, and even lower variation during the period of Chinese presence. Our findings help to understand the factors that may lead to standardization of pottery production in a cross-cultural interaction context. More homogeneous shapes during the contact periods, without any changes in clay paste composition or production technique, suggests that shape standardization was intentional. The results here further suggest that expressions of social identity or cultural boundaries in Indigenous societies through highly visible vessel qualities, such as shape, may be heightened during periods of foreign intrusion 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 Iron Age ceramic technologies.

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### Colophon

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#> tidyselect 1.0.0.9000 2020-02-23 [1] Github (r-lib/tidyselect@bb145af)   
#> tidyverse \* 1.3.0 2019-11-21 [1] CRAN (R 3.6.0)   
#> tweenr 1.0.1 2018-12-14 [1] CRAN (R 3.6.0)   
#> units 0.6-5 2019-10-08 [1] CRAN (R 3.6.0)   
#> usethis 1.5.1.9000 2020-03-20 [1] Github (r-lib/usethis@4cfa070)   
#> vctrs 0.2.4 2020-03-10 [1] CRAN (R 3.6.0)   
#> viridis \* 0.5.1 2018-03-29 [1] CRAN (R 3.6.0)   
#> viridisLite \* 0.3.0 2018-02-01 [1] CRAN (R 3.6.0)   
#> withr 2.1.2 2018-03-15 [1] CRAN (R 3.6.0)   
#> xfun 0.12 2020-01-13 [1] CRAN (R 3.6.0)   
#> xml2 1.2.5 2020-03-11 [1] CRAN (R 3.6.0)   
#> yaml 2.2.1 2020-02-01 [1] CRAN (R 3.6.0)   
#>   
#> [1] /Library/Frameworks/R.framework/Versions/3.6/Resources/library

The current Git commit details are:

#> Local: master /Users/bmarwick/Desktop/kwl.pottery  
#> Remote: master @ origin (https://github.com/LiYingWang/kwl.pottery)  
#> Head: [1861e54] 2020-02-23: Update Dockerfile

Word count: 6061