Applying a Bayesian Approach in the Northeastern North American Context: Reassessment of the Temporal Boundaries of the "Pseudo-Scallop Shell Interaction Sphere"

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Abstract. In Europe, especially for studies focusing on Palaeolithic rock shelters, Bayesian chronological modelling is gaining in popularity. In northeastern North America, conditions are usually less than optimal for applying this type of modelling, as archaeological sites are often poorly stratified and subject to substantial pedoturbation. Notwithstanding these impediments, I show that a Bayesian approach remains applicable, provided sufficient and high quality information pertaining to the stratigraphy and the datable samples is gathered beforehand. This is illustrated through a case study dedicated to the "Pseudo-Scallop Shell (PSS) interaction sphere" (Méhault 2015, 2017). The posterior distributions obtained for each of its 14 regional composites generally exceed the regional start boundaries commonly attached to the Middle Woodland period, suggesting that the PSS interaction sphere overlaps with the preceding period (i.e., Early Woodland). Only in its westernmost expression (i.e., in the Laurel culture) does the PSS interaction sphere seem to persist during the Late Woodland period.

Résumé. En Europe, et surtout avec les études consacrées aux abris sous roche du Paléolithique, la modélisation chronologique bayésienne gagne en popularité. Dans le nord-est de l'Amérique du Nord, les conditions laissent généralement à désirer (sites souvent peu stratifiés et sols perturbés), et nuisent ainsi à l'applicabilité d'une telle approche. Nonobstant ces limitations, je montre qu'elle demeure applicable, en autant qu'assez d'information de qualité ait été consignée d'emblée au sujet des échantillons datés et de la stratigraphie. Ceci est illustré à l'aune d'une étude de cas portant sur la « sphère d'interaction Pseudo-Scallop Shell (PSS) » (Méhault 2015; 2017). Globalement, les distributions *a posteriori* calculées pour chacun de ses 14 composites repoussent le *terminus post quem* conventionnellement attaché au Sylvicole moyen, suggérant ainsi que la « sphère d'interaction PSS » déborde sur la période précédente (Sylvicole inférieur). Uniquement dans ses expressions les plus occidentales (c'est-à-dire dans la culture Laurel), cette sphère d'interaction persiste-t-elle au cours du Sylvicole supérieur.

In the last two decades, Bayesian approaches to chronological modelling have become ever more computationally affordable. Several kinds of software, each armed with its own features and calculation approaches, have tremendously facilitated the usability of Bayesian techniques for a larger public of non-statisticians. However, since the efficiency of Bayesian modelling depends on prior knowledge and/or observations, these techniques are informationally demanding; they neces-

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sitate the collection of high quality data pertaining to both the contexts of excavation and to the datable samples themselves. Unfortunately, the Northeastern North American archaeological context is plagued by a series of hindrances: 1) with the notable exception of New York State (Hart and Brumbach 2005; Hart and Lovis 2007; Hart et al. 2011), a relative scarcity of good and recent datable samples (i.e., including reliable remarks concerning the nature of the material and small uncertainty associated with the age); and 2) most importantly, problematic stratigraphic contexts, which are, more often than not, poorly stratified and significantly pedoturbated. Notwithstanding these impediments, palliative solutions do exist: the data can be filtered through various "hygiene" processes, and the choice of an appropriate model can also compensate for imperfect, and frequently occurring, conditions.

The objective of this study is twofold. Basically, the present manuscript aims at articulating the principles and techniques of Bayesian chronological modelling within the contextual specificity of Northeastern North American archaeology. To illustrate this, a case study is presented, which concerns a peculiar phenomenon in Northeastern North American Prehistory: the apparent ubiquity and homogeneity, at a transregional level, of the pottery decorated with the "pseudo-scallop shell" (PSS) pattern (Méhault 2015, 2017). The objective of the present study may thus be summarized into two lines of investigation:

1. What does Bayesian chronological modelling entail? And how is it applicable to the Northeastern North American archaeological context?
2. As a case study, what are the temporal boundaries of the PSS interaction sphere? Are regional discrepancies noticeable? How do they mesh with the regional taxonomies attached to the Middle Woodland (MW) period in general, and to the early Middle Woodland (EMW) sub-period in particular?

The first point consists of a brief overview of the tenets of Bayesian modelling as applied to chronological assessment in the domain of archaeology. I also formulate a few guidelines for the operationalization of Bayesian approaches in the context of Northeastern North American archaeology: 1) by underlining the importance (for analysts) to scrutinize all available and relevant information ascribed to dated samples; and 2) by elaborating, through concrete examples, solutions for the optimization of Bayesian techniques for both stratified and non-stratified archaeological sites.

The second point concerns the prehistory of northeastern North America in that it aims to assign credible dates for both the start and end of the PSS interaction sphere within 14 different regional composites (*sensu* Syms 1977), broadly corresponding to as many hydrographic basins (Mehault 2015). In northeastern North America, the most recent attempts at building comprehensive chronological frameworks bearing on the Middle Woodland period took place approximately two decades ago. These investigations targeted regional ensembles, such as the work of Petersen and Sanger (1991) devoted to the Atlantic Coast, that of Smith (1997) for southern Ontario, and that of Reid and Rajnovich (1991) for the Laurel culture. This study distinguishes itself in its spatial scope and for its reliance on a formal Bayesian framework, which allows for the calculation of accurate credibility intervals of dates that take into account not only the raw data per se (i.e., the datable samples), but also the stratigraphical information available for each site. The EMW sub-period is usually identifiable in northeastern North America by a recognizable archaeological marker: the PSS stamp applied on pots. This marker occurs over a very broad area, spanning from the prairies of Eastern Saskatchewan to the Atlantic coast of Maine; this breadth of distribution underscores the hypothesis that, north of the Hopewellian sphere of the American Bottom (Caldwell 1964), bands were participating in a vast interaction sphere at that time, which was shaped by the transmission of ceramic know-how and probably by the circulation of the makers of these pots. However, the overall ceramic variability displayed by the potters who partook in this interaction sphere should not be reduced to just one stylistic signature. Difficulties (and subjective discrepancies between analysts) arise with the identification of the PSS stamp. The "wavy" pattern is created with some sort of toothed or serrated decorator and can be produced using multiple techniques, such as simple vertical stamping, dragging (or push-pull), rocking, and even trailing and incising. However, the wavy pattern may not consistently appear because of small subtleties in the decorating process, such as the angle at which the instrument is impressed or the intensity of its pressure on the surface of the wet clay (hence the terms such as "Laurel linear", "Laurel undragged", "Linear punctate", or "banked" used in Brose [1968]). The PSS interaction sphere must be understood as encompassing all these nuances (Figure 1).

Bayesian Chronological Modelling

Principles

Bayesian statistics aim at finding the probability that a mathematical event occurs in the light of past events relevant to the case at hand. Bayes' theorem thus consists in finding a posterior probability, which is the product of a likelihood function and prior knowledge. To chronologists, this often translates into confronting the estimated age of pieces of evidence (be they geological or archaeological)—each related to a particular past event—with the relative positioning of said pieces of evidence in the soil. Concretely, any discrepancy between the two is either due to sampling errors (spurious stratigraphic localization or wrong measured age) or to pedoturbation. Because Bayesian modelling rests upon assumptions and subjectivity (the two forming beliefs), the comprehensiveness of the data pertaining to each dated sample is of the utmost importance. Said data are composed of bits of the "reality" that is under observation and can be described as the prior knowledge that is "fed" to the model. Prior information is paramount in Bayesian modelling for it is likely to minimize uncertainty—thus potentially increasing the precision of the predicted outcome (the posterior probability)—and perhaps more importantly, because it also aids in evaluating the validity of the proposed models (Bayliss 2015; Buck and Meson 2015). Put simply, provided the model approaches as closely as possible the perceived reality, the more input we have, the more positive the effects will be in terms of both "accuracy" and "precision" (see also Scott et al. 2007). Figure 2 illustrates how these two crucial notions can be distinguished from each other. Accuracy concerns the potential for a model to approximate reality (and thus to hit the bull's eye, even if at the cost of greater dispersal), while precision bears on the ability for the model to minimize uncertainty (hence the concentrated impacts, albeit possibly far from the

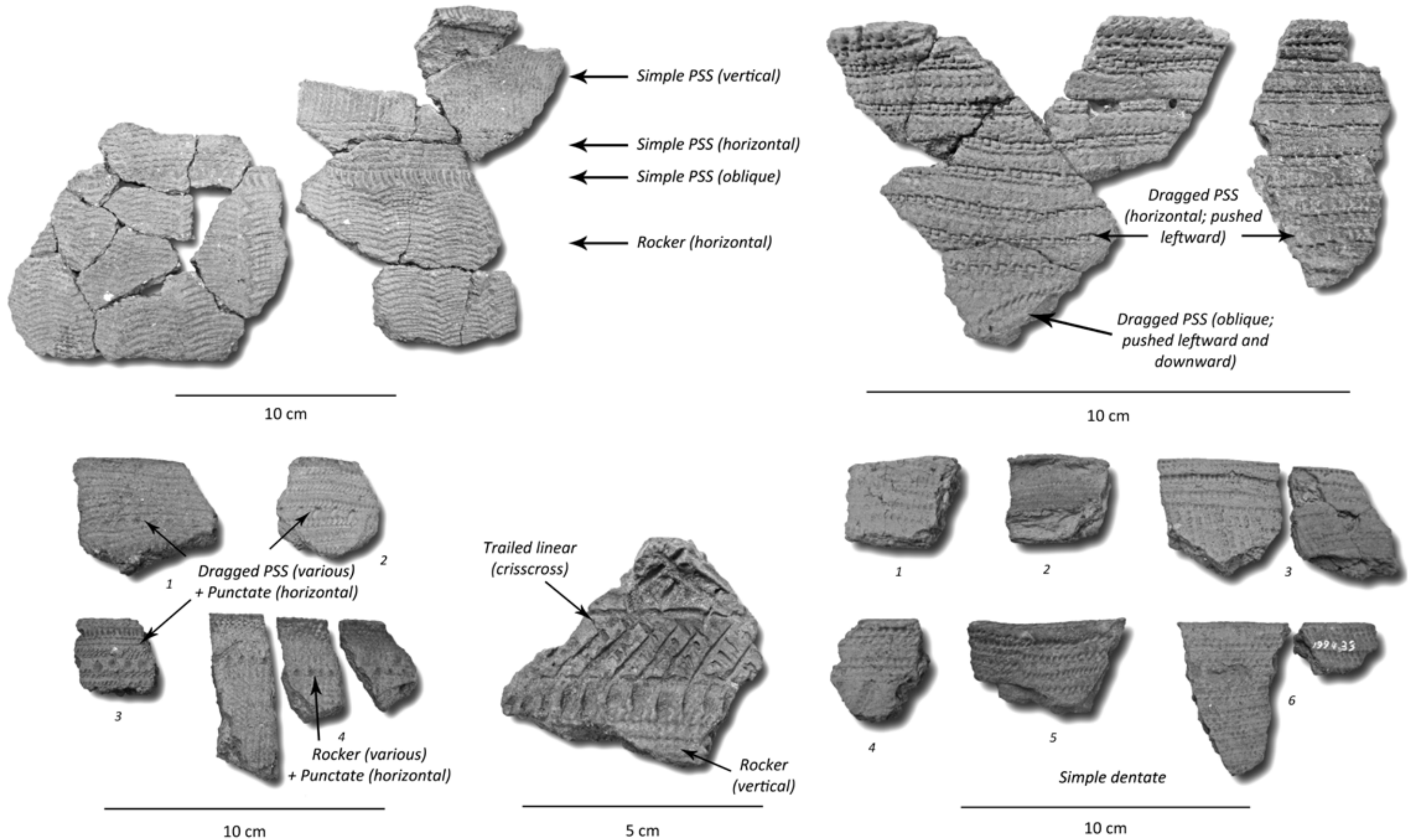


Figure 1. Some diagnostic traits of pots belonging to the Eastern PSS Horizon.

