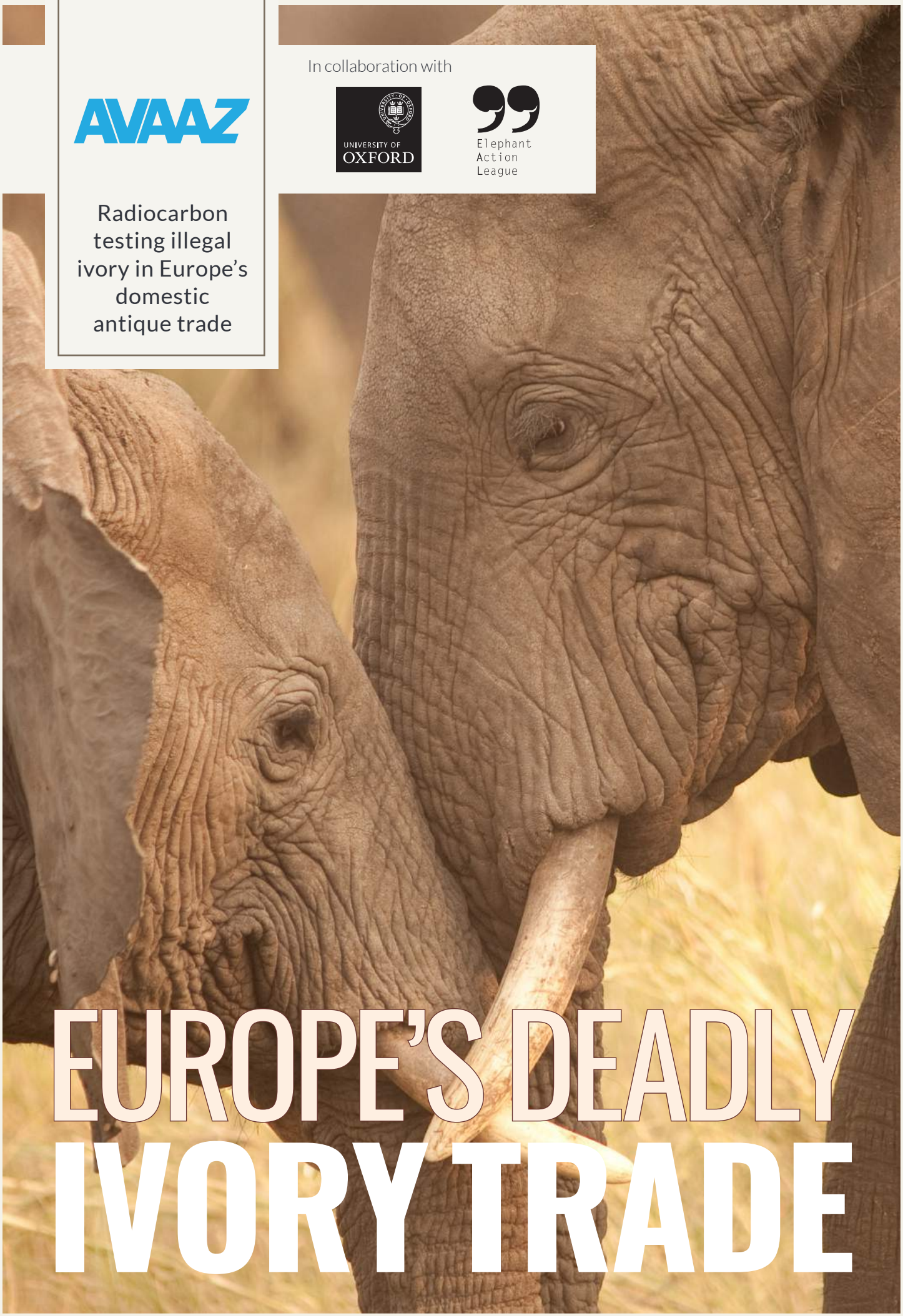
AVAAZ

Radiocarbon testing illegal ivory in Europe's domestic antique trade

In collaboration with

UNIVERSITY OF OXFORD

Elephant Action League



EUROPE'S DEADLY IVORY TRADE

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Executive summary

For as long as humans have been on Earth, there have been elephants. But shockingly, we could be on the cusp of wiping them out forever. On the African savannahs, landscapes these magnificent giants have roamed for millennia, their numbers collapsed by a third between 2007-2014.[1] In the forests of Central Africa, they declined by 66% between 2008-2016.[2] Every day another 55 are killed. And behind this catastrophe lies one driver: demand for elephant ivory.

