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Authors

de Carvalho, Fernando

Chacon, Thiago

Rybka, Konrad

et al.

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Author for correspondence:
Lev Michael
e-mail: levmichael@berkeley.edu

†These authors contributed equally.

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Deriving calibrations for Arawakan using archaeological evidence

Lev Michael[1], Fernando de Carvalho[2], Thiago Chacon[3], Konrad Rybka[4], Andrés Sabogal[5], Natalia Chousou-Polydouri[6,†] and Gereon Kaiping[6,7,†]

[1]Department of Linguistics, University of California, Berkeley, Berkeley CA 94720, USA
[2]Departamento de Antropologia, Museu Nacional - Universidade Federal do Rio de Janeiro, 20940040 - Rio de Janeiro, Brazil
[3]Departamento de Linguística, Português e Línguas Clássicas, Universidade de Brasília, 70910-900 Brasília, Brazil
[4]Leiden University Centre for Linguistics, 2300 RA Leiden, The Netherlands
[5]Language Learning Center, New Mexico Highlands University, Las Vegas, New Mexico 87701, USA
[6]Department of Comparative Language Science and Center for the Interdisciplinary Study of Language Evolution, University of Zurich, CH-8050 Zurich, Switzerland
[7]Department of Geography, University of Zurich, 8057 Zurich, Switzerland

LM, 0000-0002-9612-5996; FdC, 0000-0002-2115-7416; TC, 0000-0002-6355-3505; NC-P, 0000-0002-5693-975X; GK, 0000-0002-8155-9089

This paper identifies time calibration points for accurately rooting and dating the phylogeny of Arawakan, the largest Indigenous linguistic family of the Americas. We present and model a methodology for extracting calibration points from the archaeological record, based on principles of geographical overlap between archaeological sites and Arawakan peoples, and on continuity in material culture between archaeological finds and modern Arawakan practices. Based on a consensus model of the expansion of the Arawakan family from Central Amazonia, we focus on archaeological finds in Arawakan expansion zones, where Arawakan material culture abruptly appears in a given region, and where only a single major Arawakan subgroup/clade is present. We find 12 calibration points from archaeological sites in Arawakan expansion zones and also identify more recent calibration points from the historical record based on first mentions of ethnonyms and early sources of lexical data.

1. Introduction

This paper identifies time calibration points for accurately rooting and dating the phylogeny of Arawakan, as well as describing and modelling a general approach for extracting calibration points from the archaeological record. The Arawakan language family is the historically largest and most extensive of the Americas with some 77 known varieties and a pre-Columbian distribution that extended from the Greater Antilles to northern Argentina, and from the eastern Andean foothills to the Atlantic coast [1–3]. Arawakan peoples have also had a significant impact on their neighbours in different parts of the continent [4]. An accurately dated and detailed Arawakan phylogeny promises advances in our models of the spread of Arawakan languages and peoples across South America and beyond, and in our understanding of linguistic and socio-cultural contact among diverse peoples of the continent.

Earlier efforts to develop an absolute chronology for Arawakan [5–8] employed glottochronological methods [9–11], which rely on distance-based methods to produce the tree topology and calculate branch lengths by assuming uniform rates of lexical replacement. The latter assumption has been shown to be empirically false: lexical replacement rates are far from uniform [12–14]. By contrast, modern clock models used with computational phylogenetic methods offer the possibility to relax this assumption in various degrees, for example by allowing rates to differ among branches [15,16].

Any clock used for a phylogenetic analysis needs to be calibrated, either with a rate calibration (e.g. the assumption of constant rates of change of glottochronology) or time calibrations (e.g. by including non-modern languages). Well-calibrated

clocks are crucial for reliable divergence time estimates, but also for rooting the tree and obtaining a classification. Estimation accuracy increases with the number of calibration points and with their depth [17]. In linguistic phylogenies calibration points can be obtained directly through documentation of old languages and indirectly through historical sources, archaeological finds and loanword analysis [18].

As with the vast majority of language families in the Americas, Arawakan languages lack written documentation prior to the European invasion, which means that even the oldest such documentation is relatively recent, limiting its utility for calibration purposes.[1] Archaeology thus becomes a potentially valuable source of calibration points. As Maurits *et al.* [18] observe, the discussion of methods for selecting calibration points has been neglected in the linguistic phylogenetics literature, with the result that they are often presented with little or no justification. And these authors are especially hesitant about the use of archaeological calibration points, leading them to suggest that '[d]eveloping a more explicit and detailed account of when and how justifiable linguistic calibrations can be derived from archaeological evidence might be considered a valuable research priority for the field.' Here we aim to describe a method for extracting and justifying calibration points for a linguistic phylogeny based on extra-linguistic scholarship, primarily archaeological evidence, and to give a comprehensive example of this proposed method. We hope that it will prove applicable to other contexts. By establishing the calibrations independently of any future phylogenetic analysis, our methodology for deriving calibrations can be reviewed independently of the phylogenetic inference methodology and its outcomes.

1.1. Types of calibrations

A time calibration constrains the existence of a non-modern language to a particular time period, or more precisely, to a probability distribution of time points. Calibrations can be attached to a terminal or an internal node, also known as tip or node calibrations respectively [16].

Node calibrations constrain temporally either the most recent common ancestor of a group of related languages (proto-language), or the pre-proto-language that is assumed to have existed just after a speaker population split away from another group.[2] Node calibrations cannot have associated linguistic data and are typically derived from archaeological or ethnohistorical evidence. The transformation of available evidence into an explicit calibration distribution is far from trivial [19], as typically one has to consider not only the available raw dates, but additional factors, such as the extent of our knowledge of the history or archaeology of the area or the group, the probability that similar finds but much older could exist but are not found yet, the facility with which earlier finds could be identified, etc.

Tip calibrations are typically provided by non-modern languages, such as old written evidence, or old linguistic sources documenting an extinct or older variety. Such tips are treated like any other language included in the analysis: their position on the tree is mainly guided by the linguistic data. Other sources of tip calibrations are historical mentions of ethnonyms or archaeological finds, with the key difference that typically they are not associated with linguistic data that could guide their position on the tree. Therefore, in the case of such tips without data their position must be constrained, so that they can attach only to a particular section of the tree. Tips with no associated data have the advantage that dating information and its associated uncertainty can be used directly, without the rather arbitrary transformation step necessary for node calibrations, and this practice is recommended over pure node calibrations [16]. However, they require some prior knowledge regarding the topology of the tree in order for them to be constrained in an unequivocal manner. Last but not least, with the development of the fossilized birth–death tree prior [20], any tip can be inferred to be a sampled ancestor, i.e. an internal node along a branch. In cases where the analyst is sure about an ancestral relationship, the tip in question can even be constrained to be an ancestor.

1.2. Arawakan archaeology

Archaeologists typically employ two kinds of evidence to identify archaeological sites as generally Arawakan: (i) distinctive Arawakan ceramic traditions and (ii) distinctive Arawakan forms of spatial organization and landscape modification. On the first point, a consensus emerged among archaeologists in the 1970s that ceramics of the Saladoid-Barrancoid macrotradition were manufactured by Arawakan peoples [21].[3] Saladoid-Barrancoid is composed of at least three major subtraditions (Orinocan Saladoid-Barrancoid, Caribbean Saladoid and Amazonian Barrancoid), and subtraditions within these, such as Pocó-Açutuba in the Lower and Central Amazonia [24] and Parallel Lines in the upper Negro, Casiquiare, and upper Orinoco regions [8]. Lathrap [22] proposed a common origin for Saladoid-Barrancoid ceramics in the Central Amazon, from where they were carried to various parts of South America and the Caribbean by Arawakan-speaking peoples. While outstanding questions remain about precisely how these traditions are related to each other, there is a consensus that they are associated with Arawakan-speaking peoples due to the considerable overlap between the distribution of these ceramics and territories long inhabited by Arawakan peoples [21,22].

In addition to ceramics, scholars have identified an 'Arawakan matrix' [25], a set number of cultural traits widespread among Arawakan peoples, some of which leave traces in the archaeological record [21,26]. These include: (i) a prevalence of cooking and serving vessels, rather than burial urns or prestige goods, reflecting societies based on settled agriculture; (ii) settlements with an overall concentric organization, including central public spaces, notably circular plazas, possibly housing ceremonial houses and cemeteries; (iii) landscape modification, such as mounds and other earthworks, and (iv) riverine and terrestrial communication networks, such as roads, pointing to regional integration.

Although it is possible to associate many archaeological sites with Arawakan peoples by means of the broadly Arawakan traits just discussed, the culturally and linguistically dynamic nature of Arawakan-speaking peoples entails that over time, many have come to use non-Saladoid-Barrancoid ceramics and have adopted cultural practices distinct from those of the Arawakan matrix. These innovative 'local traditions' are thus not of a general Arawakan character, but are instead associated with particular Arawakan subgroups.

2. Methodology

In this work, we identify a combination of linguistic, ethnohistorical and archaeological calibration points for Arawakan. Linguistic

tip calibrations are derived from historical sources on pre-modern languages. Ethnohistorical tip calibrations are derived from historical documents and the oral histories of Arawakan peoples but have no accompanying linguistic data.

In order to arrive at archaeological calibrations, we need to establish associations between dated archeological finds (with their associated uncertainty) and Arawakan languages. To establish these associations, we comprehensively surveyed the South American archaeological literature to: (i) locate finds potentially identified as Arawakan; (ii) assess which, if any, Arawakan groups can be clearly associated with the finds and (iii) determine in what form their dating information can be incorporated in a phylogenetic analysis.

2.1. Surveying the Arawakan archaeological literature

We undertook a systematic survey of the Arawakan archaeological literature, drawing both on family-level syntheses [21,22] and regional ones, such as those focusing on the Arawakan expansion into (i) northwest Venezuela and northeast Colombia [6]; (ii) northern Amazonia [8]; (iii) the Lower Orinoco Circum-Caribbean area [7,27] and (iv) Central Amazonia [24].

2.2. Linking archaeological finds to the Arawakan tree

An extensive literature addresses the challenges of equating societies that produced particular sets of archaeological remains to those that spoke specific posited proto-languages [28–31]. As long established [32], material culture, language and genes exhibit potentially independent historical trajectories, meaning that great care must be taken to avoid facile associations of archaeological cultures with proto-languages. The method we describe in this section draws on the insights of Neves [33] and Maurits *et al*. [18] that such associations are most credible when linguistic diversification coincides with geographical expansion, where the geographical radiation of languages into an area is associated with the appearance of novel forms of material culture in that area. In addition, we emphasize the importance of establishing continuity in relevant aspects of material culture between the society posited to speak the relevant proto-language and that speaking the modern language.