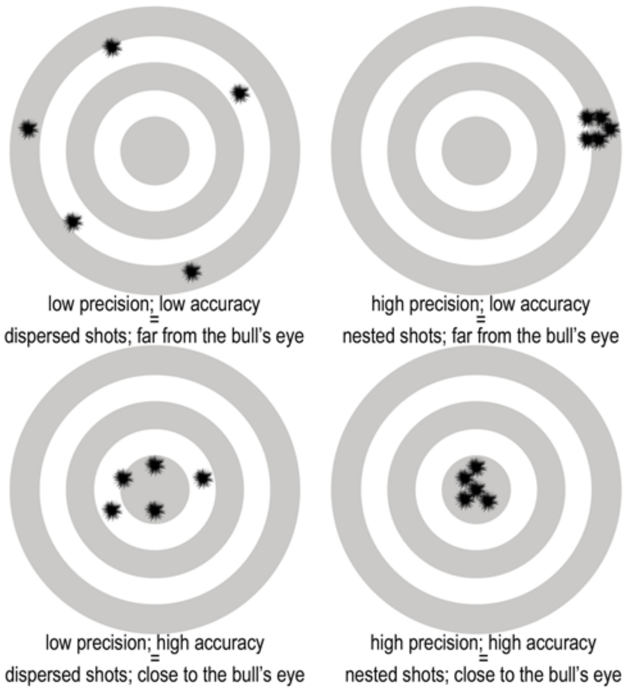


Figure 2. Visual representation of the differences between the concepts of "accuracy" and "precision".

bull's eye). An excellent model will hold the capacity to optimize these two aspects simultaneously, but it will require a lot of high-quality data (i.e., prior information). Since high-quality data is often in scarce supply, models will return imperfect outcomes, and the analyst may have to juggle accuracy and precision.

Before modelling, the dates can be filtered through a process of chronometric hygiene based on the degree of uncertainty associated with each measured age. Such a procedure privileges precision over accuracy. With a meta-analysis like the one at the heart of the present study, such a process would greatly reduce the accuracy of the models since the pool of radiocarbon dates is composed, for the most part, of samples analyzed several decades ago, at a time when laboratory techniques included incomplete pretreatment of samples and yielded much greater errors in the measurements. In that regard, the Accelerator Mass Spectrometry (AMS) technique, developed after 1977, constitutes a milestone in the advancement of chronological dating. Sacrificing the majority of the data could be a reasonable option only if dates produced more recently were available for all the sites under examination, or at least for the majority of them. Unfortunately, this is not the case here.

For modelling purposes at the archaeological site level, the priors usually consist of information regarding stratigraphy, site formation, and post-depositional processes, and all these informational fields dictate the order in which the dated samples are arranged within the model. Through this sequencing, the analyst has the opportunity to statistically and *a posteriori* flag outliers—thus revealing the presence of pedoturbation or postdepositional displacement of the sample—and then to either remove or keep them. Removing outliers would cause a reduction in accuracy, but on the other hand, the model could gain in precision, especially if the outlier is located at either one of the extremities of the sequence (start or end).

Conversely, keeping as much data as possible will preserve the integrity and the likelihood of the model (i.e., its accuracy) since it remains faithful to an observed reality (the prior knowledge) that may be noisy. Also, precision of a discrete, calibrated date apparently increases when it is modelled within bigger samples. When more dates are included in the model, and as long as the model is credible enough (for example, an ordering of dates perfectly echoing their stratigraphic sequence), the effect of major uncertainties at 1σ (in this study, some surpassing 200 years) will tend to be minimized *a posteriori* (Figure 3). However, this apparent optimization may actually just be a statistical artefact produced by the algorithms (Steier and Rom 2000). So all in all, unless newer dates are produced for the majority of the events, an analyst may wish to consider, focusing on the uncertainty that comes with the measured age may not be the best idea. On the other hand, radiometric hygiene procedures

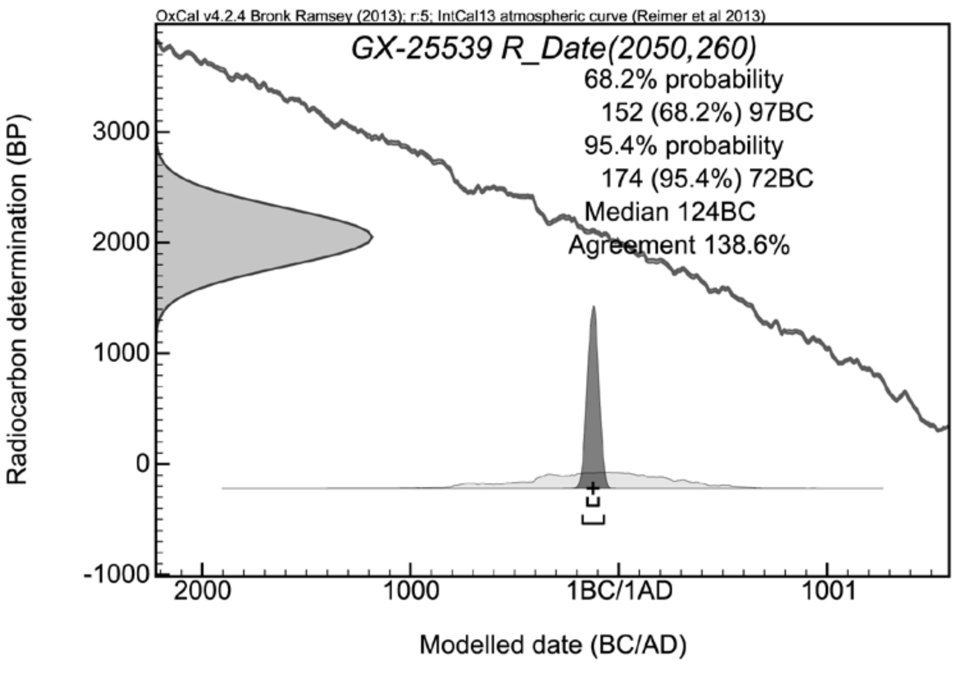


FIGURE 3. Modelled date constitutive of the modelling of the "Atlantic Coast" phase as displayed under Oxcal 4.2 (Bronk Ramsey 2009a). Because the position of the date fits extremely well within the overall sequence (Agreement = 138.6%), the prior uncertainty (σ = 260) "appears" to be drastically reduced after modelling (i.e., *a posteriori*).

that target possible instances of contamination, and other factors that could cause measurement errors in the laboratory, are relevant, for they all contribute to the elimination of inaccuracies.

Computational Considerations

Chronomodel 1.1 Software and Model Properties. In this study, models were run with Chronomodel 1.1 (Lanos and Philippe 2015a, 2015b), a newcomer to the family of software programs developed for Bayesian chronological modelling that brings a few innovative features to the chronologist's toolkit.

The sequencing of archaeological contexts, however they are understood (i.e., as layers, stratigraphic units, events, phases, or periods, etc.), is facilitated with Chronomodel through an intuitively astute interface that allows the analyst to organize the hierarchical relationships between said contexts via the use of blocks and connectors (comparable to Harris matrices or directed acyclic graphs [DAGs]; see Dye and Buck 2015). Connectors (in the form of arrows) act as constraints, but their use must be supported by prior information, such as stratigraphic ordering of the samples.

Chronomodel allows the analyst to set the Markov Chain Monte Carlo (MCMC) parameters manually. In this study, the MCMC parameters for the vast majority of archaeological sites are as follows: number of chains = 3; burn-in period = 1,000 iterations; adapt period = 1,000 iterations in each of the 100 batches; acquire period = 100,000 iterations; thinning interval = 1 (for detailed mathematical descriptions of Bayesian operations and of MCMC simulation algorithms, see the user manual for Chronomodel; Bronk Ramsey 2009a; Lanos and Philippe 2015b). Several diagnostics help assess whether the MCMC procedure returned satisfactory results (i.e., whether equilibrium in the chains has been reached and correlations between successive values are low). For a handful of runs, more substantial sampling was needed before a satisfactory equilibrium could be reached. The acquire period passed to 1,000,000 iterations with a thinning interval of 10, meaning that the same number of observations (i.e., 100,000) was made, but with a greater interval of data being discarded, which caused the autocorrelation rate to decrease more rapidly.

Moreover, Chronomodel makes use of an "Event model", which is comparable to the "combine" function in OxCal 4.2. The idea is to pool/bin several dates that are thought to relate to the same past event. With the data used in this study, information is too scarce to support such an assertion. For this reason, I do not make use of the "Event model" in the same way it was initially intended by the developers, and I limit an event to just one date, with only two exceptions: 1) samples DIC-1217 a and DIC-1217 b from the LM-8 site in Manitoba, which are in close association with the same potsherd; and 2) samples CAMS-13189, CAMS-13190, and CAMS-13191 from the Wapisu cairn in Manitoba, which are assigned to the burial of a child; as these two situations respectively correspond to one particular event, they are pooled together. Nevertheless, Chronomodel, like OxCal, permits the plotting of dates into a specific phase and the determination of the posterior distribution of its "start" and "end" boundaries. Depending on how the connectors are set (if at all), the phases can be overlapping or contiguous.

Through multiple, short examples, Lanos and Philippe (2015a:1) assert that the "Event model is more robust but generally yields less precise credibility intervals". The robustness of its algorithmic structure basically nullifies the need to remove statistical outliers and to make subsidiary runs. Accuracy is therefore preserved at the negligible expense of precision.

The Study Period (T) feature in Chronomodel permits the determination *a priori* of chronological boundaries that act as a constraint on the distribution curve of the converted calendar ages (also available in OxCal using the "Boundary" functions). Because the objective here is exploratory in nature and consists in discerning the temporal limits of the PSS interaction sphere, a consciously naïve stance is observed by ignoring the time interval usually mentioned for this cultural ensemble (also called EMW sub-period). Otherwise, the protocol would be plagued by tautology. The study period chosen thus covers the Woodland period in its entirety. Conservatively, the start boundary of this archaeological period is pushed back to 1500 cal BC, at the interface between the Terminal Archaic and the Woodland periods. The end boundary is set at cal AD 1550, i.e., the beginning of the Contact period. In brief, T is defined as [–1500, 1550].

Bayesian Point-estimators. Multiple interval estimates and point-estimators are available to communicate the results of a chronological modelling that follows a Bayesian approach.

The most conservative solution consists in keeping the extreme values of the highest posterior density (HPD), which is roughly equivalent to a credibility interval. Conventionally, the interval at 2-sigmas (i.e., 95%) is considered. However, because it is based on extreme values, the 95% HPD region will likely produce intervals that are inconsistent with the temporal boundaries commonly assigned to known archaeological manifestations. As a consequence, unless uncertainty is minimal, these intervals may sometimes appear useless to archaeologists. As with any other distribution, one way to narrow down the intervals without sacrificing credibility is to consider centrality measurements: mean, median, and mode, called maximum *a posteriori* (MAP) in Bayesian statistics. At this point, it is important to remember that Bayesian statistics differ from frequentist statistics in that they are probabilistic in essence, with calculations based on heavy resampling procedures. Consequently, with each analytical run, Bayesian interval estimates and point-estimators will most probably vary. Bearing this in mind, the maximum *a posteriori* estimate is more labile than both the mean and the median. In the present study, I chose the posterior median as a centrality measure, but the mean could have represented an equally good choice. These two point-estimators are also conceptually more in line with Bayesian statistics as they bear on the overall shape of the distribution curve (its skewness and kurtosis), while in some, albeit rare, instances the maximum (or maxima) *a posteriori* could prove unrepresentative of the whole distribution.

Using Archaeological Knowledge as Prior Information

Different Types of Samples Date Different Events

In Bayesian analysis, each archaeological sample corresponds with a specific past event. In this study, the dated materials are of different natures, and are therefore testimonies of different events. First, charcoals date the death of a vegetal, but the wood can be short-lived (e.g., a small twig) or long-lived (e.g., the heartwood of an old oak). The offsets associated with charcoals can thus cover several centuries ("Old Wood" problem). Unfortunately, this kind of information is absent from the vast majority of the data, and the problem grows larger when we consider the possibility that an unknown number of these samples are bulk samples, that is to say, samples gathered from various vegetal species, and—to make things worse—sometimes from various strata.

We also have TL/OSL (thermoluminescence/optically-stimulated luminescence) dates, which, here, refer to the last exposure of pots to a temperature above 400°C. These samples are of a better quality than charcoals for they are directly drawn from the artifacts that are composed of minerals, and are not simply more or less loosely associated with them. In parallel, we find the cumulated carbonized residues (encrustations), which are also drawn from the artifacts, of interest here (pots). But these samples are potentially affected by a freshwater reservoir offset (FRO) in situations where the pots served to process freshwater resources. To assess this, the isotopic ^{13}C:^{12}C ratios (or $\delta^{13}C$) must be examined. Very low ratios (inferior to –30‰) may be indicative of the presence of old carbon, and therefore of an anomalously old sample. Out of a total of 323 radiocarbon dates, the values of said isotopic signature were known for only 161 samples (49.85%), none of which exceeds that threshold, although several samples in the New York State (NYS) composite flirt with this critical value (see Supplementary Material 1a, available online at the CAA website, http://canadianarchaeology.com/caa/publications/canadian-journal-archaeology/41/2). In the context of northeastern North America, the FRO has been dismissed as negligible on the basis of both the absence of ethnohistorical evidence of cooking fish in ceramics, and the results of fatty-acids determination, which also weaken the importance of the cooking of fish in ceramic containers (Lovis and Hart 2015; Skibo et al. 2016). Furthermore, other instances, where it was later shown that pots contained carbon contributed by fish (Taché and Craig 2015), had surprisingly returned younger AMS dates from residues than expected (Taché and Hart 2013).