Finally, governments are starting to act, bringing down the shutters on ivory markets all over the world, recognising that the legal ivory trade drives demand for ivory, and gives cover to the illegal trade. China has banned ivory and already started closing its giant trade. Hong Kong just passed a historic law to do the same. The US has adopted a near-total ban on ivory trade across state lines, and the UK has announced a ban on nearly all ivory sales.

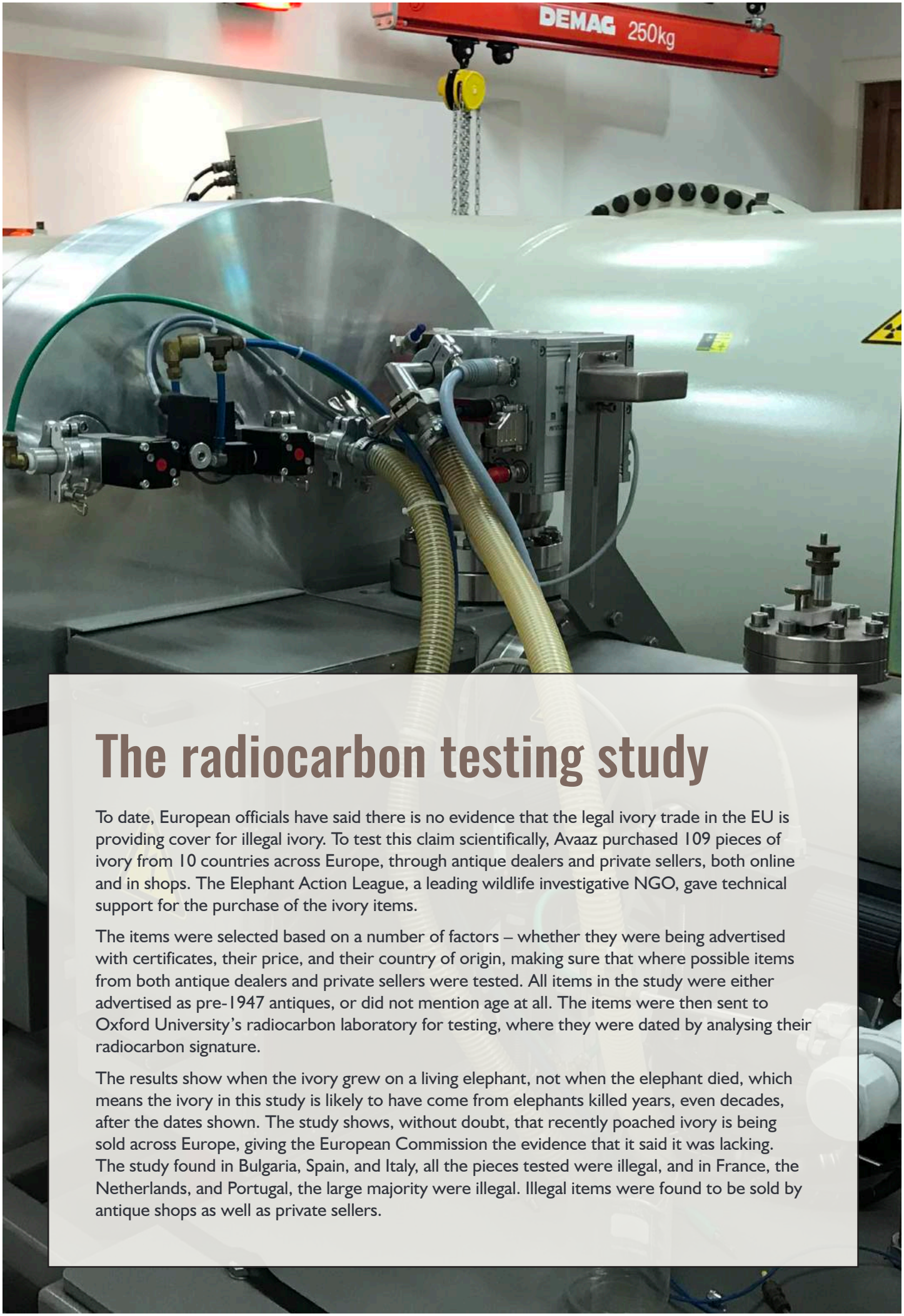
But despite being a major donor for elephant protection and conservation in Africa, the EU is still presiding over a thriving domestic trade in ivory. Within Europe, it is still legal to trade worked ivory originally acquired before 1947 without restriction. For the first time, this study shows that this legal trade is covering up an illegal trade. There is a widespread practice in countries across Europe of selling 'antique' ivory that actually dates from much later – and this illegal trade includes ivory from elephants poached and slaughtered in the last few years.