As Neves [33] observes, the most promising contexts for postulating associations between archaeological complexes and linguistic or culture groups involve 'expansion zones', where: (i) a population arrives in a previously uninhabited region; or (ii) a new population brings novel technologies or ideological systems to a region. Expansion zones are also important for linguistic reasons: they are often inhabited by a single well-established subgroup of the language family, which facilitates the association.

While there is no reason to believe that any of the regions into which Arawakan expanded were uninhabited before their arrival, Arawakan peoples did bring with them distinctive cultural practices that left clear material traces, as discussed below.

2.2.1. Identifying Arawakan expansion zones

In order to identify expansion zones, it is necessary to have at least an approximate model of the expansion of Arawakan peoples across South America. Fortunately, there is a broad consensus among archaeologists and ethnohistorians that Arawakan peoples expanded south from the vicinity of the confluence of the Negro and Amazon Rivers and north from the upper Negro and Orinoco River watersheds [21,22], as depicted in figure 1. From there, Arawakan peoples moved into the Orinoco basin and then along the Caribbean coast, and further, into the insular Caribbean. South of the Amazon, Arawakan peoples expanded southward along major rivers, such as the Xingu, Madeira, Purus and Ucayali, leading to the distribution of modern Arawakan peoples in southern Amazonia.

Other minority hypotheses regarding Arawakan origins and expansion, which we discard, posit a proto-Arawakan homeland in southwestern Amazonia or western Amazonia. The southwestern homeland hypothesis [5] was mainly inspired by the incorrect classification of independent language families of the south-central Andean altiplano, such as Uru-Chipaya, and those of the Andean foothills, such as Harakmbut, as Arawakan. These errors [37] led to the mistaken impression that southwestern Amazonia was the place of greatest internal diversity of the family, and thus the likely proto-Arawakan homeland [38]. The western Amazonian homeland hypothesis was most recently advanced in a phylogeographical analysis [35], which proved to be based on problematic cognacy judgements [39], and in any case yielded essentially uninformative results, as the posterior distribution of the homeland encompassed a vast area of South America [40].

On this consensus model, regions in the vicinity of the Negro basin were long inhabited by Arawakan peoples, while areas more distant from this region are areas of more recent Arawakan habitation. For purposes of expositional convenience, we partition the geographical distribution of Arawakan languages into four major areas: (i) the **Caribbean-Atlantic Area**, consisting of the following expansion zones: (a) the western Caribbean littoral (Colombia and Venezuela); (b) the eastern Caribbean littoral (the Guianas) and northern Atlantic littoral (northeastern Brazil) and (c) the Lesser and Greater Antilles; (ii) the **Central and Northwest Amazon Area**, consisting of the following expansion zones: (a) the upper Negro and Orinoco headwaters regions (Brazil and Venezuela); (b) the Caquetá-Japurá basin and (c) the Colombian and Venezuelan llanos; (iii) **Southern Amazonia**, consisting of the following expansion zones: (a) the western Guaporé (Bolivia) and (b) the upper Xingu (Brazil); and (iv) **Western Amazonia**, consisting of: (a) the upper Purus basin (Brazil and Peru) and (b) the middle and upper Ucayali (Peru). At this stage, the long Arawakan habitation on the middle Amazon, middle and lower Negro, and nearby major tributaries, such as the Caquetá-Japurá, make associating particular finds in this region with particular nodes in the Arawakan tree challenging. We discuss several of these cases in the electronic supplementary material, appendix B.

2.2.2. Linking archaeological remains to Arawakan peoples

We link archaeological finds with peoples who spoke Arawakan languages in two ways: (i) by identifying the finds as belonging to the broader Saladoid-Barrancoid ceramic tradition and Arawakan matrix practices typically associated by archaeologists and ethnohistorians with Arawakan and/or (ii) by linking a local tradition to an Arawakan subgroup by geographical and temporal overlap.

Geographical connections between archaeological sites and particular Arawakan subgroups are compelling to the degree that there is considerable **geographical overlap** between the sites in question and the known distribution of that subgroup, and only that subgroup.[4] Obviously, this geographical connection is easiest to establish in Arawakan expansion zones in which only members of a single clade are present. In such cases, it is plausible that the sudden appearance of Arawakan material culture in a given area corresponds to the arrival of Arawakans there, who subsequently developed and diversified into the modern Arawakan peoples found in the area. In other cases, it may be possible to identify more than one wave of Arawakan expansion and to distinguish different temporal layers, with each layer related to distinct archaeological or historical records (see §3.2.1). In either case, it is important when arguing for an association between archaeological finds and a particular Arawakan language or subgroup, to exclude possible associations with other Arawakan groups. Moreover, if the claim is that finds are

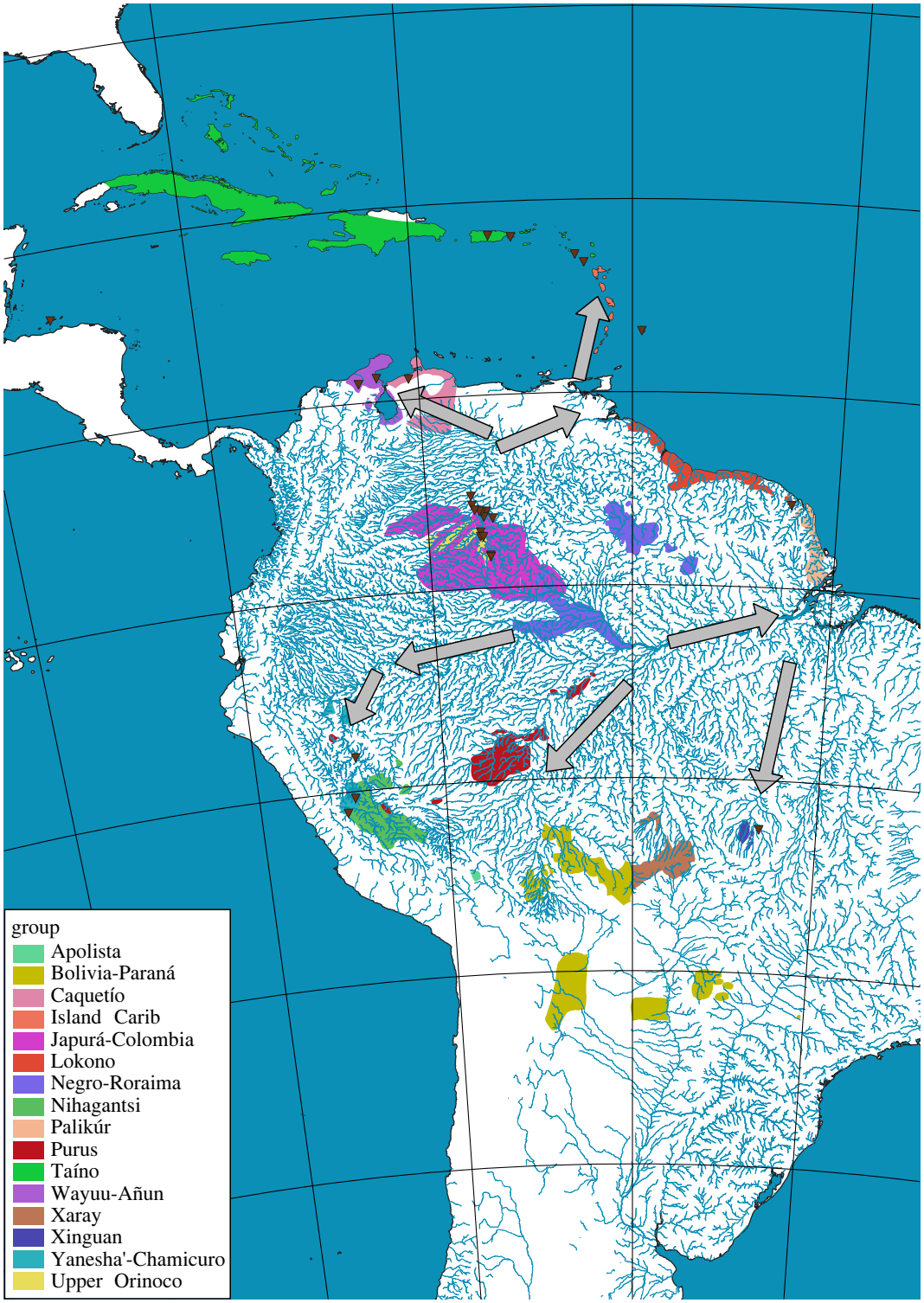

Figure 1. Distribution of Arawakan languages and migration routes from central Amazon (based on maps in [34–36]).

associated with a group of languages, it is important to establish that this group is monophyletic, i.e. there are no other languages that share the same most recent common ancestor with the group in question.

Temporal overlap can be established when there is continuity in material culture that links archaeological remains found in the sites of interest to modern or historical practices of Arawak peoples. We rely on the archaeological literature for these judgements of similarity and continuity.

2.3. Creating explicit calibration distributions

Once a linguistic–archaeological link is established, the next steps are to select dating information available for the archaeological finds and to translate this information into a calibration prior distribution.

Dating information for a particular site or tradition can be direct (e.g. based on radiocarbon dates) or indirect (e.g. based on stratigraphy). Since we are mostly dating expansions, the earliest dates from a site or an archeological complex are most relevant to us. Ideally, organic material (e.g. charcoal remains) in the lowest (earliest) Arawakan-associated stratum of a site has been ^{14}C-radiocarbon-dated. However, often this is not the case, and then we prefer dates from explicitly dated material over dates indirectly derived from the stratigraphy, even when the indirect date would be earlier.

In order to translate the dating information into calibration distributions for a Bayesian analysis, we follow the three principles below:

Table 1. Glossary of the terms and symbols used to describe calibrations.

term	definition
node	a node in the tree, which can be a tip (aka 'terminal node' or 'leaf node') or an internal node. A tip can be a Language, an Ethnonym or a Culture
proto(*node 1*, *node 2*, …)	the most recent common ancestor (MRCA) of *node 1*, *node 2*, … Note that this type of designation of an ancestor does not necessitate that the group of *node 1*, *node 2*, etc is monophyletic. Other tips can be inferred to be descendants of this MRCA in addition to those listed
pre-*node*	the language or culture that later became *node*, just after the split from its closest relative/sibling
Name Culture	this tip is based on archaeological evidence and has no accompanying linguistic data.
Name Ethnonym	this tip is based on ethnohistorical evidence and has no accompanying linguistic data
node ∼ *distribution*	the date associated with the *node* to the left is drawn from the probability *distribution* to the right
uniform(*lower*, *upper*)	a uniform distribution with *lower* years BP[16] as the latest date and *upper* years BP as the earliest date
normal($\mu = mean$, $\sigma = std$)	a Gaussian normal distribution with a given *mean* in years BP and standard deviation *std* in years
constrain *node* to be an ancestor	constrain *node* to be a 'sampled ancestor', i.e. a node along a branch that leads to one or more attested tips as direct descendants[17]
monophyletic(*node 1*, *node 2*, …)	*node 1*, *node 2*, … are more closely related to each other than to any other *node* in the data set. They form a subgroup (or clade) in the tree

Principle 1: If we know from the archeological record that a clade cannot have existed at a certain point in time, but must have existed at a later time (i.e. we have a lower and an upper bound on the age of pre-proto-language), then we employ the maximum entropy distribution, which is the distribution that encodes the least amount of prior knowledge. (For a minimum and a maximum value, this maximum entropy distribution is the uniform distribution.) We do not apply this principle if some other, encompassing clade has an older calibration and thus constrains the maximum age of the inner subgroup indirectly.