Here, the data was compiled from multiple sources: the Canadian Radiocarbon Database (Martindale et al. 2016), academic works, and various State and Provincial archaeological journals. The number of dates retained amounts to 323, while 71 dates were rejected *a priori* (see Supplementary Material 2, available online at the CAA website, http://canadianarchaeology.com/caa/publications/canadian-journal-archaeology/41/2). These dates correspond to 140 sites (Figure 4) split up into 14 different regional ensembles, called "composites" so as to conform to the taxonomy in use in the "Laurel World" (Rajnovich 2003; Syms 1977).

Ordering of Data Requires Stratigraphic or Depositional Reconstruction

To illustrate the importance of stratigraphic information for refining chronological models, I hereby draw examples from the case study dedicated to the PSS interaction sphere. Relevant stratigraphic information (see Supplementary Material 3, available online at the CAA website, http://canadianarchaeology.com/caa/ publications/canadian-journal-archaeology/41/2), theoretically

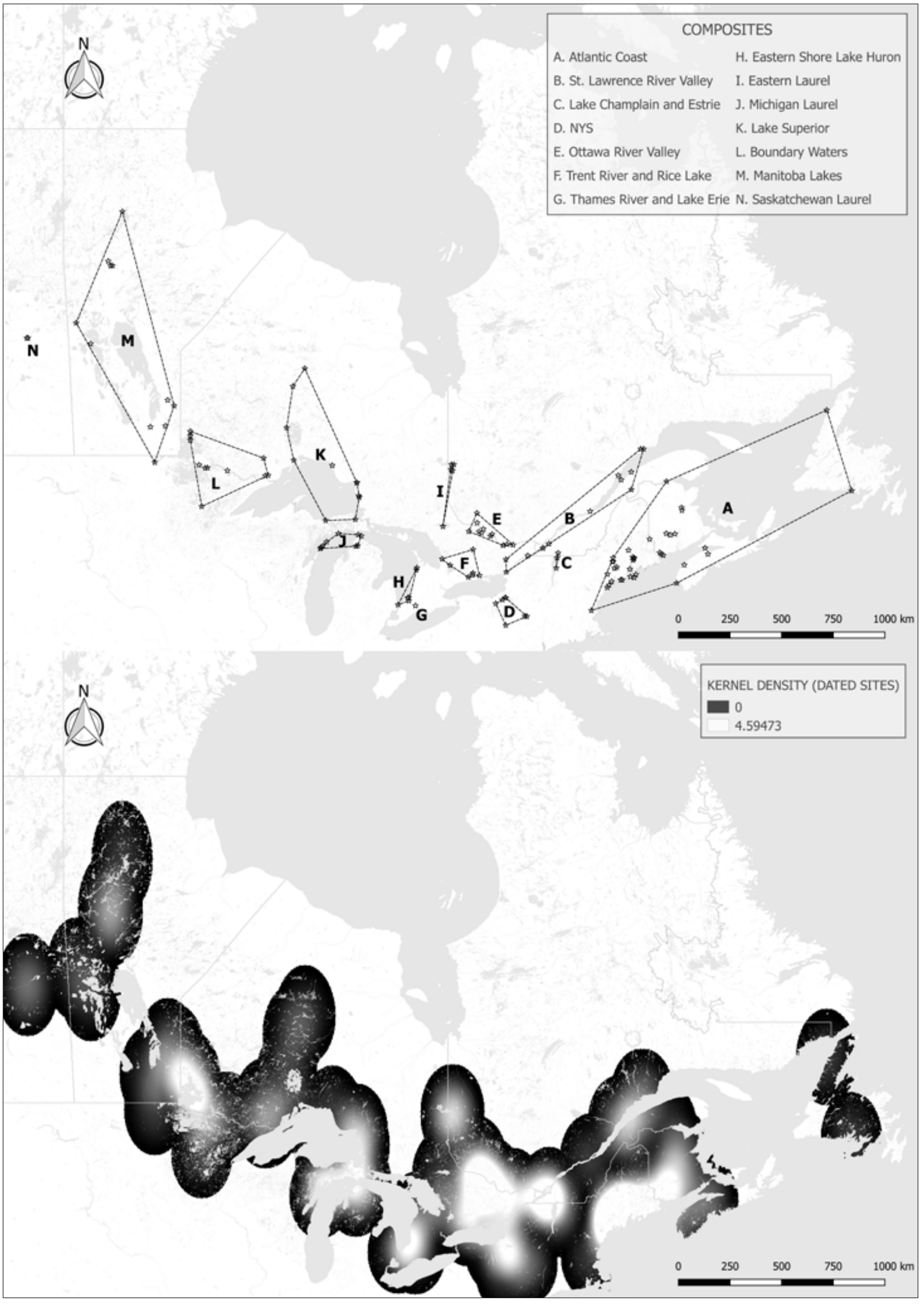


FIGURE 4. Top: localization of the sample of dated sites (n = 140) belonging in the 14 composites that shape the PSS Horizon. Bottom: heatmap of said dated sites (Quantum GIS 2.12.3 [QGIS Development Team 2016]; kernel shape = triweight; search radius [bandwidth] = 200 km, i.e., the group mobility radius for hunter-gatherers as estimated by Whallon [2006]).

usable as a prior, is only available for 43 sites out of 140 (30.71%). Most sites are open areas that are poorly stratified and sometimes considerably pedoturbated. Some have rudiments of stratigraphic information, such as the depth of the datable samples, but this information is only useful when there is a way to know how these relative depths relate to each other. For example, a sample found at 60 cm below the surface is not necessarily older than another found at 38 cm in a different section of the same site, because different pedological processes could have affected the two sections. However, if we have good reasons to assume that the pits were affected by similar site formation processes, and if we have at our disposal a sample big enough to satisfy statistical requirements (however, the vast majority of sites are composed of very small ceramic assemblages [less than five]), then a ratio (relative depth of the sample weighted by the maximum depth of the non-pedoturbated part of the pit until sterile levels have been reached) can be calculated, in a fashion identical to the one I followed on station 3-avant at Pointe-du-Buisson (or PduB3-avant; BhFl-1d), where several statistical layers were identified (Méhault 2015). Also, even in cases where sites are stratified, the vertical localization is not always comprehensively reported (as is the case with the Rosie site, for instance). In other situations, it is the sequence of features from which the dated samples were extracted that remains opaque. For example, at Augustine Mound, what was the sequence of burials? Unless they can be sorted depending on the composition of the assemblage discarded with the human remains (seriation), we are stuck with a "chicken or egg" dilemma, since burials are "rarely" found on top of each other, and absolute dating thus becomes the last resort for resolving this conundrum.

At the composite (regional) level, the stratigraphic information is irrelevant, because it is technically impossible to determine how all local stratigraphic contexts relate to one another. They all belong to the same geological era (Holocene) and, perhaps entirely, to the current climatic age of the Holocene (Subatlantic, which started at least 2,500 years ago). Chronostratigraphy is of little help here.

Now, I will present two situations in which stratigraphy is turned into a very useful prior. One example involves a stratified site, and the other a non-stratified one.

A Stratified Site: Oxbow (CfDl-1). Figure 5 shows the localization of both the datable samples and the stratigraphic layers. Several samples were rejected beforehand, due to a series of reasons generally linked to measurement errors, and others are flagged *a posteriori* (after modelling) due to an incongruence between their positioning in the model and their stratigraphic localization (Table 1). If these statistical outliers represent the majority of the samples, they are likely to cast doubt over the overall integrity of the stratigraphic sequence, which is not the case here. So, they may rather be explained by measurement errors or their isolated displacement in the soil. Removing them from the model could increase precision, but because Chronomodel is fairly robust (Lanos and Philippe 2015a) to statistical outliers, it is better to keep them and preserve accuracy.

A Non-stratified Site: PduB 3-avant (BhFl1-d). This is a weakly sedimented, intensely reoccupied, and pedoturbated

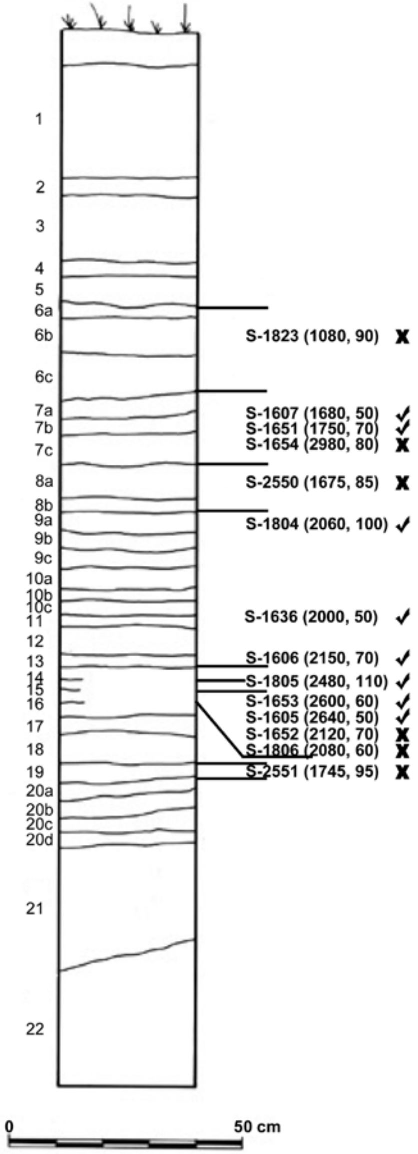


FIGURE 5. Stratigraphic localization of the dated samples excavated at the Oxbow site (CfDl-1) in 1984. Crosses indicate *a priori* (errors in measurement) and *a posteriori* (statistical) outliers. Modified from Allen 2005:55.

site (the units are 31 cm deep on average, with only 14 cm of undisturbed soil), but this is also where the largest assemblage of vessels (n = 1,686) of the PSS interaction sphere has been excavated. Fifteen field seasons were dedicated to this site, so that archaeologists benefit from an exhaustive corpus of sketches and field notes. Through a process of "stratimetric hygiene", these pieces of information aided me in identifying and isolating the most drastic agents of pedoturbation (Méhault 2015, 2017). Eventually, the localization of the pots (sorted according to their chrono-cultural affiliation) in the reconstructed intact/original soil was achieved (Figure 6).

Notwithstanding important overlaps, the chrono-cultural sequence of the vessels statistically corresponds with that of the reconstructed intact soil, which is expressed as a ratio (Figure 7). This ensures that comparisons can be drawn from the vertical localization of the artifacts across the entirety of the site. The Wilcoxon matched-pairs signed-rank test (Figure 7) demonstrates that pots of the Early Woodland (EW) and the PSS interaction sphere (EMW and middle Middle Woodland [MMW] sub-periods) are significantly separated from more recent chrono-cultural taxa.

To confirm that the reconstructed stratigraphic sequence can serve as a valid prior, three pots were selected for their salient stylistic characteristics, thought to possess some temporal resonance, and sent to the laboratory (Beta Analytic Inc.) for dating (Figure 8). The three dated pots are composed of various numbers of vertically localized sherds: 1 for pot 1543; 9 for pot 2296; and 6 for pot 464. The bars show the dispersal of said sherds from which a mean depth is calculated (circle). Pot 1543, the oldest of the three, is localized at the lowest

TABLE 1. Illustration with the Oxbow site of a two-steps procedure involving: (i) a chronometric hygiene based on prior information attached to dated samples (rejected beforehand, i.e., before modelling); and (ii) a filtering of samples flagged as outliers *a posteriori* (after modelling) using two programs: OxCal 4.2 and Chronomodel 1.1. Under OxCal, the outliers are flagged thanks to outlier model "General",T(5),U(0,4),"t" (Bronk Ramsey 2009b) which produces two indices (the agreement [of the date to the model] and a posterior threshold set at 5%, beyond which the position of the sample is deemed suspicious), but also through visualization (the gap thereof between the prior and the posterior distribution curves). Under Chronomodel, the outliers are detectable through the display of abnormally high posterior densities of individual standard deviations (σ_i).