The study finds:

- Three quarters (74.3%) of ivory tested is fake antique ivory being sold illegally.
- One in five (19%) pieces of ivory tested are from elephants that were alive in the 1990s and 2000s and killed after the global trade in new elephant ivory was outlawed.
- This is an EU-wide problem – high levels of illegal ivory were found in almost every country tested
- The most recent ivory tested in the study was dated from after 2010.

It is clear that the EU's ivory laws are not being properly enforced, and illegal ivory is being traded openly both online and in shops across the continent. **The European Commission is currently reviewing whether EU restrictions on the ivory trade go far enough. This study provides a clear and categorical answer to that question: they do not.** To ensure that elephants are protected, the Commission should close the antique ivory loophole, end ivory exports from Europe, and shut down the EU's internal trade in raw tusks. This is the only way it can preserve its status as a leader in fighting the wildlife trade and protecting African elephants.

[1] *www.greatelephantcensus.com/final-report/*
[2] *https://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/WWF_CA_Biomonitoring_Report.pdf*

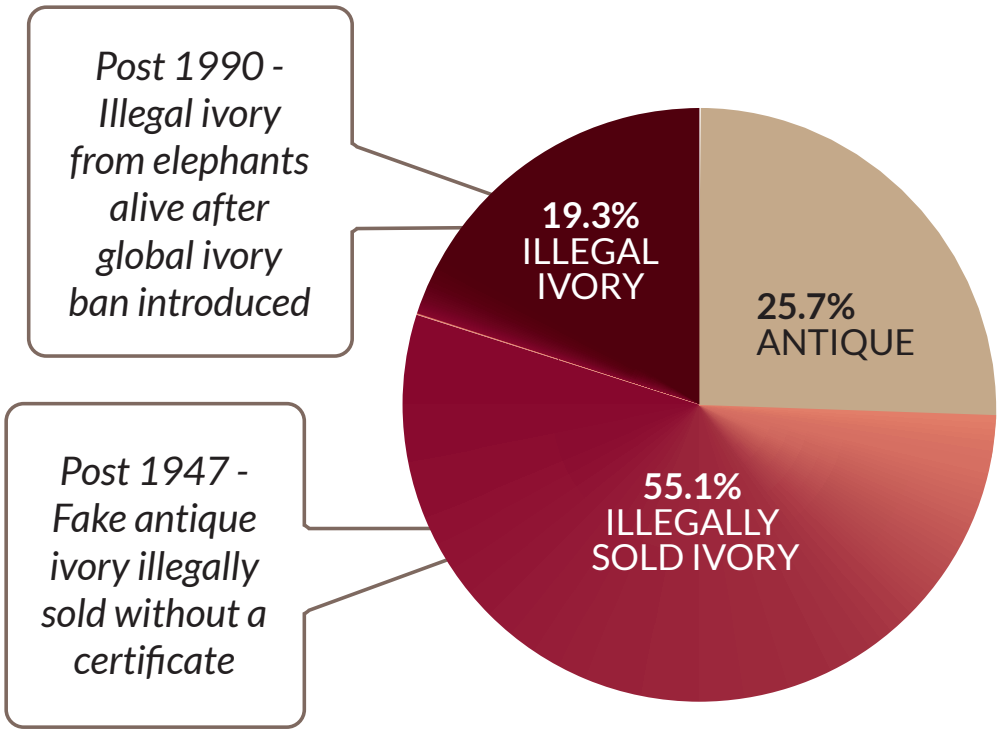


The radiocarbon testing study

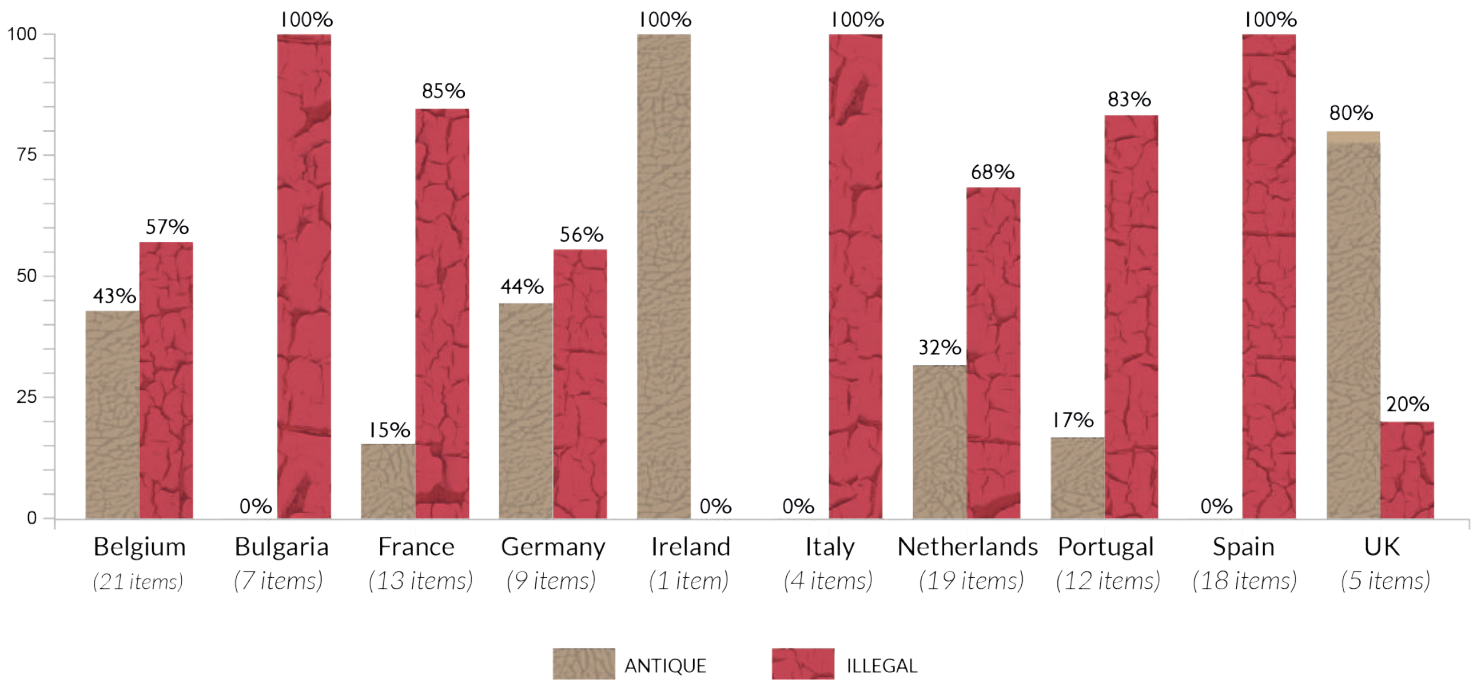
To date, European officials have said there is no evidence that the legal ivory trade in the EU is providing cover for illegal ivory. To test this claim scientifically, Avaaz purchased 109 pieces of ivory from 10 countries across Europe, through antique dealers and private sellers, both online and in shops. The Elephant Action League, a leading wildlife investigative NGO, gave technical support for the purchase of the ivory items.