Principle 2: If the subgrouping structure (topology) is beyond doubt, i.e. where only one language or a widely accepted group of closely related languages is plausibly associated with a given set of archaeological finds, we use a Culture[5] tip without associated linguistic data. The distribution in this case is the archeological date distribution and the Culture tip and the associated languages are constrained to be monophyletic.

Principle 3: If there is no clear maximum age and the subgrouping is uncertain, then the question that drives the design of the calibration is 'How likely is it that we are we missing older evidence?', or, more applicably, 'How many factors need to come together to enable us to retrieve and date the reported archeological finds after the speaker population in question split?'. The expected waiting time until a chain of independent rare events has occurred, where the waiting time for each type of event does not depend on when the last event of this type happened (exponential waiting time distribution) is a gamma distribution.

In practice, all our calibration points are either governed by Principle 1 or Principle 2, or associations between dates and clades were so uncertain that we rejected the calibration candidate altogether. As such, we were not able to apply and refine Principle 3 on the Arawak calibrations.

We formalize the derived calibrations using a limited vocabulary of terms listed and defined in table 1. The terms can be subsequently used for the automatic implementation of calibrations and constraints in phylogenetics software, such as BEAST2 [41].

3. Results

The results provided in this paper consist of a comprehensive list of all calibrations we have identified as useful for an Arawakan phylogeny, as well as all the possible calibrations we have considered but ultimately did not find sufficiently trustworthy. In this section, we discuss calibrations based on archaeological evidence, while in electronic supplementary material, appendix B, we discuss possible archaeological calibrations we ultimately rejected. In each case, we provide arguments for the calibrations in question in terms of the general methodological principles outlined in §2. Calibrations based on colonial era historical documentation, which are relatively conceptually straightforward, are presented along with brief explanations when necessary in electronic supplementary material, appendix A.

3.1. Archaeological calibrations

In this section, we discuss archeological finds associated with Arawakan peoples in each of the regions where Arawakan languages are or have been spoken. We describe each set of finds, the distribution of Arawakan languages in the area of the finds, then gauge whether the evidence for an association between the finds and some historical language, or group of languages, is sufficient to derive a calibration, based on the criteria described in §2.2. To make our approach transparent, we discuss not only cases where we have been successful in deriving calibrations, but also cases where we judge the association to be too tenuous to yield reliable calibrations. We summarize the finds in table 2 and conclude each subsection with a standardized box summarizing the calibrations we derive from the evidence in the formalized vocabulary explained in table 1.

3.2. Caribbean–Atlantic area

The Caribbean–Atlantic area stretches along coastal mainland South America from the mouth of the Amazon in the east, to the western Caribbean coast. It is delimited in the north by the Greater Antilles, by the Colombian-Venezuelan llanos in the west, and the Tumucumaque range in the south. The region is home to two Arawakan clades: Caribbean and Palikuran. For the members of these clades, we propose

Table 2. Summary of calibrations.

language(s)/subgroup	culture(s)	date	monophyly	geographical overlap	exclusion of other associations	continuity	comments
pre-Taíno	Saladoid of Greater Antilles	uniform (2445, 2800)	–	✓	✓	✓	node calibration
pre-Old Island Carib	Barbados Palo Seco	uniform (1490, 1690)	–	✓	✓	✘	node calibration. Subsequent cultural shift
Añun, Wayuu	Hornoid	normal ($\mu = 2420$, $\sigma = 50$)	✓	✓	✓	✓	
Caquetío	Dabajuroid	normal ($\mu = 1100$, $\sigma = 70$)	–	✓	✓	✓	
Palikuran	Aristé	normal ($\mu = 1760$, $\sigma = 45$)	✓	✓	✓	✓	
Maipure	Iboa	normal ($\mu = 1730$, $\sigma = 80$)	–	✓	✓	✓	continuity to 1500 CE through Nericagua culture
Yavitero, Baniva (Guainia), Baniva (Xié)	Carutico	normal ($\mu = 1800$, $\sigma = 80$)	✓	✓	✓	✘	we interpret Iboa and Carutico as sister cultures
Xinguan	Kuhikugu	normal ($\mu = 900$, $\sigma = 60$)	✓	✓	✓	✓	
Bolivia-Paraná	Santa Paula	normal ($\mu = 900$, $\sigma = 60$)	✓	✘	✓ (assuming expansion model)	✘	requires subsequent cultural shift
Nihagantsi	Hupa-Iya	uniform (1860, 2600)	✓	✘	✓	✓	continuity to modern times through the Naranjal tradition
Ashéninka (Norte)	Naranjal	fixed(500)	–	✘	✓	✓	
Yanesha'	Enoqui	normal ($\mu = 1050$, $\sigma = 80$)	–	✓	✓ (assuming no downriver migration)	✓	

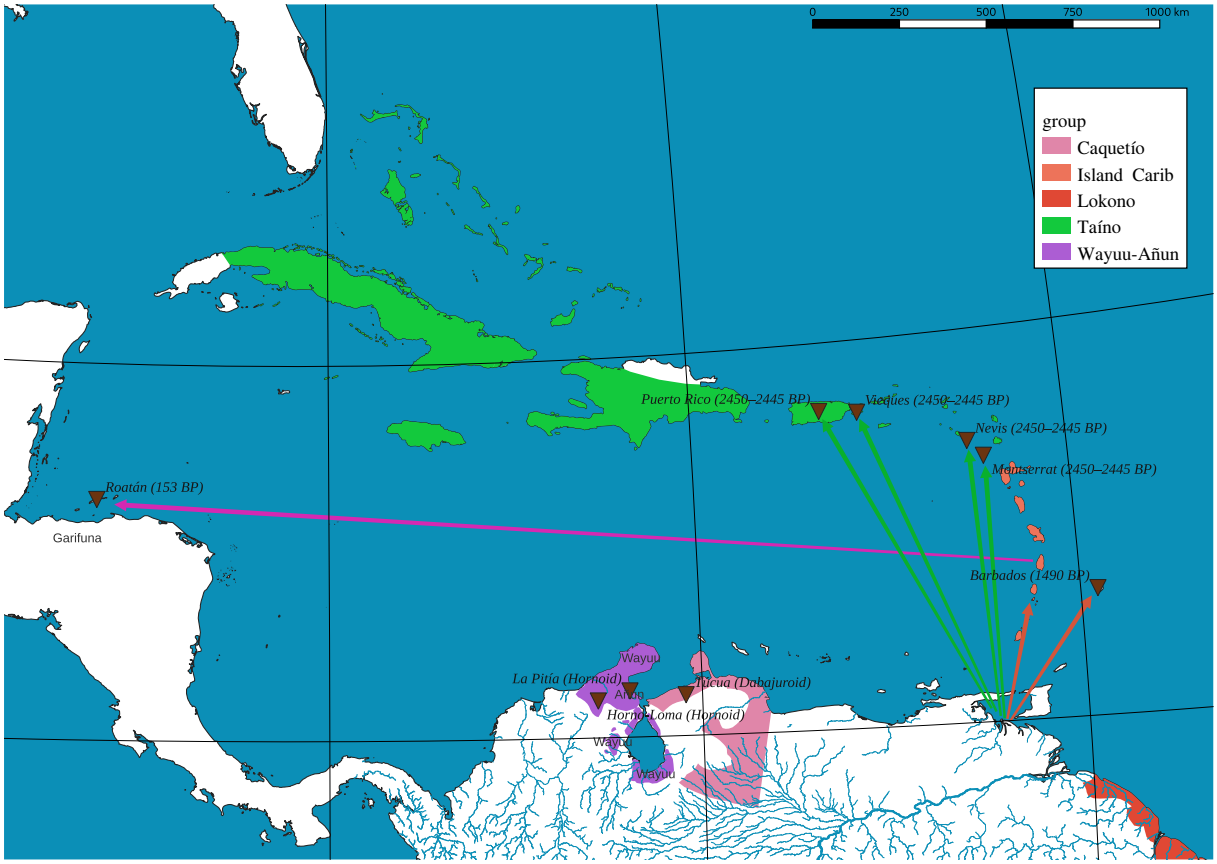

Figure 2. Arawakan languages and archaeological sites in the Caribbean region.

calibration points based on archaeological evidence of expansions into the Greater and Lesser Antilles, and the Caribbean and Atlantic coast. Additionally, one rejected archaeological calibration point (for Lokono), and two tip calibration points based on historical evidence (for Aruan and Garifuna), are discussed in electronic supplementary material, appendices B and A, respectively.