Sample	Convent. Age (BP)	Description as Submitted to CARD 2.1	Place within Model
S-2551	1745±95	unit 84-6, N59.5-60.0/E161.0-166.0, 192–196 cm depth, Level 19	Rejected beforehand; anomalously young
S-1806	2080±60	unit 78-12, Levels 15 and 16, datum level A/1121-1131, associated with a hearth and [undecorated + smoothed] pottery	Flagged *a posteriori*; age incongruent with stratigraphic localization
S-1652	2120±70	unit 78A, datum level A/1109, associated with a hearth, point, and dentate decorated [+ rocker-stamped + smoothed] pottery	Flagged *a posteriori*; age incongruent with stratigraphic localization
S-1605	2640±50	unit 78-11, datum level A/1060-1063, with an elongated hearth, feature 50, an expanding stemmed point and a variety of pottery styles [PSS + rocker-stamped + smoothed]	Included
S-1653	2600±60	unit 78-11, datum level A/1059-1062, associated with a projectile point, cord-wrapped decorated and plain [undecorated + smoothed] pottery	Included
S-1805	2480±110	unit 78-12, Level 14, 140 cm depth, associated with a straight stemmed point [+ undecorated + smoothed pottery]	Included
S-1606	2150±70	unit 78-12, datum level A/1058-1060, associated with a bipointed quartz projectile point [+ dentate decorated + smoothed pottery]	Included
S-1636	2000±50	unit 78-11, datum level A/1050-1053, a burned area north of a house structure	Included
S-1804	2060±100	unit 79-14, datum level A/1037-1040, associated with a straight stemmed point	Included
S-2550	1675±85	unit 84-4, N59.0-59.5/E161.0-162.1, 124 cm depth, Level 8a	rejected beforehand; anomalously young
S-1654	2980±80	unit 78-10, datum level A/1028-1030, associated with a projectile point, flake, and sherds [PSS decorated + rocker-stamped + punctuated + smoothed]	Flagged *a posteriori*; age incongruent with stratigraphic localization
S-1607	1680±50	unit 78-11, datum level A/1028-1030, with charcoal stained pit, feature 35, a contracting stemmed point and a circular house structure [+ shell tempered, cord-wrapped decorated + undecorated + smoothed pottery]	Included
S-1651	1750±70	unit 78-10, Level 7, datum level A/1028-1030, associated with a projectile point and pecked design pottery	Included
S-1823	1080±90	unit 79-14, Level 6, datum level A/1014-1016, associated with cord-wrapped stick decorated pottery	Rejected beforehand; associated with Ceramic Period 4

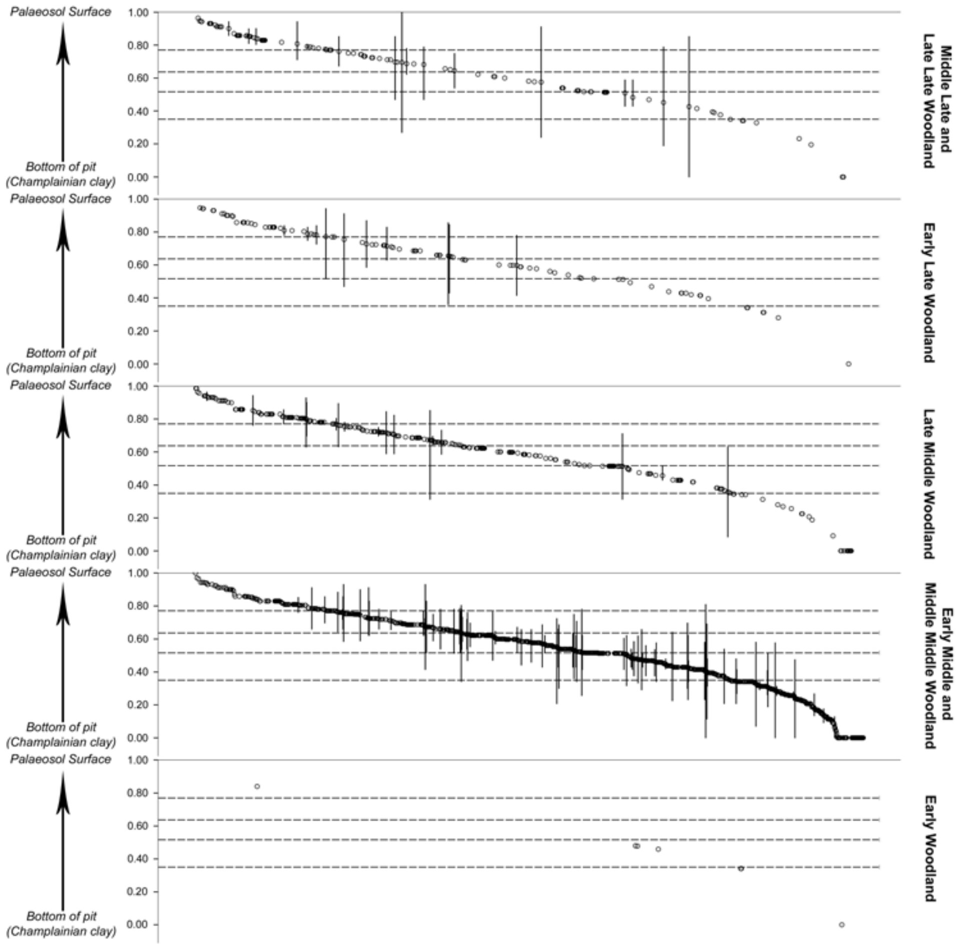
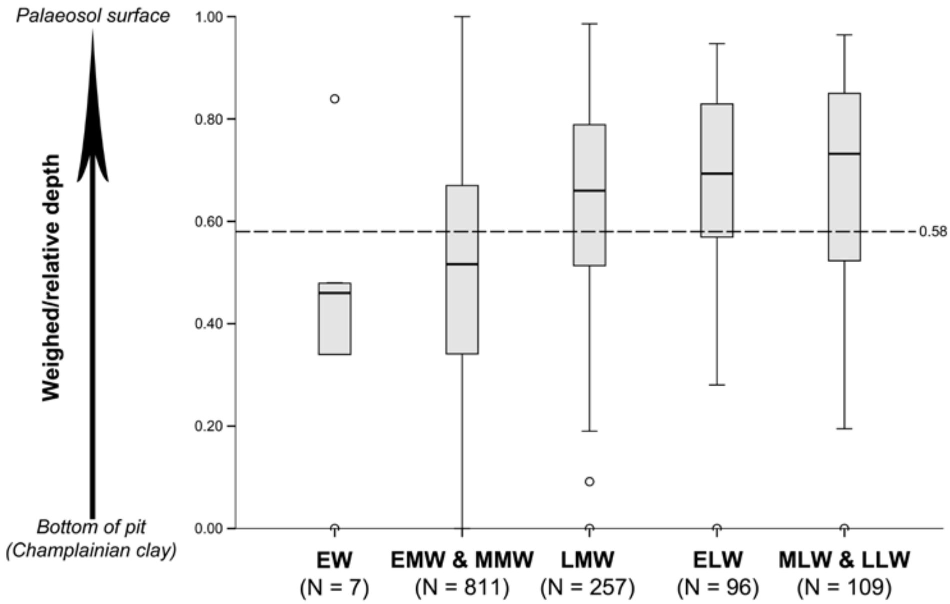


FIGURE 6. Scatter plots illustrating, for each chrono-cultural taxon identified at PduB3-avant (BhFl-1d), the vertical localization of pots (N = 1,280) inside the intact/original soil. Based on a corpus of pots for which at least one sherd has been localized in situ, the soil is virtually split into quintiles (delimitated by dotted lines) in each of which 20% of the pots (n = 256) are found. The whiskers indicate the spread across the soil of the sherds belonging to the same pot.

boundary of the second deepest quintile. Pots 2296 and 464 are both localized in the third quintile. Although pot 464, the most recent of the three, is on average localized at a slightly greater depth than pot 2296, it seems reasonable to conclude to a partial agreement between the stratimetric localization of the sherds and the absolute age of the pots to which they belong. Eventually, the quintile position was kept as a prior, as the statistical equivalent of a stratigraphic layer.

Questionable Dates

With any form of chronological assessment, controversy is most likely to arise



Sample1-Sample2	Test statistic	Std. error	Std. test statistic	*p*-value	Dunn-Bonferroni adj. *p*-value
EW-EMW & MMW	-139.018	140.304	-0.991	0.322	1.000
EW-LMW	-356.175	141.592	-2.515	0.012	0.119
EW-ELW	-421.885	144.706	-2.915	0.004	0.036
EW-MLW & LLW	-440.955	144.118	-3.060	0.002	0.022
EMW & MMW-LMW	-217.157	26.458	-8.208	0.000	0.000
EMW & MMW-ELW	-282.867	39.894	-7.090	0.000	0.000
EMW & MMW-MLW & LLW	-301.937	37.707	-8.007	0.000	0.000
LMW-ELW	-65.710	44.212	-1.486	0.137	1.000
LMW-MLW & LLW	-84.781	42.249	-2.007	0.045	0.448
ELW-MLW & LLW	-19.071	51.735	-0.369	0.712	1.000

FIGURE 7. Vertical localization of a population of 1280 pots found at PduB3-avant (BhFl-1d) according to their respective chrono-cultural affiliation (EW = Early Woodland; EMW & MMW = early and middle Middle Woodland; LMW = late Middle Woodland; ELW = early Late Woodland; MLW & LLW = middle and late Late Woodland). Kruskal-Wallis test based on the median is highly significant at the $\alpha = 0.1\%$ level (K-W = 143.163; degrees of freedom = 4; asymptotic sig. (2-sided test) < 0.001). Below figure: post-hoc tests (Wilcoxon matched-pairs signed rank). In grey: the pairs that significantly (at the $\alpha = 5\%$ level) contribute to the overall K-W test; there is a clear demarcation between on one side the two older taxa, and on the other side the more recent taxa.

when dated samples associated with an extreme measured age become the object of scrutiny, for it is those samples that decisively alter the outcomes of the modelling procedures. It is thus necessary to explain why certain "problematic" samples were kept whereas others were dismissed (Supplementary Material 2). In general, the discussion revolves around the stratigraphic location of the samples and the artefacts or ecofacts they were found in association with. As a starting point, I must admit that I tend to give the benefit of the doubt to the excavators or to the analysts responsible for producing the controversial results.

Early Dates. On the Atlantic Coast, at least four sites produced samples with

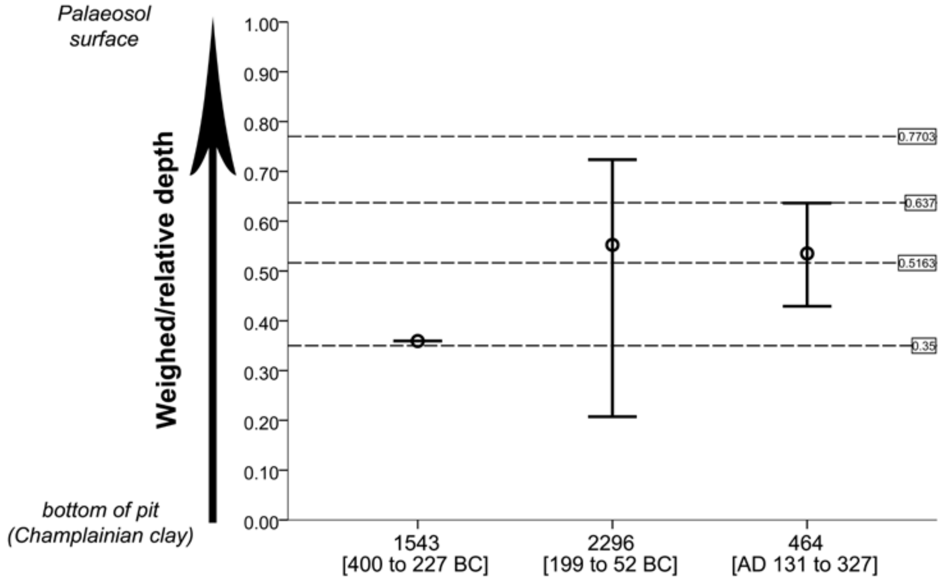


FIGURE 8. Vertical localization of three dated pots excavated at PduB3-avant (BhFl-1d) across the original soil. The whiskers indicate the spread of the sherds belonging to the same pot. The posterior distributions of the modelled dates are presented at 2σ, i.e., 95.4% of credible interval.

very old measured ages (Supplementary Material 1b): Oxbow (CfDl-1), Rosie (ME15.231), Mud Lake Stream (BkDw-5), and Kidder Point (ME41.40). Nevertheless, these samples were associated with decorated Woodland ceramics and there is no objective reason to reject them. In the St. Lawrence River Valley, the Wyght site (BfGa-11) produced one old sample (S-1843, 2530 ± 120 BP) that was also in close association with decorated sherds. A similar scenario was found at the Whitson Lake (sites BlGk-15 and BlGk-19) in the Ottawa River Valley (S-1291, 2580 ± 170 BP).

Further west, a few early dates appear more controversial. At the Donaldson site, just south of the Bruce Peninsula, two samples could be perceived as anomalously old for a Middle Woodland occupation (S-470, 2535 ± 150 BP; and S-119, 2480 ± 60 BP). As those samples seem associated with Vinette 1 ceramics, it could be tempting to just dismiss them. However, Wright and Anderson (1963) observed a co-occurrence of Meadowood and early Saugeen artifacts, and therefore believed in the contemporaneity uniting the two episodes. Moreover, in the same composite, the existence at Burley site (AhHl-15) of an even older sample (C-608, 2619 ± 220 BP), submitted to the Canadian Radiocarbon Database (CARD) as a Middle Woodland/ Saugeen culture sample, gives more credit to this possibility. My own statistical observations at PduB3-avant (Wilcoxon test in Figure 7) do likewise.

A similar rationale is applicable in the Lake Superior area. At Michipicoten Harbour (ClIf-2), a very old sample (S-1265, 3120 ± 430 BP) was extracted from charcoals of a hearth associated with decorated potsherds. Although

Dawson (1981:37) judged this ceramic, produced by paddle-and-anvil, uncharacteristic of Laurel, the fact still remains that they are decorated and thus different from typical EW pots (Vinette 1, Brainerd, and LaSalle Creek wares). Such a disagreement is rooted in the opposition between a monothetic and essentialist/typological view of material culture, on one hand, and a polythetic and materialist/evolutionary perspective on the other hand that makes it entirely plausible for traits, otherwise thought to be mutually exclusive, to coexist. The fact that these decorated pots were manufactured using the paddle-and-anvil technique disqualifies them as "textbook" Laurel, but it also furthers the argument that a continuity might exist between EW wares and PSS-decorated pottery from the following sub-period (EMW). Close to Michipicoten Harbour, another old sample was excavated at Wawa site (S-1266, 2490±250 BP). According to Dawson (1981:37), the ceramic recovered along with this sample was also manufactured with the paddle-and-anvil technique, and "pseudo-scallop shell impressed decorations are virtually absent". This is a puzzling formulation, which actually implies that this type of decoration is present, albeit in small quantity.

In the vicinity of Lake Michigan, at Rock Island II site (47DR128), an early date (I-6334, 2540 ± 270 BP), which is associated with North Bay linear stamped sherds (a decoration indistinguishable from Laurel linear, sometimes called "banked"), is kept even though it is statistically flagged as an outlier. Indeed, sample I-6334 comes from stratum C2, above stratum C3 where younger samples were exhumed, thus revealing either pedoturbation or a measurement error in the laboratory. However, since we have enough information at our disposal to apply an unambiguous stratigraphic constraint to the chronological modelling, keeping the outlier in the model cannot significantly alter the results (Lanos and Philippe 2015a). Furthermore, I-6334 is not in disagreement with another early date (WIS-725, 2470 ± 65 BP) found at the Richter site (47DR73), associated this time with PSS decorated ceramics.

Late Dates. On the Atlantic Coast, several late dates are associated with PSS interaction sphere ceramics: at Kidder Point site (Beta-5859, 1170 ± 100 BP) and l'Anse à Flamme (S-1977, 1335 ± 115 BP) with PSS decorated pottery; and at Sand Point site (CjAx-1; SI-2185, 1320 ± 90 BP) with rocker stamped pottery.

In the St. Lawrence River Valley, at station 3-avant at Pointe-du-Buisson (BhFl-1d), pottery encrustation extracted from a PSS-decorated pot returned a Late Woodland (LW) date (Beta-377395, 860 ± 40 BP).

In the Georgian Bay, at Kitchikewana Camp site (13HR43), attached to the Trent and Rice Lake phases (Curtis 2002) due to the shared affinity between the ceramic assemblages (Mortimer 2012), two late samples (BGS-2668, 1217 ± 45 BP; and WAT-2865, 1100 ± 70 BP) are associated respectively with PSS, and PSS and channeled ceramics.

On the Thames River in southwestern Ontario, at the Boresma site (AfHi-121), a late sample (Beta-34700, 1260 ± 90 BP) is associated with rocker stamp, dentate, and cord-wrapped stick decorations. On the Saugeen River, at the Thede site (BcHi-7), another late sample (GaK-2955, 1260 ± 90 BP) was found along with dentate-decorated ceramics.

In his synthesis of archaeological research conducted in the Voyageurs

National Park, located inside the Boundary Waters region, Richner (2008:29–30) contests that Laurel manifestations in this area could have persisted after cal AD 650, based on the radiocarbon dates obtained at the well-stratified McKinstry site (21KC2) in particular, and the absence of overlap between Laurel and Blackduck materials at the same site. The bone of contention seems to concern two sites. Firstly, the late Laurel date (I-2594, 1010 ± 100 BP) obtained at Long Sault site (DdKm-1), also known as Armstrong Mound, is rejected by Richner since it was extracted from a pine log at the base of the mound which was not in direct association with Laurel ceramics. However, from his own admission, the material found in the mound itself is of Laurel affiliation. Secondly, Ballynacree (DkKp-8; Reid and Rajnovich 1991) is a multicomponent site with occupations spanning from the Archaic period to the post-Contact era. One house excavated there was identified as Laurel due to the relative abundance of Laurel ceramics on its floor, including a few instances of PSS. Three very overlapping dates measured from charcoal samples (DIC-2884, 710 ± 65 BP; DIC-2876, 710 ± 45 BP; and DIC-2885, 680 ± 55 BP) have caused much turmoil within the community of Laurel archaeologists, for they push back far in time the end of Laurel culture to around cal AD 1300. Richner (2008:29–30) rightly points out that the co-occurrence of small, triangular points, most likely of Late Woodland age, and Archaic darts is probably indicative of pedological mixing and a lack of vertical separation. He therefore wonders whether the three dates mentioned above could not relate to these Late Woodland occupations rather than to Laurel ones. He further insists on the singularity of Ballynacree as the sole-known very late Laurel site, and uses this assumption to dismiss the relationship between the late dates and the Laurel component, but as I have just shown, perhaps Ballynacree is not as exceptional as Richner would have us believe. Elsewhere in the Laurel World, a few instances suggest that decorative motifs, long thought to be exclusive of the MW period, may have persisted well within the LW period. At Wabinosh River (EaJf-1), another charcoal sample associated with Laurel ceramics returned a comparable date (S-681, 710 ± 175 BP). The possibility that archaeologists may have, at times, and especially when the implications of radiocarbon techniques were not fully understood, employed a bulk-sampling strategy, thus mixing samples of different ages, cannot be rejected beforehand, but neither can it be systematically demonstrated. For instance, nothing indicates the excavators at Ballynacree followed this procedure. Moreover, I find it intriguing that, in spite of the possible mixing affecting the deposit at Ballynacree, the three dates in question all fall within a minuscule threshold of 30 years. If mixing was so overwhelming, as Richner suggested, should we not expect a much bigger dispersal for the measured ages? As a consequence, like Brandzin-Low (1997), I would tend to trust the excavators of the site (Rajnovich 2003; Reid and Rajnovich 1991) and accept these three dates as valid Laurel ones.

Further east, in the Manitoba Lakes composite, at LM-8 site (EfKv-39), dated bone collagen (DIC-1216, 940 ± 55 BP) was found in component 3 in association with dentate-decorated Laurel ceramics. Moreover, in eastern Saskatchewan, at the Crown site (FhNa-86), two samples of bone collagen (S-2555, 825 ± 155 BP; S-725, 725 ± 75 BP) were also associated with bossed Laurel pottery.

Results

The results of the chronological modelling for the PSS interaction sphere are broken down into 14 composites, presented from east to west, and ending with Laurel culture sites. For each composite, the maximal 95% HPD interval and the interval based on the *a posteriori* median starting and ending dates are shown at both the archaeological site level and at that of the composite. The intervals at the composite level are expected to be larger since their modelling involves more dates but no stratigraphic prior. Because this informative prior (i.e., the stratigraphic ordering of the samples) is only available at the site level (albeit for less than 30% of the cases), priority is given to this analytical level. Additionally, even though it is less conservative than the maximal 95% HPD interval, priority is also awarded to the interval based on the medians, as it appears to be more realistic. As a cautionary note, it must be stated that the timespans based on the median region are positively sample-size-dependent at the $\alpha = 5\%$ level (calculations based on the "raw/unrounded values" and to the exclusion of sites represented by only one sample, confronted with "number of dated samples": Pearson's $r = 0.482$, one-tailed $p < 0.001$). Finally, where needed, in order to facilitate comparisons between conventional chronological boundaries, those calculated in the present reassessment are rounded to the nearest 100 years.

Atlantic Coast

On the Atlantic Coast (Figure 9), manifestations pertaining to the PSS interaction sphere may emerge at Oxbow by 1135 cal BC and may persist at Kidder Point until cal AD 854. Unsurprisingly, at the composite level, more uncertainty is introduced, with a start at 1290 cal BC and an end at cal AD 1035. The new boundaries for the Atlantic Coast composite, ranging from 1100 cal BC to cal AD 900, largely exceed, in both directions, the conventional limits used by local archaeologists: nine sites push back the *terminus post quem* for Ceramic Period 2 (200 cal BC): Oxbow (CfDl-1), Rosie (ME15.231), Mud Lake Stream (BkDw-5), Kidder Point (ME41.40), Partridge Island (BgDr-48), Evergreens (ME69.6), Augustine Mound (CfDl-2), Turner Farm (ME29.9), and Bob (ME74.148); and five sites break the *terminus ante quem* for Ceramic Period 3 (cal AD 600): Kidder Point, Turner farm, Knox (ME30.21), Sand Point (BgDs-6), and l'Anse à Flamme (CjAx-1).

St. Lawrence River Valley

In the St. Lawrence River Valley (Figure 10), these manifestations seem to first appear at the Wyght site (BfGa-11), in 775 cal BC, and to last until cal AD 1175 at station 3-avant at Pointe-du-Buisson (BhFl-1d). At the composite level, the PSS interaction sphere may span from 886 cal BC to cal AD 1185. In the St. Lawrence River Valley composite, the conventional start for the EMW sub-period (400 cal BC) is exceeded at three sites (Wyght, Ault Park, and Hector Trudel at Pointe-du-Buisson) and pushed as far back as 800 cal BC. The conventional end for this sub-period is only broken at station 3-avant at Pointe-du-Buisson. I must, however, concede that I entertain doubts about the validity of the sample (Beta-136890, 860 ± 40 BP) that places the end of the PSS interaction sphere well into the early Late Woodland (ELW) sub-period, but the catalogue stipulates that this date was extracted from a pot on which PSS decorative patterns were identified. Since I