3.2.1. Taíno

There is a general consensus that Saladoid pottery was spread to the Greater Antilles by the ancestors of the Taíno (figure 2), leading us to employ dates associated with the appearance of Saladoid pottery in the region to calibrate the split of Taíno [tain1254] from its sister language(s). There are several arguments for linking the Saladoid ceramics of the Greater Antilles with the Taíno. First, the Saladoid pottery of the Greater Antilles shows continuity with that of the mainland Orinoco region and contrasts with the finds predating its appearance in the islands [42]. These facts support the interpretation that Saladoid pottery was introduced to the islands from the mainland, as opposed to a local development. Second, its geographical distribution in the Caribbean coincides with that of the Taíno. Third, Taíno (with its dialects) was the only Arawakan language spoken in the Greater Antilles at the time of European colonization; there is no evidence of other Arawakan languages ever being spoken there [7]. Fourth, Saladoid pottery shows continuity with later Taíno pottery, in particular the Chican Ostionoid style of the Taíno, which developed through the interaction with the non-Saladoid inhabitants of the islands. While it is uncontroversial to associate the Taíno with the spread of Saladoid pottery, it is important to note that the Taíno migration was likely preceded by a period of scouting and trade. As a result, although the earliest Saladoid finds in the Greater Antilles date to 2800–2220 BP, in Puerto Rico, which could thus constitute the earliest possible date for calibrating the split between Taíno and its sister language(s), we instead take the date of the first permanent Saladoid settlements: Montserrat, Nevis, Puerto Rico and Vieques dated to 2450–2445 BP [43]. Given the extensive archeological research in the region and the fact that after 2220 BP numerous other Saladoid settlements were established in northern Lesser Antilles [42,43], the likelihood of finding significantly earlier permanent settlements is small. In summary, we conclude that Taíno must have separated from its sister languages by 2450–2445 BP. By Principle 1, we use a uniform distribution with the two most extreme dates as endpoints for calibration.

pre-Taíno~Uniform(2445, 2800)

3.2.2. Old Island Carib

There is consensus that Barrancoid-influenced Palo Seco pottery was spread to the Lesser Antilles by the ancestors of Old Island Carib[6] (figure 2), leading us to employ dates associated with the appearance of Barrancoid pottery in the Lesser Antilles to calibrate the split of Old Island Carib [isla1278] from its sister language(s). There are several arguments for associating these finds with Old Island Carib. First, the Barrancoid-influenced pottery of the Lesser Antilles originates in the mainland. Around 1 CE, Barrancoid pottery started to spread from the Lower Orinoco towards the Saladoid settlements of Trinidad. In Trinidad, the pottery appears exclusively at Saladoid sites, suggesting that its bearers lived among Saladoid people, where it developed into the Palo Seco complex [27,44]. Second, prior to the

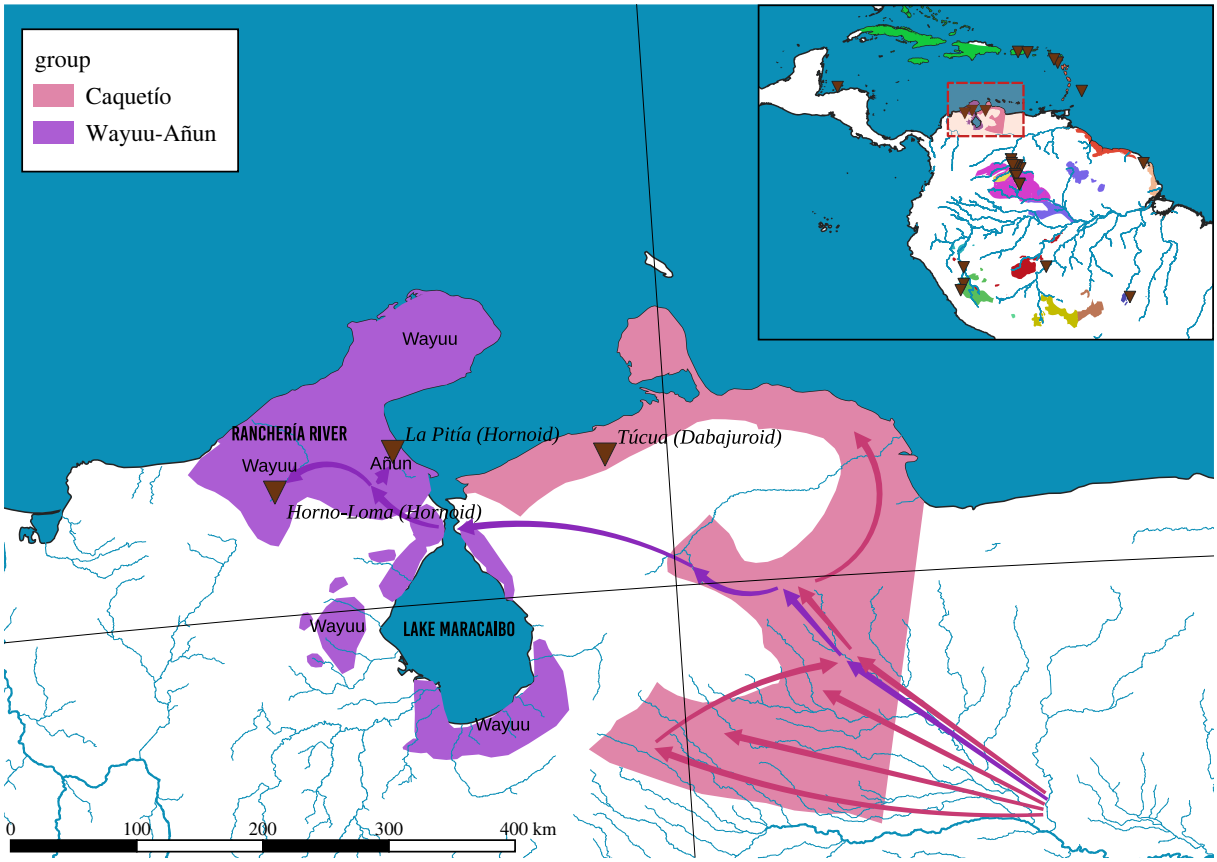

Figure 3. Wayuu-Añun and Caquetío languages and associated archaeological sites.

appearance of Barrancoid-influenced pottery makers in the Lesser Antilles, most of the islands show no evidence of permanent habitation [42]. This includes Barbados, the location of the first permanent Palo Seco settlement in the Lesser Antilles. Significantly, Barbados Palo Seco pottery is limited to the south coast, suggesting that settlement came from, and that subsequent interactions were focused on, the mainland. Third, the distribution of Barrancoid-influenced pottery coincides with that of Old Island Carib at the time of European colonization, and there is no evidence of other Arawakan languages ever being spoken in this part of the Antilles [7]. That said, such Barrancoid-influenced pottery, arguably spread by the ancestor of Old Island Carib, was soon discontinued. In historic times, the Old Island Carib people, by then a mixed society of Arawakan and Cariban people [45], made pottery characteristic of the latter people. As in the case of the Saladoid finds discussed in relation to the Taíno people, although the earliest Barrancoid-influenced finds in the Lesser Antilles date to 260–660 CE (Barbados), we consider this to be evidence of a scouting phase. The other end of the calibration range for the split of Old Island Carib from its sister language(s) is given by the earliest permanent settlement on Barbados 1490 BP [43].

pre-(Old Island Carib)~Uniform(1490, 1690)

3.2.3. Wayuu-Añun

Wayuu [wayu1243] and Añun [para1316] are two closely related languages that form a well-established subgroup [1–3]. Here we associate the remains of the Hornoid subtradition of the broader Arawakan Macro-Tocuyanoid tradition with the ancestor of these languages, on the basis of geographical overlap and cultural continuity, and we use the first appearance of the Hornoid tradition in an area historically inhabited by the Wayuu as a tip calibration with no associated linguistic data.

Hornoid sites are found in the coastal Sinamaica area at La Pitía, further inland along the Ranchería River, and in the Betijoque area, on the southeastern edge of Lake Maracaibo [6]. Hornoid is identified as a subtradition of Macro-Tocuyanoid [6], which is associated with Arawakan peoples that expanded into what is now northwest coastal Venezuela and northeastern coastal Colombia, and specifically with the ancestors of the modern Wayuu and Añun [46].

We concur with this association, noting that there is significant geographical overlap between Hornoid sites and the early colonial era distribution of Wayuu and Añun peoples, as evident in figure 3. In particular, the region of the Hornoid site of La Pitía in the Sinamaica area was occupied by Wayuu and Añun [6], and the Ranchería area was inhabited by Wayuu-Guajiros in the early colonial period [47] and is still considered a culturally important area for the Wayuu [48].

Significantly, the La Pitía site was continually occupied by the bearers of Hornoid pottery for over 2000 years until the first half of the sixteenth century [49], establishing continuity between Hornoid and the colonial era Wayuu and Añun, who lived there in the early colonial period and continue to do so today [50].[7] Another plausible form of cultural continuity involves the localized cemeteries in Hornoid sites and the preponderance of the feminine forms in Hornoid figurines and funerary urns, which can be interpreted as evidence of matrilineality in Hornoid culture, and which connects with the modern Wayuu use of matrilineal clan-based cemeteries [51].

Although there is a C^{14} date from La Pitía, its interpretation is not straightforward (see electronic supplementary material, appendix B), and we instead use dates from the

better documented Ranchería valley for deriving a tip calibration with no associated linguistic data. The earliest C^{14} date in the Ranchería valley is 2420 BP ± 50 [6,51].

Monophyletic(Wayuu, Añun, Hornoid Culture)

Hornoid Culture~Normal($\mu = 2420$, $\sigma = 50$)

Constrain Hornoid Culture to be an ancestor

3.2.4. Caquetío

At the time of the European invasion, the Caquetío people inhabited much of the coastal region of what is now the state of Falcón, the Barquisimeto Plateau and the adjacent islands of Aruba, Bonaire and Curaçao. In these same regions are also found ceramics of the closely related Tierroid and Dabajuroid traditions, which have been explicitly associated with the Caquetío [6,46], leading us to use the appearance of these traditions in historical Caquetío territory as a calibration along the branch leading to Caquetío [arub1238].

The distribution of the related Tierroid and Dabajuroid ceramics corresponds to the historical distribution of the mountain and coastal Caquetío, respectively. Furthermore, the two traditions continued into colonial times at the Caquetío sites: Tierra de los Indios in the mountains and Médanos de Coro near the coast, respectively [6].

A Dabajuroid site in Túcua yields the earliest C^{14} date that we can associate with the Caquetío: 1100 ± 70 BP [6]. The earliest Tierroid sites are thought to be contemporaneous, but no early dates are available for them [46].

In electronic supplementary material, appendix B, we discuss an association that has been suggested between the Caquetío and the Gavan complex found in the Llanos region, which we do not find sufficiently well-supported to base a calibration on.

Monophyletic(Caquetío, Dabajuroid Culture)

Dabajuroid Culture~Normal($\mu = 1100$, $\sigma = 70$)

Constrain Dabajuroid Culture to be an ancestor

3.2.5. Palikuran

Palikuran is a subgroup that consists of Palikúr [pali1279] and two poorly attested varieties, Marawan and Karipurá, that are either very closely related to Palikúr [52], or simply Palikúr dialects [3,53]. In this section, we associate Palikuran with the Aristé ceramic tradition and use dates associated with this tradition as a tip calibration with no associated data along the branch leading to the Palikuran subgroup. Support for this association includes geographical overlap between Aristé sites and traditional Palikúr territory, and the continuity between aspects of Aristé material culture, especially funeral urns, and Palikúr material culture in the early colonial period.

The distribution of 12 of the 18 Palikuran clans in the early colonial period [54] coincides significantly with the distribution of archaeological sites exhibiting Aristé ceramics [55]. Further, the modern Palikúr consider the savannahs of the Urucauá River, in the centre of the Aristé region, to be their heartland [56]. The remaining six Palikúr clans of the early colonial period lived further south, closer to the mouth of the Amazon, where the Mazagão ceramic tradition is found. In response to the violence of the early European colonizers, these clans fled to the north where they joined the northern clans and fused with them, and other groups, to form the modern Palikúr [57].

The Aristé and Mazagão traditions appear to have diversified from a single original tradition (either the Amazonian Polychrome or the Amazon Incised and Punctate Tradition [58,59]), with the Mazagão tradition having been influenced by neighbouring ceramic traditions to a greater degree than the Aristé tradition. Although the early Mazagão tradition may be older than the early Aristé tradition, C^{14} dates are only available for the Aristé tradition.

Evidence for continuity between the Aristé tradition and the historical Palikúr culture, which survived along the Oyapock and Urucauá Rivers until the eighteenth century, includes records of the Early Aristé practice of secondary urn burials recorded among the Palikúr of the seventeenth and eighteenth centuries [56], and some Late Aristé motifs found in urn decorations which resemble motifs used in modern Palikúr art [60].

Consonant with the oral history of south to north Palikúr migration, the appearance of Aristé ceramics in French Guiana was chosen as a tip calibration with no associated data on the branch leading to the Palikuran subgroup. In Montagne Favard (figure 4), we find the earliest C^{14} date of 1760 ± 45 BP [56].

Aristé Culture~Normal($\mu = 1760$, $\sigma = 45$)

Monophyletic(Aristé Culture, Palikúr, Karipurá, Marawan)

Constrain Aristé Culture to be an ancestor

3.3. Central and northwest Amazon area

This area, depicted in figure 5, is rich in archaeological sites associated with Arawakan peoples, who are believed to have inhabited the region for several thousand years (see §2.2.1). As a result, it is challenging to associate Arawakan sites with particular nodes in the phylogeny, with one exception that we discuss in this section: the Upper Orinoco subgroup. The reader is referred to electronic supplementary material, appendix B for discussion of other possible associations that were not retained.

3.3.1. Upper Orinoco subgroup

The Upper Orinoco subgroup [3] encompasses Maipure [maip1246] and the closely related languages Yavitero [yavi1244], Baniva (Guainia) [bani1260] and Baniva (Xié) [ware1257].[8] Maipure was historically spoken near the confluence of the Ventuari and Orinoco rivers. The Baniva dialects occupied the areas of the Upper Guainía, Upper Xié and Tomo (all tributaries of the Upper Rio Negro), while the Yavitero were also initially located in the Xié and Tomo [3,61,63]).[9] On the basis of geographical overlap, we associate the Iboa-Nericagua ceramic tradition with pre-Maipure, and the Pueblo Viejo and Carutico traditions with Proto-Baniva-Yavitero, yielding two tip calibration points with no associated linguistic data on the respective branches.

The Iboa-Nericagua sequence consists of two phases, an earlier Iboa phase with finds located in the Upper Orinoco and Lower Ventuari rivers, and a later Nericagua phase considered a development from the Iboa phase because: (i) Iboa ceramics precedes and overlaps stratigraphically with the earliest Nericagua finds; (ii) the geographical range of Nericagua sites encompasses Iboa sites and (iii) there are continuities in decorative and tempering techniques between Iboa and Nericagua [64]. All Iboa sites occur within historical Maipure territory, with dates ranging from 1730 ± 80 BP (our calibration) to 940 ±

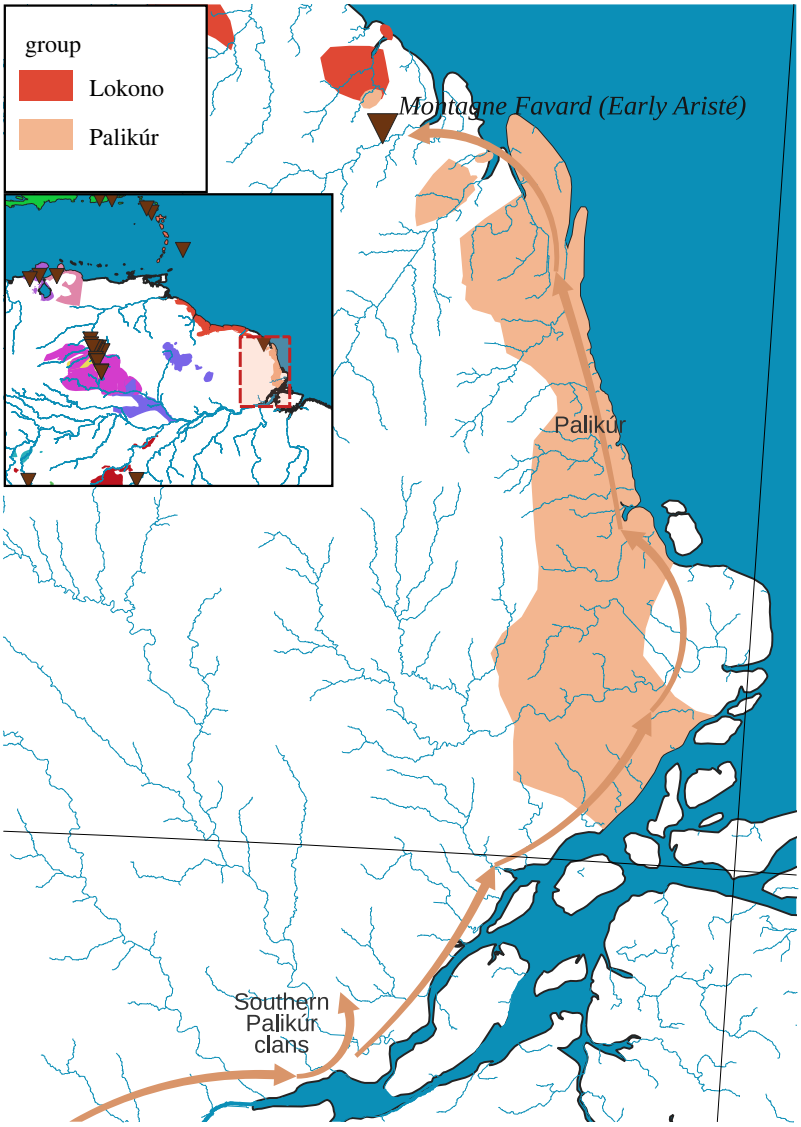

Figure 4. Palikúr and associated archaeological site.

60 BP, as do the 17 Nericagua phase sites that have been found, with dates ranging between 1159 ± 122 and 544 ± 113 years BP [61,64,65]. The Nericagua sites are larger than those of the Iboa phase, with areas ranging from 50 to 400 m in diameter; with some exhibiting Arawakan matrix features like mounds arranged around a central plaza, and ceremonial sites.

Supporting the association of Iboa-Nericagua with pre-Maipure, to the exclusion of proto-Baniva-Yavitero, no Iboa-Nericagua ceramics have been found in the areas where the speakers of Baniva and Yavitero are now located, nor in the region that they probably occupied prior to the more recent arrival of Guipuinave [puin1248] and Warekena Velha (two languages of the Japurá-Colombia subgroup).[10] However, Pueblo Viejo and Carutico ceramics found in Baniva and Yavitero territory are similar to Iboa ceramics in terms of decorative and tempering techniques [64], and form part of the broader Parallel Lines tradition, suggesting that Iboa-Nericagua and Carutico/Pueblo Viejo are sister traditions. The dates of the Carutico phase (1800 ± 80 BP–800 BP), which are similar to those of the Iboa-Nericagua sequence, are consistent with this conclusion, while Pueblo Viejo is dated between 1400 and 1000 BP.

The preceding observations suggest that Iboa-Nericagua and Carutico/Pueblo Viejo sequences are sister ceramic phases produced by the speakers of pre-Maipure and proto-Baniva-Yavitero, respectively, after the split between the two. The phases are roughly contemporaneous, and their geographical distribution coincides with the distributions of the languages of the two branches. Nericagua ceramics date to as late as 1500 CE, which allows us to link this tradition to the historic speakers of Maipure.

Monophyletic(Iboa Culture, Maipure)

Iboa Culture~Normal($\mu = 1730$, $\sigma = 80$)

Constrain Iboa Culture to be an ancestor

Monophyletic(Carutico Culture, Baniva (Guainia), Baniva (Xié), Yavitero)

Carutico Culture~Normal($\mu = 1800$, $\sigma = 80$)

Constrain Carutico Culture to be an ancestor

3.4. Southern Amazonia

According to the consensus model of the Arawakan expansion, Arawakan peoples expanded into Southern Amazonia along two major tributaries, the Xingu and the Madeira, which each join the Amazon downriver of its confluence with the Negro. As evident in figure 6, each river basin is home to a single Arawakan clade, the Xinguan subgroup in

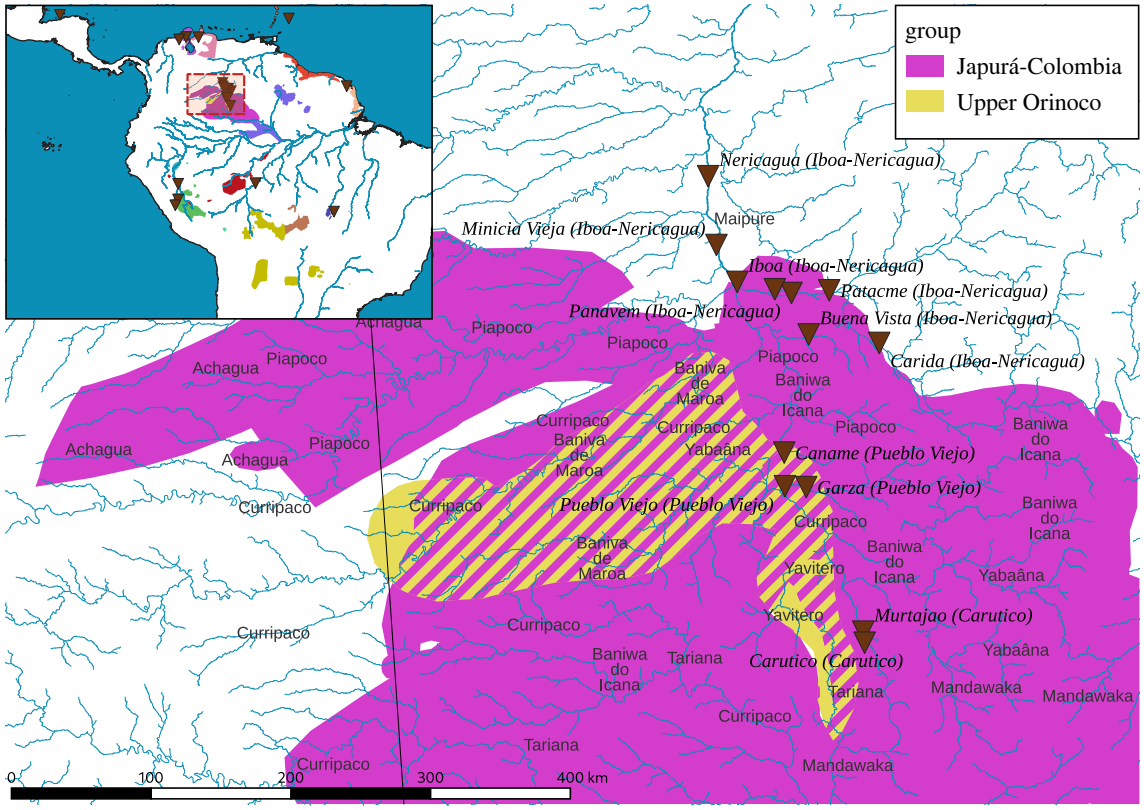

Figure 5. Language groups and archaeological sites in the Upper Rio Negro and Orinoco (adapted from [61,62]). Northwest Amazonian languages and associated archaeological sites.

the first case, and the Bolivia-Paraná in the second, for both of which we have found calibration points.