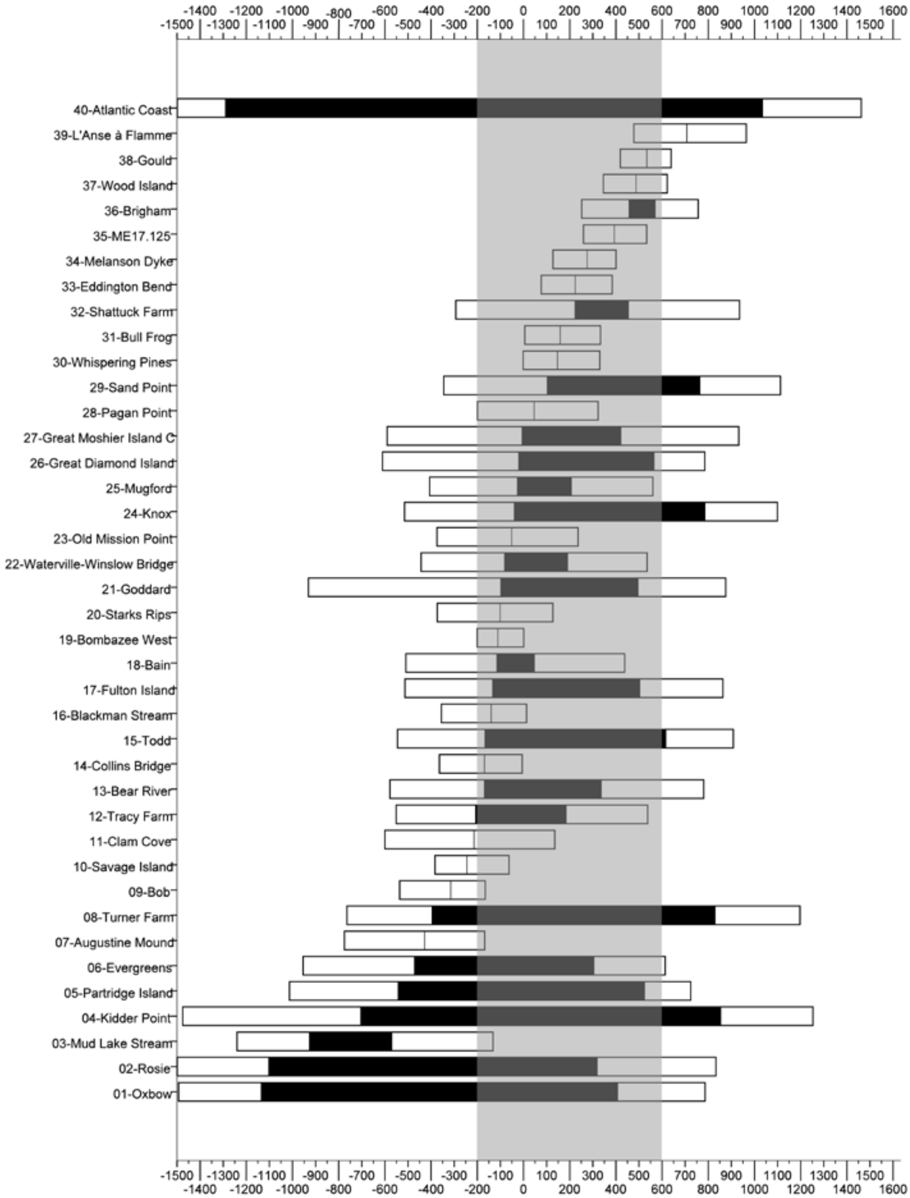


FIGURE 9. Results of the chronological modelling of the PSS interaction sphere manifestations in the Atlantic Coast composite. At the archaeological site level, results are sorted according to the earliest occurrence of PSS interaction sphere material based on the *a posteriori* median starting dates. Results at the composite level are displayed at the top of the figure. White bars indicate the maximal 95% HPD intervals; black bars indicate the intervals based on the median starting and ending dates. The grey area highlights the conventional boundaries defined by Petersen and Sanger (1991) for the Ceramic Periods 2 and 3.

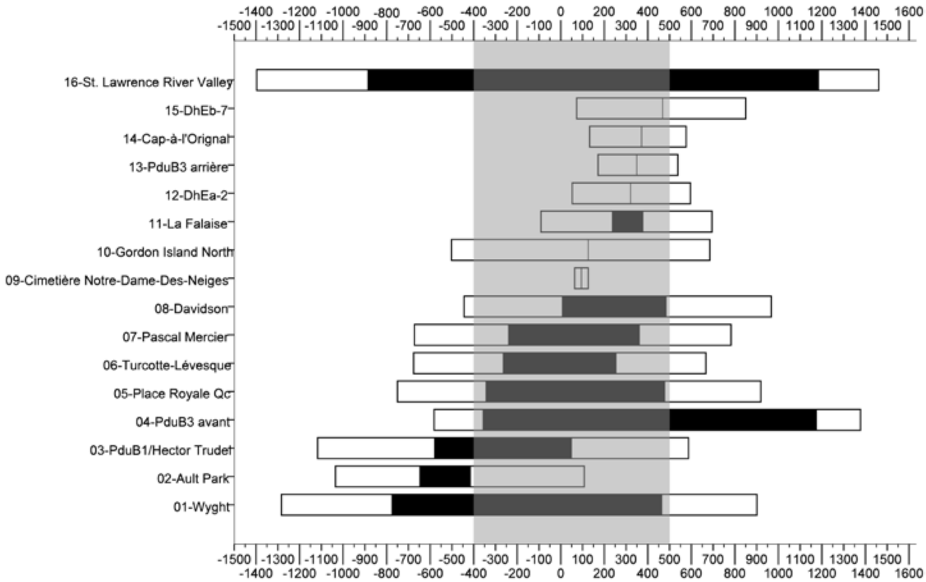


FIGURE 10. Results of the chronological modelling of the PSS interaction sphere manifestations in the St. Lawrence River Valley composite. The grey area highlights the conventional boundaries for the early Middle Woodland sub-period in southern Quebec as underlined by Gates St-Pierre (2010).

could not find the pot in question, neither in the museum nor in the university collections, I cannot dismiss this identification. Were it not for this problematic sample, the conventional end boundary of cal AD 500 would be almost perfectly met in the present reassessment at four sites: Wyght, Place Royale (CeEt-9), Davidson (CkEe-2), and DhEb-7.

Lake Champlain and Estrie

In the Lake Champlain and Estrie composite (Figure 11), the PSS interaction sphere may start at Besette 1 (VTFR-140) in 39 cal BC and may end at the Winooski site (VTCH46) in cal AD 384. At the composite level, it may last from 126 cal BC to cal AD 408. In the Lake Champlain and Estrie composite, the assemblages date back to the second phase of the PSS interaction sphere (cal AD 0 to cal AD 400), that is to say, to the MMW sub-period.

New York State (NYS)

In New York State (Figure 12), these manifestations may appear at the Vinette site in 317 cal BC and may end at the Simmons site in cal AD 443. At the composite level, the timespan goes from 354 cal BC to cal AD 508. The reassessment for the New York State (NYS) composite corroborates the chronological interval deducible from the work accomplished by John Hart, who has been very active at the forefront of radiocarbon dating in New York State, using, for the most part (10 out of 13), AMS dating of very reliable samples directly extracted from the pots, namely carbonized residues (Hart and Brumbach 2005; Hart and Lovis 2007; Hart et al. 2011). This

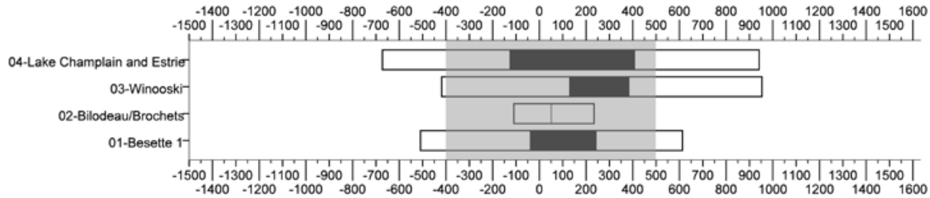


FIGURE 11. Results of the chronological modelling of the PSS interaction sphere manifestations in the Lake Champlain and Estrie composite. The grey area highlights the boundaries proposed by Méhault (2015).

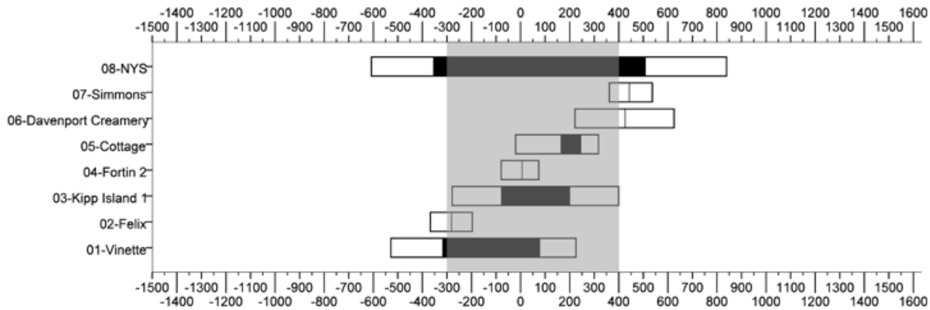


FIGURE 12. Results of the chronological modelling of the PSS interaction sphere manifestations in the New York State (NYS) composite. The grey area highlights the conventional boundaries for early Point Peninsula as deduced from Hart and Brumbach (2005).

confers an exceptional robustness to the aforementioned timespan.

Ottawa River Valley

In the Ottawa River Valley (Figure 13), these manifestations seem to appear at Whitson Lake (BlGk-15 and BlGk-19) in 688 cal BC and to last at Radiant 3 (CaGn-1) until cal AD 741. At the composite level, the dates may span from 784 cal BC to cal AD 801. In the Ottawa River Valley composite, both the conventional starting and ending dates for Daechsel's (1981) "Ottawa River Valley phase" (400 cal BC and cal AD 800) are pushed back in time (to 700 cal BC and cal AD 700), with a *terminus post quem* exceeded at two localities: Whitson Lake and Constance Bay (BiGa-2 and BiGa-3).

Trent River and Rice Lake

In the Trent River and Rice Lake composite (Figure 14), the PSS interaction sphere may emerge two centuries later than previously thought (400 cal BC) at Dawson Creek (BaGn-16) in 236 cal BC, and may end at Kitchikewana Camp (13HR43) in cal AD 939, that is to say, approximately one century later than anticipated (cal AD 800). At the composite level, the timespan goes from 283 cal BC to cal AD 947.

Thames River and Lake Erie

This composite (Figure 15) is represented here by just one site: Boresma (AfHi-121). It may start in 185 cal BC, i.e., later than anticipated (400 cal BC), and end in cal AD 785, in agreement with the conventional end boundary (cal AD 800).

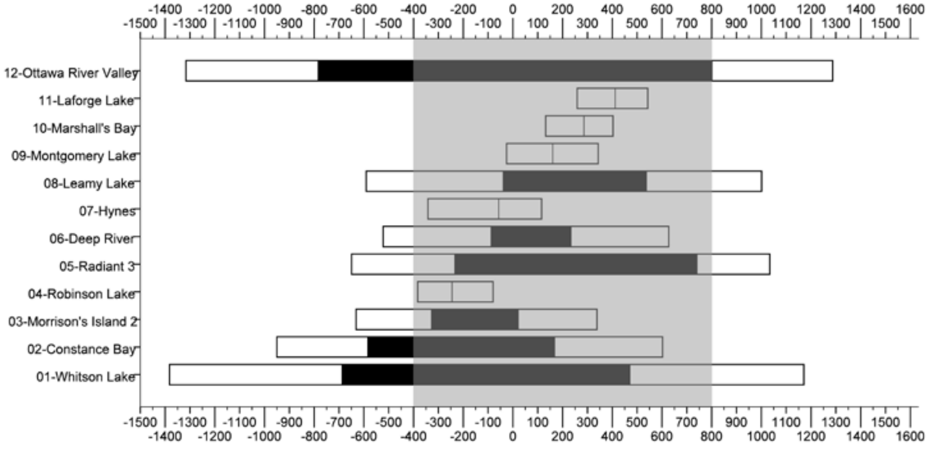


FIGURE 13. Results of the chronological modelling of the PSS interaction sphere manifestations in the Ottawa River Valley composite. The grey area highlights the conventional boundaries for the Ottawa River Valley phase defined by Daechsel (1981).

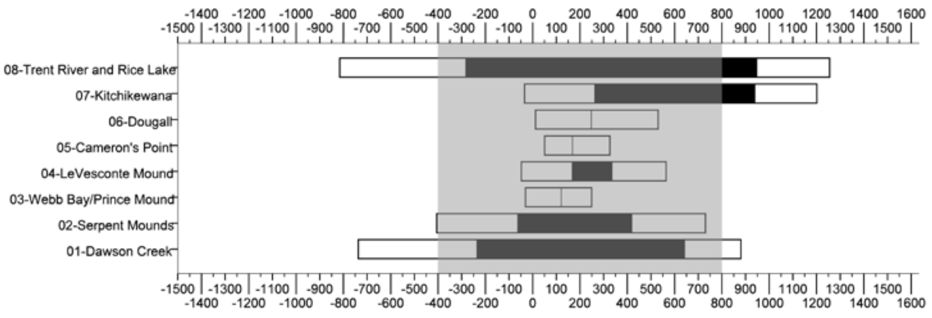


FIGURE 14. Results of the chronological modelling of the PSS interaction sphere manifestations in the Trent River and Rice Lake composite. The grey area highlights the conventional boundaries for the coupled Trent and Rice Lake phases proposed by Curtis (2002).

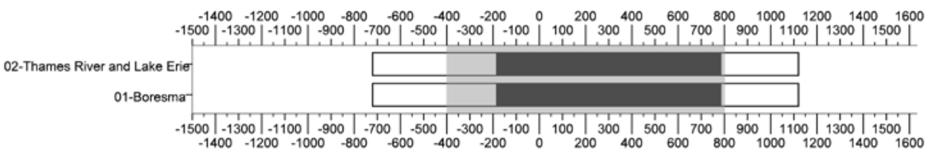


FIGURE 15. Results of the chronological modelling of the PSS interaction sphere manifestations in the Thames River and Lake Erie composite. The grey area highlights the conventional boundaries for the Middle Thames River Complex defined by Wilson (1990) and later reassessed by Smith (1997).