3.4.1. Xinguan subgroup

The languages of the Xinguan subgroup—Yawalapití [yawa1261], Waura [waur1244], Mehinaku [mehi1240] and Kustenau [kust1238]—form an established Arawakan subgroup [2,3] that clusters in a compact region of the upper Xingu River. In this section, we associate remains found in this multi-ethnic acculturation zone [67,68] with the ancestors of the modern Xinguan Arawakan peoples.

Sites identified as Arawakan in the upper Xingu go back to the so-called first phase of Xinguan occupation (1500–1200 BP) [69], but their dating is problematic due to stratal mixing [70]. The earliest reliable dates are those of the Kuhikugu site, dated to 900 ± 60 BP, which exhibits Saladoid-Barrancoid pottery and Arawakan matrix features such as central plazas, roads and defensive ditches [70]. The ceramics found at Kuhikugu and earlier sites strongly resemble those produced by modern Xinguan Arawakans, who are historically known as the specialized providers of pottery for the Xinguan multi-ethnic trade networks [67,68]. Association of this site and others in the Upper Xingu region with Arawakan peoples is based on proximity to Xinguan Arawakans, continuity in ceramics traditions, and clear similarities in material culture and landscape management techniques between the Xinguan sites and sites elsewhere in the Amazon that are securely associated with Arawakans, notably the Parecís [pare1272], to the west of the Upper Xingu [71]. Although Cariban peoples are also found in the region, their recent arrival in approximately 1700 CE rules them out as being associated with these older sites [67]. The same applies to the local Tupian groups, the Awetí [awet1244] and the Kamayurá [kama1373], whose arrival in the Upper Xingu is even more recent, to the point of being recorded in Xinguano oral history [67].

The status of Xinguan as a monophyletic clade is uncontroversial, with limited internal differentiation. This being the case, we do not associate the Kuhikugu date to any specific node of the Xinguan tree, but instead constrain the relevant dating information to be associated with the clade as a whole.

> Monophyletic(Yawalapití, Waura, Mehinaku, Kustenau, Kuhikugu Culture)
>
> Kuhikugu Culture~Normal($\mu = 900$, $\sigma = 60$)
>
> Constrain Kuhikugu Culture to be an ancestor

3.4.2. Bolivia-Paraná subgroup

The Bolivia-Paraná subgroup is an established subgroup consisting of languages found in the *Llanos de Mojos* region—Baure [baur1256], the Mojeño varieties and Paunaka [paun1241]—and Terena [tere1279], further to the east [1,72]. Although there are ample archaeological remains in this region, associating them with the Arawakan groups of the region is difficult. We instead argue for an association with a site to the north, outside the Llanos de Mojos.

Associating archaeological sites in the Llanos de Mojos with Arawakan peoples is made difficult by the following considerations. First, key diagnostics of Arawak occupation, such as Barrancoid ceramics and circular plaza organization, are absent [73]. Second, some of the material culture features commonly seen as diagnostic of Arawakan sites (raised fields, trenches, large villages with plazas/public ceremonial spaces) are also historically attested among other, non-Arawakan peoples of the region [74], such as the Cayuvava [cayu1262] and, possibly, the Movima [movi1243] [75]. Third, the archaeological remains found in the territory of the two major Arawakan groups of the region, the Mojeño

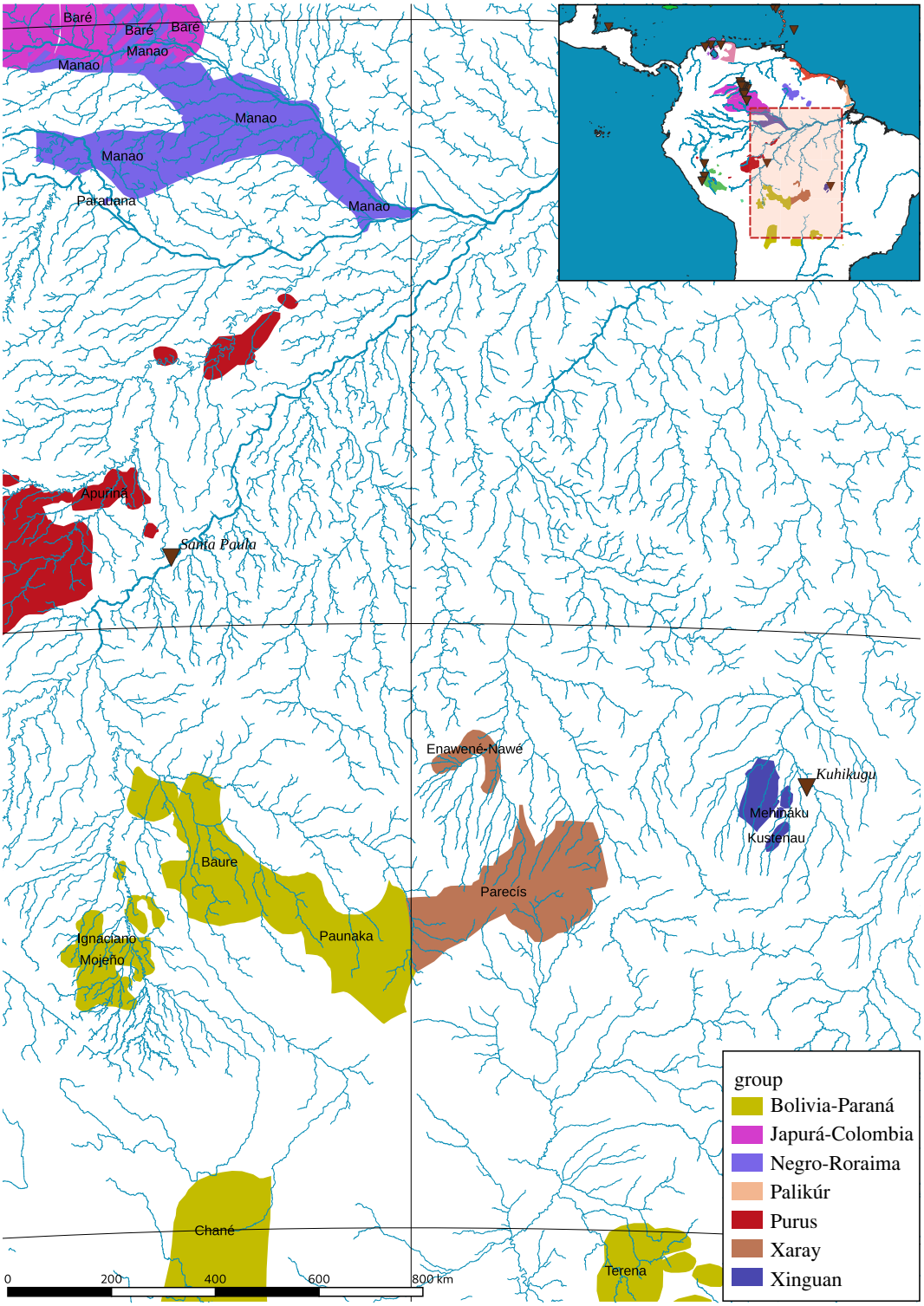

Figure 6. Southern Arawakan languages and associated archaeological sites.

and the Baure, display striking differences [73]. This is either inconsistent with a simple explanation of their emergence from a single and culturally cohesive population of invaders, or is indicative of significant mutual influences with local, non-Arawakan populations. Either way, and coupled with the first two points, this makes it very difficult to associate regional sites with Arawakans specifically.

The most promising association we have identified between archaeological finds and the Bolivia-Paraná subgroup lies outside of the Llanos de Mojos region proper: the Santa Paula site is in the upper Madeira, upriver from the city of Porto Velho. This site has been argued to be Arawakan on the basis of features such as Pocó-Açutuba ceramics and landscape modifications such as mounds and plazas [76]. Crucially, this site stands mid-way along a path from the mouth of the Madeira River on the lower Amazon, to its upper reaches, where the Llanos de Mojos and the majority of the Bolivia-Paraná languages are found. The location of this site is precisely what one would predict for the ancestors of the Bolivia-Paraná group on the basis of the consensus model of Arawakan expansion. The layers associated with Pocó-Açutuba ceramics at the Santa Paula site have been carbon dated to 1530 ± 30 BP [76]. Since the central Amazon dates for the Pocó-Açutuba sites go back 3000 BP [24], the chronologies are consistent with a migration of Arawakan-speaking bearers of Pocó-Açutuba ceramics up the Madeira River.

Despite the lack of geographical overlap between the Bolivia-Paraná groups and the Santa Paula site, the Bolivia-Paraná subgroup offers the best candidate for an association with this site of all the Arawakan subgroups south of the Amazon. The remaining southern Arawakan groups, such as the Parecís and the Enawene Nawe [enaw1238], the Purus subgroup and the Xinguan Arawakan languages, are all plausibly associated with population movements along other southern affluents of the Amazon, such as the Purus and/or the Juruá (for the Purus subgroup), the Tapajós (for Parecís and Enawene Nawe) and the Xingu (for Xinguan Arawakan). The possibility remains, however, that the Santa Paula site could be associated with an extinct sister to Bolivia-Paraná. For this reason, we have chosen to associate the Santa Paula dates to the Bolivia-Paraná subgroup, either as an ancestor or an extinct sister.

Monophyletic(Santa Paula Culture, Old_Baure, Baure, Paunaka, Ignaciano, Old_Mojeño, Terena)

Santa Paula Culture~Normal($\mu = 900$, $\sigma = 60$)

3.5. Western Amazonia

According to the consensus model of the Arawakan expansion, Arawakan peoples expanded into Western Amazonia by two routes: (i) by following the Amazon itself upriver and continuing up the Ucayali and (ii) by following the Purus River, a tributary that meets the Amazon upriver of its confluence with the Negro. The Ucayali basin is home to two established Arawakan subgroups, the Yanesha'-Chamicuro and Nihagantsi subgroups, while the Purus basin and adjacent areas are home to the eponymous Purus subgroup.

3.5.1. Nihagantsi subgroup

The Nihagantsi[11] languages constitute a group of closely related languages spoken in the area of upper Ucayali River and its major affluents: the lower Urubamba, Ene/Tambo/Apurimac and Pachitea [1,2,78]. We associate the Nihagantsi languages with the Hupa-Iya tradition of the Central Ucayali region, which is linked with the speakers of Proto-Nihagantsi (PN) via continuity in the relevant ceramics traditions [22].

Hupa-Iya is a Barrancoid ceramic style that appears abruptly in the central Ucayali region in approximately 2200 BP, which is attributed to the arrival of an Arawakan people from the Amazon proper [22]. It is connected to the ancestors of the modern Nihagantsi peoples via the Naranjal ceramic complex of the Chanchamayo area [22]: '[t]he broad/line incised decoration of Naranjal strongly suggests that the fifteenth- to nineteenth-century style [of the Naranjal complex] is directly derived from Hupa-Iya through 1,500 years of gradual simplification'. The distribution of the Naranjal ceramic complex up through the nineteenth century corresponds clearly, and exclusively, to the location of speakers of Ashéninka (Norte) [ashe1271], one of the modern Nihagantsi languages.[12] The Naranjal tradition is dated to 500–100 BP, based on its association with Franciscan missions over that time interval.

Drawing on the basic model of the Arawakan expansion we adopt in this paper (see §2.2.1), we infer that the Hupa-Iya tradition represents the material culture of speakers of Proto-Nihagantsi, as they worked their way up the Ucayali, en route to the juncture where the Urubamba and Tambo Rivers join to form the Ucayali (figure 7). Judging by the modern distribution of the Nihagantsi languages, it was in the vicinity of this juncture that Proto-Nihagantsi began to diversify, as its speakers spread into the different smaller river basins of this general region.

The Hupa-Iya tradition is dated to approximately 2150 BP [22]. This date is based not on direct C^{14} dates for Hupa-Iya remains, but rather on stratigraphic inference using C^{14} dates for the tradition that immediately replaced it, the Yarinacocha tradition (1860 ± 110 BP), and the one that preceded it, the Shakimu tradition (2600 ± 200 BP). Since not much archaeological work has been carried out in the Central Ucayali region, and only a single Hupa-Iya site has been excavated, dates earlier than 2200 BP for the Hupa-Iya tradition are certainly plausible.

Monophyletic(Ashéninka (Norte), Naranjal Culture)

Naranjal Culture~Fixed(500)

Constrain Naranjal Culture to be an ancestor

Monophyletic(Ashéninka (Norte), Asháninka, Nomatsigenga, Matsigenka, Pajonal Ashéninka, Caquinte, Hupa-Iya Culture, Naranjal Culture)

Hupa-Iya Culture~Uniform(1860, 2600)

Constrain Hupa-Iya Culture to be an ancestor

It must be noted that there could be other hypotheses concerning the relationship of Hupa-Iya to other Arawakan groups, for example to Yanesha'-Chamicuro instead of Nihagantsi, but such scenarios would require a downriver migration of Chamicuro from the Hupa-Iya site (see §3.4.2 for discussion of migration parsimony arguments) and other incongruencies, such as the lack of any stylistic continuity between Hupa-iya and Yanesha' ceramics.

3.5.2. Yanesha'-Chamicuro

The Yanesha'-Chamicuro (YC) clade [1,37,79] consists of two languages: Yanesha' [yane1238], mainly spoken in the upper Pachitea basin, and Chamicuro [cham1318], originally spoken on the Samiria, a tributary of the lower Ucayali [80] (figure 7).[13] The calibration date for this clade derives from finds on the upper Pachitea that we associate with speakers of pre-Yanesha' on grounds of geographical overlap and continuity in ceramics traditions.

The archaeological sequence on the upper Pachitea begins with the Cobichanqui tradition, followed by the Pangotsi and Nazaratequi traditions [81]. These traditions do not resemble Saladoid-Barrancoid, and it is unclear to what groups they should be associated. Lathrap suggests an association between Nazaratequi and speakers of pre-Yanesha', based on perceived similarities to the Enoqui tradition [22], which is solidly associated with pre-Yanesha' (see below), but Allen's more detailed study finds no significant connection between the Nazaratequi and Enoqui traditions [81]. Due to this uncertainty, we do not posit an association between the Nazaratequi tradition and speakers of pre-Yanesha'.

The Nazaratequi tradition is briefly interrupted by the Panoan Naneini tradition, which is in turn replaced by the Enoqui tradition, which Lathrap identifies with the 'proto-historic and historic Amuesha [i.e. Yanesha']', on the basis that it is 'the most widespread and latest ceramic complex in the area occupied until very recently by the Amuesha' [22]. Allen also identifies several similarities with modern Yanesha' ceramics [81].

There are no reliable Enoqui C^{14} dates, but Allen provides a date of 1249 ± 51 BP for one dated Naneini site, together

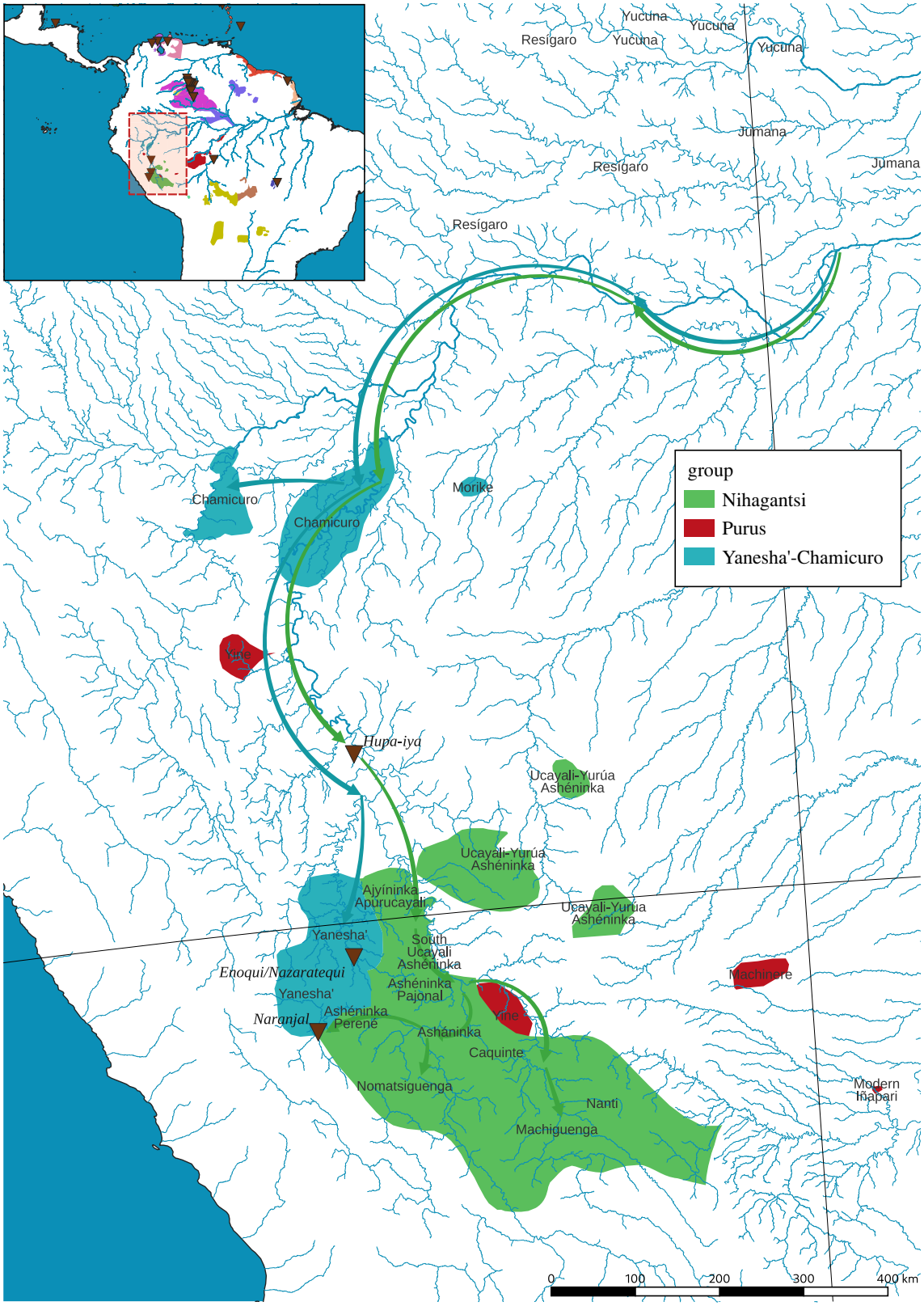

Figure 7. Western Arawakan languages and associated archaeological sites.

with a stratigraphic estimate that the Naneini occupation lasted 200–300 years [81]. This leads us to posit a calibration date of 1050 ± 80 BP for the start of the Enoqui tradition.