Eastern Shore Lake Huron
On the Eastern Shore of Lake Huron (Figure 16), in Southwestern Ontario, these manifestations seem to emerge at the Donaldson site (BdHi-1) in 786 cal BC and to end at the Thede site (BcHi-7) in cal AD 796. At the composite level, they may persist from 889 cal BC to cal AD 841. The local end boundary for the MW period (here, the Saugeen culture) is also confirmed at cal AD 800, but the start boundary is pushed four hundred years back in time at two sites: Donaldson and Burley (AhHl-15).

Eastern Laurel
In its easternmost portion (east of Lake Nipissing; Figure 17), the Laurel culture may start at the Bérubé site (DdGt-5) in cal AD 166, that is to say, two centuries earlier than anticipated (cal AD 400), and may end at the Roger Marois site (DcGt-4) in cal AD 854, thus corroborat-

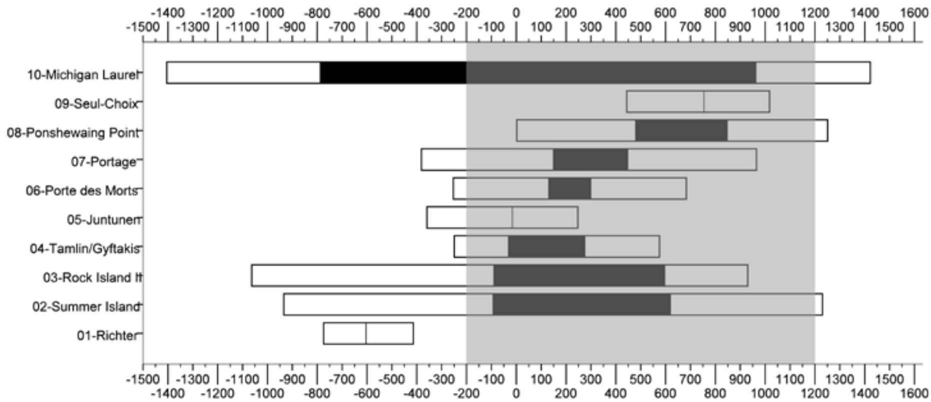


Figure 16. Results of the chronological modelling of the PSS interaction sphere manifestations in the Eastern Shore Lake Huron composite. The grey area highlights the conventional boundaries for the Saugeen culture reassessed by Smith (1997).

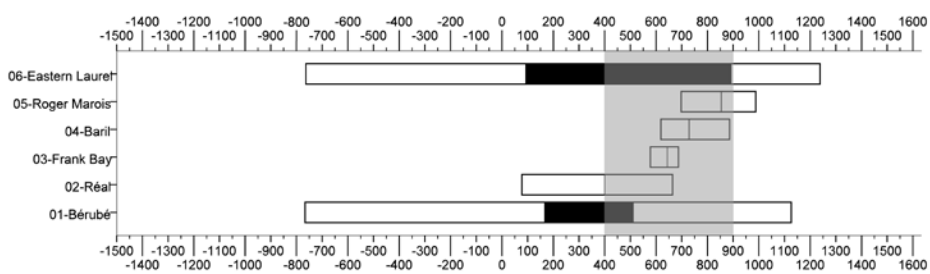


Figure 17. Results of the chronological modelling of the PSS interaction sphere manifestations in the Eastern Laurel composite. The grey area highlights the conventional boundaries for this Laurel composite proposed by Côté and Inksetter (2001).

ing the conventional end boundary of cal AD 900. At the composite level, the timespan goes from cal AD 93 to 892.

Michigan Laurel

The PSS interaction sphere material found around Lake Michigan (Figure 18) is not exclusively Laurel. At Summer Island, for instance, it displays characteristics of both Point Peninsula and North Bay (Brose 1968; Mason 1969). This material seems to appear earlier than anticipated (200 cal BC) at the Richter site (47DR128), as early as 604 cal BC, and to not persist at Ponshewaing Point beyond cal AD 848. At the composite level, the dates may range from 788 cal BC to cal AD 963.

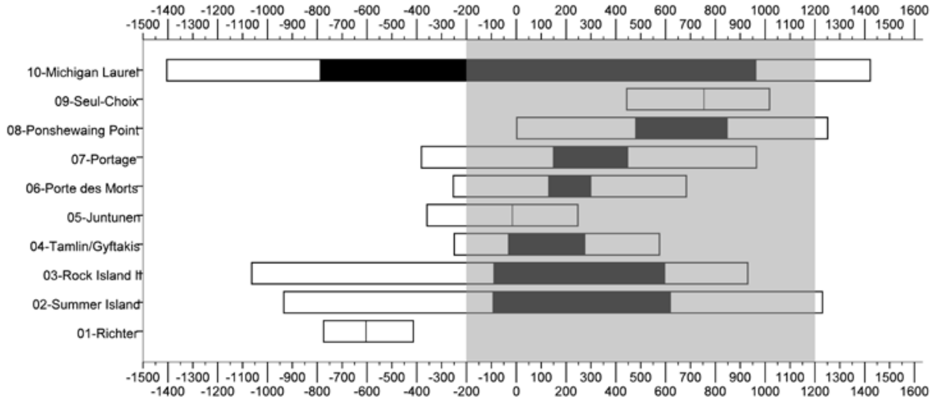


FIGURE 18. Results of the chronological modelling of the PSS interaction sphere manifestations in the Michigan Laurel composite. The grey area highlights the conventional boundaries put forward for Laurel Culture by Rajnovich (2003).

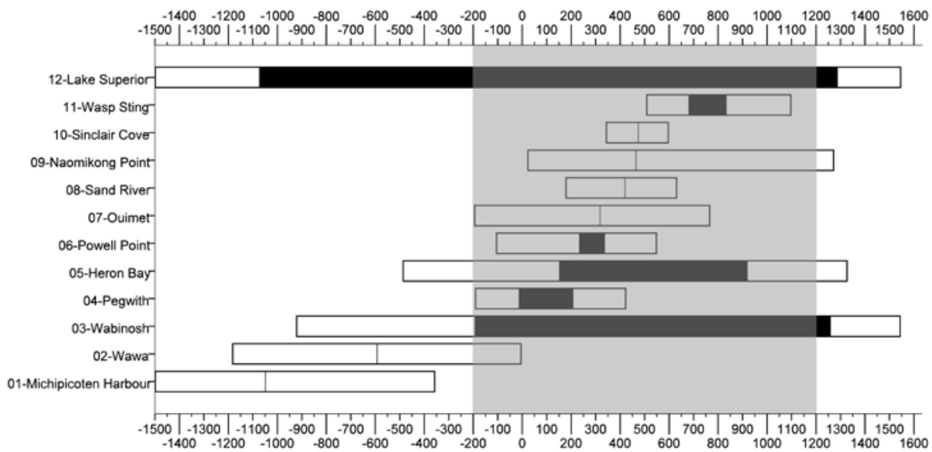


FIGURE 19. Results of the chronological modelling of the PSS interaction sphere manifestations in the Lake Superior composite. The grey area highlights the conventional boundaries put forward for Laurel Culture by Rajnovich (2003).

Lake Superior
Around Lake Superior (Figure 19), these manifestations apparently last a very long time, and may start at Michipicoten Harbour (ClIf-2) in 1049 cal BC and end at the Wabinosh River site (EaJf-1) in cal AD 1258. At the composite level, the timespan may go from 1072 cal BC to cal AD 1287.

Boundary Waters
In the Boundary Waters area (Figure 20), the PSS interaction sphere may emerge earlier than the conventional start boundary (200 cal BC) at Smith site (21KC3) in 460 cal BC. It may also vanish at another site (Ballynacree, DkKp-8), later than expected (cal AD 1200) in cal AD 1369. At the composite level, it may start in 608 cal BC and last until cal AD 1375.

Manitoba Lakes
In the Manitoba Lakes composite (Figure 21), Laurel culture seems to start at Wapisu UNR 26 (GkLs-1) in 42 cal BC and to end at Notigi Lake (GlLu-4) in cal AD 1129. At the composite level, its temporal depth may go from 157 cal BC to cal AD 1275.

Saskatchewan Laurel
In east central Saskatchewan (Figure 22), Laurel pottery is found very late in time, in close association with material of the River House complex (Meyer et al. 2006). Laurel material may not appear at Crown site (FhNa-86) before cal AD 868 and may persist there until cal AD 1297. At the composite level, the dates may range from cal AD 848 to 1313. Assemblages containing Laurel culture artifacts occur for a relatively short period of time and quite late in the Woodland sequence, between cal AD 900 and 1300, thus confirming the end boundary proposed by Meyer et al. (2006).

Discussion and Conclusion

The regionalized, chronological boundaries of the PSS interaction sphere

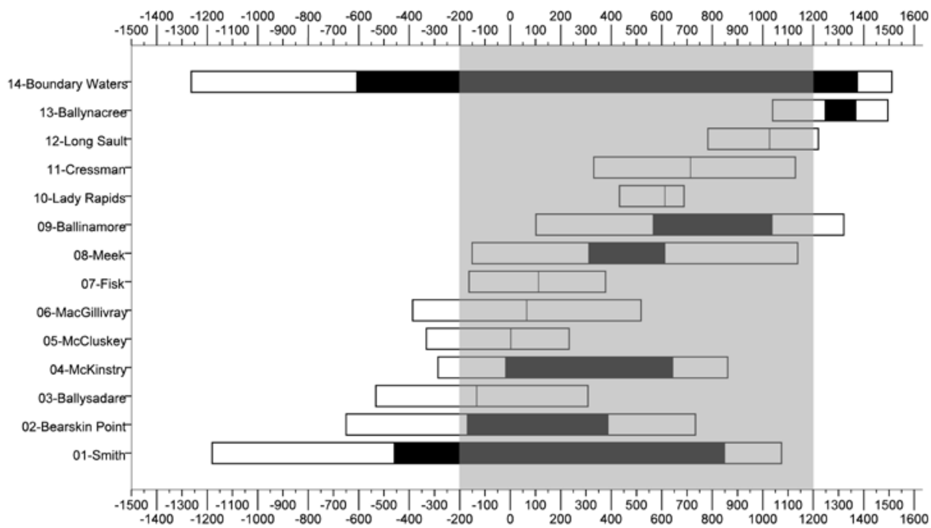


FIGURE 20. Results of the chronological modelling of the PSS interaction sphere manifestations in the Boundary Waters composite. The grey area highlights the conventional boundaries put forward for Laurel Culture by Rajnovich (2003).

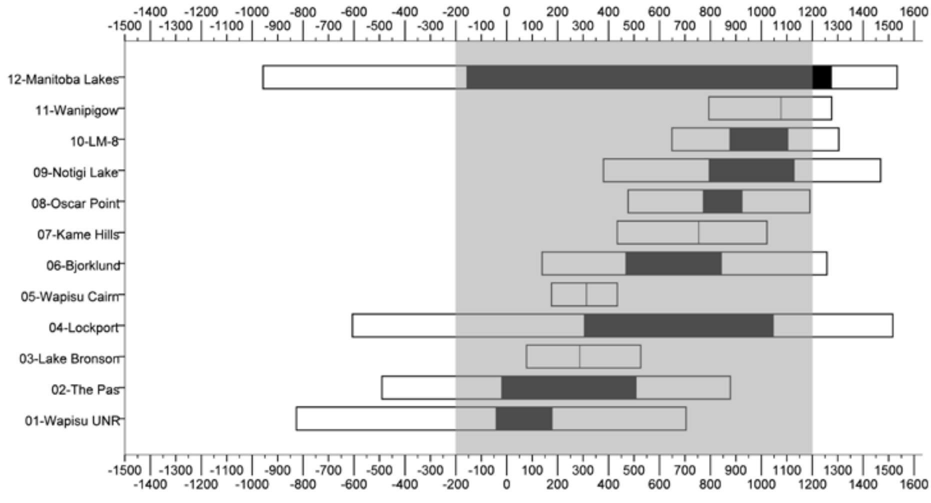


Figure 21. Results of the chronological modelling of the PSS interaction sphere manifestations in the Manitoba Lakes composite. The grey area highlights the conventional boundaries put forward for this Laurel composite by Branzin-Low (1997).