We correspondingly associate the Enoqui tradition with speakers of pre-Yanesha', and not, for example, with speakers of Proto-Yanesha'-Chamicuro. We reject this latter association on the basis of a geographical parsimony argument informed by the model of Arawakan expansion adopted in this paper. According to this model, the simplest interpretation of the distribution of Yanesha' and Chamicuro is that Proto-Yanesha'-Chamicuro (PYC) was spoken either on the lower Ucayali or further downriver, on the upper Amazon proper, and that as PYC made its way up the Ucayali, it split, leaving speakers of pre-Chamicuro on the lower Ucayali, while speakers of pre-Yanesha' continued moving up the Ucayali. Eventually the pre-Yanesha' reached the mouth of the Pachitea, the Ucayali's largest tributary, which they followed upriver into the Andean foothills region. According to this model, by the time pre-Yanesha' material culture appears on the upper

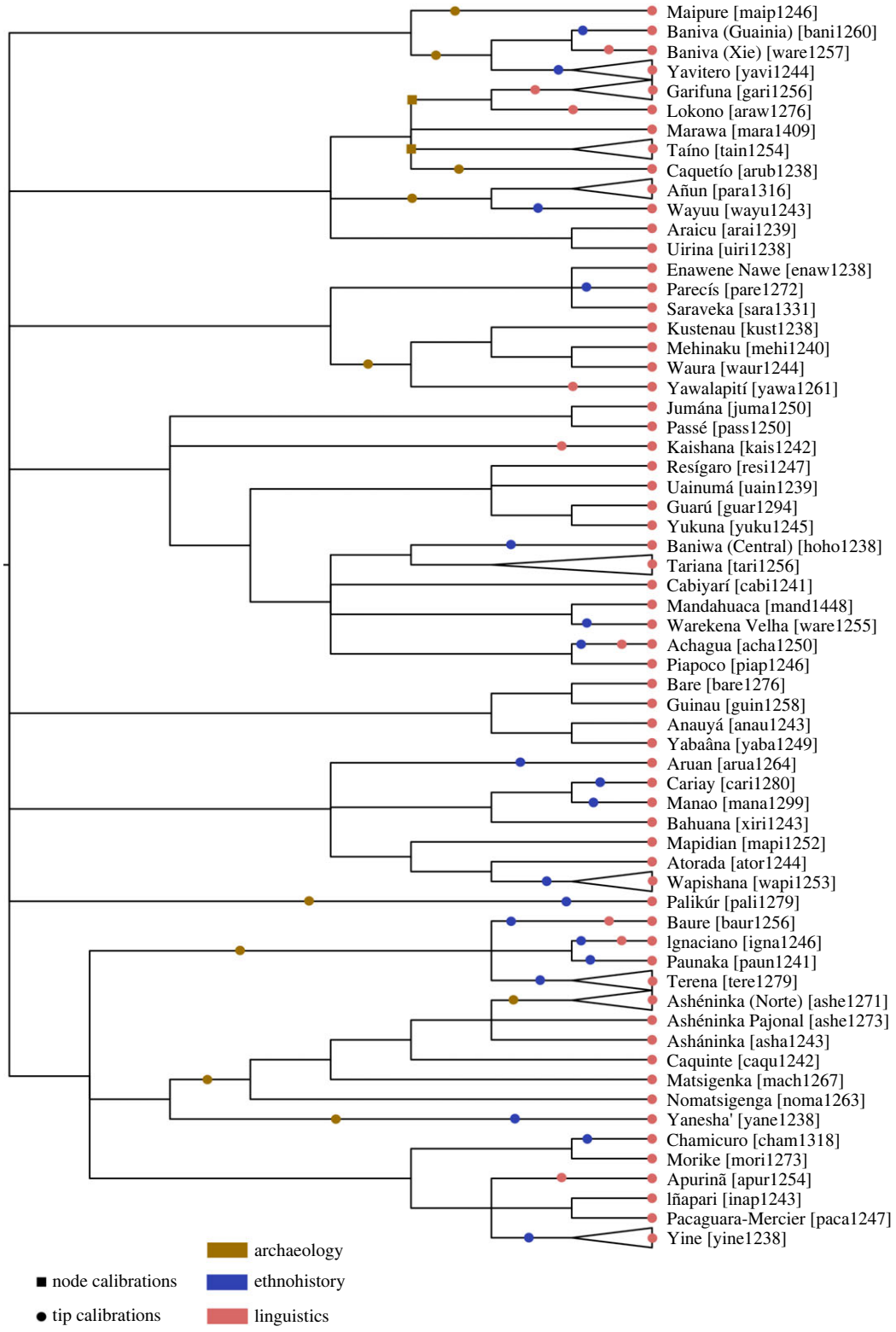

Figure 8. Arawakan calibration points summary. The tree is a cladogram and the depth of calibration points is arbitrary.

Pachitea, pre-Yanesha' and pre-Chamicuro would have been distinct languages.

While the hypothesis that the finds on the upper Pachitea were left by speakers of PYC is not wholly implausible, it would require PYC speakers to first migrate up the Ucayali and Pachitea, for the PYC to split on the upper Pachitea; and then for pre-Chamicuro speakers to migrate back down the Pachitea, and far back down the Ucayali.[14]

Monophyletic(Enoqui Culture, Yanesha')

Enoqui Culture~Normal($\mu = 1050$, $\sigma = 80$)

Constrain Enoqui Culture to be an ancestor

4. Summary and conclusion

In this paper, we have identified calibration points for a phylogeny of the Arawakan family, focusing on the archaeological literature to obtain calibration points for internal nodes, but also drawing on the colonial literature to obtain tip calibrations (see electronic supplementary material, appendix A). These calibration points are summarized graphically on the Arawakan tree from Glottolog [82] given in figure 8. This tree represents an informal consensus based on previous major classification [1–3].[15]

As evident in figure 8, we have identified calibrations for the majority of the larger subgroups in this classification, with the exception of Japurá-Colombia, which is located in the middle of the tree. As discussed in the electronic supplementary material, appendix B, Japurá-Colombia is spoken in a non-expansion zone area that has been inhabited by Arawakan peoples for so long that it is difficult to associate archaeological finds with particular subgroups. The oldest calibration we have is 2800–2445 BP for Taíno, with most other calibrations being more recent than 2000 BP. This recency bias stems from our necessary focus on expansion zones, and the fact that associations between archaeological remains and Arawakan subgroups/languages become easier to make the closer we get to the present.

Beyond the Arawakan-specific goal of moving towards a robust phylogeny of this family, this paper also responds to the call of Maurits *et al*. to improve the practice of obtaining and providing evidence for calibration points in linguistic phylogenetics [18]. In the first place, this paper presents evidence and arguments in favour of specific calibrations, as well as those against possible calibrations we ultimately discard (electronic supplementary material, appendix B), which can be evaluated separately from phylogenetic analysis of the linguistic data. And second, we have modelled an approach to extracting calibrations from archaeological literature that could be applied to other language families that, like Arawakan, exhibit two key characteristics: first, their history is characterized by significant geographical expansion into new areas; and second, they are either generally associated with distinctive forms of material culture in the archaeological record, or exhibit local cultural continuity between archaeological eras and the modern period.

Data accessibility. All calibration data are available in CLDF format and can be found at Open Science Framework: https://doi.org/10.17605/OSF.IO/Q54KJ [83].

Supplementary material is available online [84].

Authors' contributions. L.M.: conceptualization, investigation, methodology, project administration, resources, supervision, writing—original draft and writing—review and editing; F.d.C.: conceptualization, investigation, methodology and writing—original draft; T.C.: conceptualization, investigation, methodology and writing—original draft; K.R.: conceptualization, investigation, methodology and writing—original draft; A.S.: conceptualization, investigation, methodology and writing—original draft; N.C.-P.: conceptualization, data curation, methodology, project administration, supervision, writing—original draft and writing—review and editing; G.K.: data curation, formal analysis, methodology, visualization and writing—original draft.

All authors gave final approval for publication and agreed to be held accountable for the work performed therein.

Conflict of interest declaration. We declare we have no competing interests.

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Endnotes

[1]Arawakan oral history has thus far not yielded viable calibration points either, although it does give important insight into certain aspects of Arawakan diachrony, such as migration routes (see, e.g. §3 for Palikuran, and electronic supplementary material, appendix B for Piapoco and Achagua).

[2]A calibration for a proto-language would correspond to a crown calibration in biological literature, while a calibration of a pre-proto-language would correspond to a stem calibration [19].

[3]As Heckenberger [8] observes, a number of synonyms exist for this macro-tradition: Incised-Rim [21], Modeled-Incised [22] and Parallel Lines-Incised [23].

[4]Archaeological remains lying on a highly plausible migration trajectory between the Arawakan homeland region and the location of the clade, is also evidence for a geographical connection (see §§ 3.3.2 and 3.4.1).

[5]We are of course making no claim that a given culture is constrained to the narrow interval of a radiocarbon date. The use of the term 'Culture' is done for convenience to distinguish such tips from linguistic tips.

[6]The name *Island Carib* is often used for the sister language of Garifuna (also known as Dominica Island Carib) and their most recent common ancestor language. Here we use Old Island Carib for the common ancestor to avoid confusion.

[7]Colonial records also mention the Cocina people, also believed to be Arawakan and very closely related to the Wayuu, who became extinct in the twentieth century.

[8]Baniva (Guainia) [bani1260] together with its sister dialect Baniva do Xié [ware1257] (also known as Warekena do Xié) are also known as Baniva de Maroa. They should not be confused with Baniwa (Central) [hoho1238] (a dialect of Baniwa-Koripako [bani1259]), nor with Warekena Velha [ware1255], which are both distinct languages belonging instead to the Japurá-Colombia branch.

[9]Other Arawakan groups that currently occupy this zone belong to the Japurá-Colombia branch, such as Baniwa-Koripako, Mandahuaca, Warekena and Piapoco. However, they have arrived in more recent times to this area compared to Upper Orinoco languages.

[10]For the Warekena Velha, Gonzalez-Nañez [66] reports that, until 1753 CE, according to the observations of the Jesuit missionary Szentmartonyi, they (under the name Guarequena) were living in the Marié river, a tributary of the Rio Negro, in the lower Içana, and in the Siapa, a tributary of the Casiquiare. As for the Guipuinave, Gonzalez-Nañez argues that they have migrated from the south, arriving in the region only by the beginning of the eighteenth century.

[11]Also known as Campa(n) or Kampa(n); this term is deemed pejorative by some speakers of these languages, however [77], and the term is avoided here.

[12]Note that the map suggests that Naranjal is at the very edge of Asháninka (Norte) territory, this is a somewhat misleading artefact of the language polygons, as Naranjal is located in an unambiguously Asháninka area.

[13]Not all authors group these two languages together, treating them instead as single-member subgroups [2,3]. Nothing in this section depends crucially on Yanesha' and Chamicuro forming a subgroup, as the calibration we provide is on the Yanesha' branch, subsequent to its split from whatever its sister language may be.

[14]It should be noted, however, that no archaeological remains have been associated with the Chamicuro on the lower Ucayali that would allow us to evaluate their long-term occupation of the lower Ucayali, as posited by the migration hypothesis we adopt here.

[15]For the most part the differences between these classifications are not germane, as we are simply using the Glottolog tree to display the calibration points in a graphical manner.

[16]All dates are adjusted to BP (before present), with present being the year 1950.

[17]Unfortunately, current phylogenetic models do not permit specifying what other languages *node* is an ancestor of, so we have to declare this using the Monophyletic formal declaration.

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