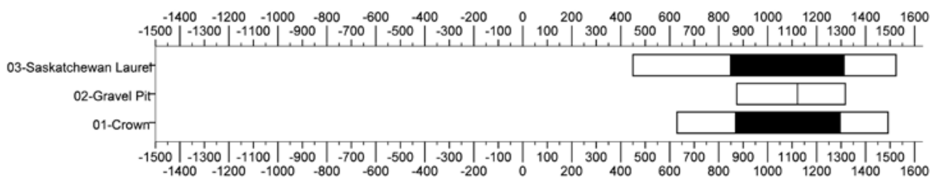


Figure 22. Results of the chronological modelling of the PSS interaction sphere manifestations in the Saskatchewan Laurel composite. Prior to this study, the only proposed boundary for this composite is its *terminus ante quem:* cal AD 1300 (Meyer et al. 2006).

presented above may raise eyebrows among readers due to their partial nonconformity to those more commonly ascribed to the EMW and MMW subperiods. As Table 2 illustrates, out of a total of 140 archaeological sites, the PSS interaction sphere seems to start earlier than expected in 21 cases (15.00%), and to last later than anticipated in 9 cases (5.71%). Again, the calculations are very sample-size-dependent. Both the number of sites and the number of dates are positively correlated with both the number of dates exceeding the conventional start boundary (Pearson's $r=0.933$, one-tailed $p<0.001$; and Pearson's $r=0.931$, one-tailed $p<0.001$) and the number of dates exceeding the conventional end boundary (Pearson's $r=0.926$, one-tailed $p<0.001$; and Pearson's $r=0.914$, one-tailed $p<0.001$).

Evidence for Cultural Continuity between Early Woodland and Middle Woodland Periods?

In nine composites out of 14, the newer boundaries exceed, in one or both directions, those of the local taxonomical schemes and overlap with earlier and/or later chrono-cultural taxa, thus convey-

Table 2. Summary of the chronological reassessment (results are rounded to the nearest 100 year to facilitate comparisons) of the PSS interaction sphere and estimation of its temporal overlaps with the preceding and following (sub-)periods.

Composite	N Sites	N Dates	Conventional Start	Conventional End	Conventional (Sub-)Period(s)	Source	Start (this study)	End (this study)	N Sites Exceeding Start	N Sites Exceeding End
Atlantic Coast	39	90	200 cal BC	cal AD 600	Ceramic Periods 2 and 3	Petersen and Sanger 1991	1100 cal BC	cal AD 900	9 (23%)	5 (13%)
St. Lawrence River Valley	15	39	400 cal BC	cal AD 500	early Middle Woodand	Gates St-Pierre 2010	800 cal BC	cal AD 1200	3 (20%)	1 (7%)
Lake Champlain and Estrie	3	5	400 cal BC	cal AD 500	early Middle Woodland	Méhault 2015	cal AD 0	cal AD 400	–	–
NYS	7	13	300 cal BC	cal AD 400	early Point Peninsula	Hart and Brumbach 2005	300 cal BC	cal AD 400	–	–
Ottawa River Valley	11	27	400 cal BC	cal AD 800	Ottawa Valley Phase	Daechsel 1981	700 cal BC	cal AD 700	2 (18%)	–
Trent River and Rice Lake	7	15	400 cal BC	cal AD 800	Trent and Rice Lake phases	Curtis 2002	200 cal BC	cal AD 900	–	1 (14%)
Thames River and Lake Erie	1	4	400 cal BC	cal AD 800	Middle Thames River Complex	Smith 1997	200 cal BC	cal AD 800	–	–
Eastern Shore Lake Huron	6	15	400 cal BC	cal AD 800	Saugeen culture	Smith 1997	800 cal BC	cal AD 800	2 (33%)	–
Eastern Laurel	5	6	cal AD 400	cal AD 900	Eastern Laurel Composite	Côté and Inksetter 2001	cal AD 200	cal AD 900	1 (20%)	–
Michigan Laurel	9	22	200 cal BC	cal AD 1200	Northern Lake Michigan Laurel?	Rajnovich 2003	600 cal BC	cal AD 800	1 (11%)	–
Lake Superior	11	25	200 cal BC	cal AD 1200	Lake Superior Composite	Rajnovich 2003	1000 cal BC	cal AD 1300	2 (18%)	1 (9%)
Boundary Waters	13	31	200 cal BC	cal AD 1200	Boundary Waters Composite	Rajnovich 2003	500 cal BC	cal AD 1400	1 (8%)	1 (8%)
Manitoba Lakes	11	27	200 cal BC	cal AD 1200	Manitoba Lakes Composite	Brandzin-Low 1997	cal AD 0	cal AD 1100	–	–
Saskatchewan Laurel	2	4	?	cal AD 1300	Saskatchewan Laurel Composite	Meyer et al. 2006	cal AD 900	cal AD 1300	–	–
PSS INTERACTION SPHERE	140	323	–	–		–	–	–	21 (15%)	9 (6%)

ing an impression of cultural continuity between the Early and Middle Woodland periods in most regions of northeastern North America. The differences between the chronological boundaries attached to the "conventional" taxonomy of the MW period and the one dedicated to the PSS interaction sphere may, at least partially, take root in the intrinsic characteristics that shape them. While the former is based upon multiple lines of evidence (material culture, but also subsistence strategies, settlement patterns, and networks of trade of raw materials) and is delineated as much by the boundaries of the cultural manifestation to which it pertains, as by the ending of the preceding manifestation and the beginning of the one that follows, the latter stems exclusively from the analysis of peculiar decorative patterns visible on the pots. Therefore, the taxonomy of the PSS interaction sphere has no pretense to replace the preexisting schemes. It is, however, valid in its own right, as the by-product of an extended channel of cultural transmission and sociality operating over as much as two millennia and across most of non-Hopewellian northeastern North America. Undeniably, the PSS interaction sphere is a cultural manifestation ascribable, "for the most part", to the MW period. I am not suggesting that we are faced here with a stylistic stasis or that the PSS interaction sphere should be viewed as a monolithic ensemble. On the contrary, as I have shown for the St. Lawrence composite (Méhault 2015:191–201, 2017), and as others have demonstrated elsewhere (Ceramic Periods 2 [200 cal BC to cal AD 300] and 3 [cal AD 300 to 600] on the Atlantic Coast by Petersen and Sanger 1991; phases Trent [400? cal BC to cal AD 0] and Rice [cal AD [0 to 700] in the Rice Lake area by Curtis 2002; and Pike Bay [200 cal BC to cal AD 300] and McKinstry [cal AD 300 to 600] complexes [i.e., phases] in the Boundary Waters composite by Reid and Rajnovich 1991), stylistic trends visible on pots manufactured over the course of the PSS interaction sphere support the partition of this interaction sphere into at least two successive phases or sub-periods (EMW and MMW), even though they remain linked through the persistence, in one way or another, of the PSS motif and related techniques (especially dragging and rocker-stamping). Although they cannot be deemed overwhelming (observations are valid for 21 archaeological sites out of sample of 140), the temporal overlaps visible in Table 2 between the PSS interaction sphere and the preceding period, i.e., the EW period, appear to be significant (affecting eight of the 14 composites). In comparison, the temporal overlaps between the PSS interaction sphere and the late Middle Woodland (LMW) sub-period seems rather marginal (only nine sites out of 140 and five composites out of 14). As for the overlap with the Late Woodland period, outside of the Laurel World, where it is visible in four composites, the situation warrants skepticism, with only one instance (in the St. Lawrence River Valley composite, at station 3-avant at Pointe-du-Buisson). For reasons already stated, it is unlikely that freshwater reservoir offsets (FROs) altered the results in a significant manner. However, it is not impossible that old wood samples contributed, to an indeterminate degree, to pushing back the temporal limits of this interaction sphere. Notwithstanding this caveat, it remains plausible that pots of the PSS interaction sphere really are older than previously thought, perhaps emerging during the EW period as a development of the Vinette 1, Brainerd, and LaSalle Creek wares. The plausibility of a cultural continuity, at least from the standpoint of ceramic products, between the PSS interaction sphere (and thus the MW period) and the EW period, should require serious consideration. For the moment, several arguments can be invoked in support of this hypothesis. This continuity was already made implicit in Ritchie's (1980[1965]) "ware" designation of Vinette 1 (for EW) and Vinette 2 (for MW). Also, and as previously mentioned, the mixing of Meadowood material with EMW ceramics has been noted at the Donaldson (Wright and Anderson 1963) and Batiscan (Taché 2005) sites. It could be argued that this mixing is merely the consequence of both pedoturbation and shallow sedimentation, but I believe that there is more to it. As a matter of fact, I have shown earlier that, at station 3-avant at Pointe-du-Buisson (BhFl-1d), after I had undertaken a chronometric hygiene procedure, the vertical distribution of a sample of 811 Woodland ceramics was statistically dichotomous, with the EW and EMW/MMW material on one hand, and that of the more recent chrono-cultural taxa on the other (see the Wilcoxon matched-pairs signed rank test in Figure 7).

Need for More Reliable Prior Information

Since outcomes of Bayesian approaches so decisively depend on prior knowledge, information pertaining to the context of excavation and to the datable material is of the utmost importance. It also forces archaeologists to engage in a scrupulous evaluation of the reliability of this prior knowledge. As has recently been stated in the European Palaeolithic context (Discamps et al. 2015), Northeastern North American Prehistory (as an archaeological topic) is also in dire need of better control over the stratigraphic composition of archaeological sites. Multiple hindrances can impede the applicability of Bayesian modelling for a majority of sites. They include, but are not limited to: weak sedimentation; non-stratification; numerous, sporadic, or even continuous occupations; and pedoturbation. However, using the case of Pointe-du-Buisson, I have shown that, even with non-stratified sites and/or pedoturbated sites, these obstacles are not insurmountable, provided that the size of the collection is big enough (for obvious statistical reasons), that we know as much as possible about the history of the site and detect potential agents of perturbation, and that we have site maps and properly drawn stratigraphy sketches at our disposal. In line with these remarks, unless a solution is found to relate discrete stratigraphic contexts at various multi-occupation sites with one another, phasing must be constrained to the archaeological site level. Considering that this relationship (i.e., stratigraphic ordering of datable samples) was already found to be only available at the intra-site scale in half of the situations in the present study, this objective looks out-of-reach for the moment. As expected, subsuming all the data of one region (here composite) into one model as a whole implies that we forsake the stratigraphic constraint and leads to less-precise outcomes (i.e., greater time intervals).

Moreover, researchers publishing new dates and/or submitting them to databases (such as CARD in Canada) need to do so in the most exhaustive manner possible (Bayliss 2015). In particular, attention should be paid to the following variables: sampling strategy (bulk [to avoid at all cost!] or targeted); wood essence and anatomy (short-lived parts such as twigs, grains, or seeds should be preferred); laboratory pretreatment, synthesis, and measurement, and the ratio of stable isotopes ^{13}C:^{12}C ($\delta^{13}C$).

Future Directions

The chronological boundaries of the (at least two) phases that compose the PSS interaction sphere remain to be elucidated in all but three regional composites: "Atlantic Coast", "Trent River and Rice Lake", and "Boundary Waters". This will require sampling strategies based on relative chronology and stylistic characterization of the ceramic products (see Méhault 2017), followed by the dating of said pots using AMS or OSL/TL techniques.

Moreover, the results presented here agree with others conducted in northeastern North America which also stem from a materialist standpoint and target discrete elements in the archaeological assemblages—thus dismissing the idea of a diffusion of archaeological traits as a package—to show that the temporal depth of said elements does not neatly conform to a clear-cut, chrono-cultural taxonomy composed of contiguous taxa, but rather to a mosaic of overlapping ones. For example, Smith (1997) documents the co-occurrence for 300 years of MW and Princess Point occupations (recognized through the decorative use of the cord-wrapped stick on pots and the adoption of maize) in southern Ontario. The complex transition between MW and LW manifestations was also addressed in New York State, through the dating of diagnostic pots and the dismantling of the culture-historical "Owasco" construct (Hart 2011), and through the study of the co-occurrence of Jack's Reef and small, triangular projectile points (Rieth 2013). This evolutionary rethinking of the taxonomy of the Woodland Period in northeastern North America could be furthered via a Bayesian approach, through using absolute dates obtained from EW, MW, and LW artifacts and ecofacts, and by running different phasing models (sequential, contiguous, overlapping, and parallel/independent) in order to compare their relative goodness-of-fit with the real-world data.

Finally, another line of investigation worthy of interest could lead us towards an articulation of the temporal variation of the PSS interaction sphere with its geographical discrepancies. This could consist in unraveling the diffusion of the diagnostic traits constitutive of this interaction sphere across northeastern North America using "isochronic mapping" in order to detect possible spatiotemporal patterns in the spread of said traits.

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