The items were selected based on a number of factors – whether they were being advertised with certificates, their price, and their country of origin, making sure that where possible items from both antique dealers and private sellers were tested. All items in the study were either advertised as pre-1947 antiques, or did not mention age at all. The items were then sent to Oxford University's radiocarbon laboratory for testing, where they were dated by analysing their radiocarbon signature.

The results show when the ivory grew on a living elephant, not when the elephant died, which means the ivory in this study is likely to have come from elephants killed years, even decades, after the dates shown. The study shows, without doubt, that recently poached ivory is being sold across Europe, giving the European Commission the evidence that it said it was lacking. The study found in Bulgaria, Spain, and Italy, all the pieces tested were illegal, and in France, the Netherlands, and Portugal, the large majority were illegal. Illegal items were found to be sold by antique shops as well as private sellers.



Status of ivory tested, EU-wide



Status of ivory tested, by country

Europe – the ivory market you've never heard of

European law states that worked ivory originally acquired before 1947 can be traded without restriction in the EU. Ivory produced between 1947 and 1990 can only be traded with a government-issued certificate, and ivory newer than 1990 is completely banned[3]. In practice, this means worked ivory can be freely bought and sold across Europe, as long as the seller says it is antique (pre-1947). There is no legal requirement to provide any proof of age of the ivory (although in 2017, France introduced a requirement for all antique ivory items over 200g to to be sold with a certificate).

European Commission data shows that several tonnes of ivory items are traded legally within the EU every year, including both worked and raw ivory. Law enforcement agencies say the trade in antique worked ivory online is impossible to police effectively due to the difficulties establishing the age of ivory (the only reliable method is radiocarbon testing),[4] and it is easy to find more recent ivory illegally on sale all over Europe, including ivory from the current poaching crisis in Africa. This ivory is sold openly, both online by private sellers, and by antique dealers.

Many EU countries have large stockpiles of raw ivory tusks which date from the colonial era. Current rules allow this raw ivory to be traded internally, but in 2017 the European Commission issued guidance to member states to end the export of raw ivory tusks, and reported in 2018 that member states were complying with this guidance.

Europe remains a major exporter of legal worked ivory, mainly to big Asian markets where demand for ivory is fuelling the poaching crisis in Africa. This study focuses on domestic sales of worked ivory within the EU rather than the export trade.

[3] *http://ec.europa.eu/environment/cites/pdf/guidance_ivory.pdf*
[4] *https://www.interpol.int/Media/Files/Crime-areas/Environmental-crime/Project-Web-An-investigation-into-the-ivory-trade-over-the-Internet-within-the-European-Union*

How Europe's ivory rules create a deadly loophole

The EU's ivory trade completely bans the trade of ivory acquired after elephants were given maximum protection under the CITES convention, agreed to by governments to govern the global trade in wildlife products (1st July 1975 for Asian elephants and 18th January 1990 for African elephants). Under the EU's rules, all ivory acquired after 1947 and before 1990 must not be sold without a certificate issued by the relevant member state, but as worked ivory acquired before 1947 can be freely traded without any certificates, this creates a loophole that provides cover for the illegal trade. None of the ivory tested as part of this study was sold with a certificate, and the most recent ivory uncovered by the study came from elephants killed in the past few years.

Momentum to end the ivory trade

The international ivory trade has been banned by CITES since 1989. However, many countries have continued to allow the domestic sale of ivory. As a growing body of evidence emerges showing how domestic ivory markets, drive the poaching crisis in Africa, that is now changing, with real momentum towards closing down legal ivory markets all over the world.

The 1.1 million strong call for an ivory ban is delivered to Hong Kong's lawmakers ahead of the vote

The International Union for the Conservation of Nature passed a resolution in 2016 calling for the closure of all domestic ivory markets,[5] and later that year CITES changed its position on domestic ivory trade, calling for the closure of ivory markets that contribute to the poaching crisis.[6]

A host of countries across the world are in the process of adopting new and improved ivory bans and restrictions:

[5] *https://portals.iucn.org/library/node/46428*
[6] *https://www.cites.org/sites/default/files/document/E-Res-10-10-R17.pdf*

- Hong Kong, the world's largest ivory market, voted in January 2018 to phase out the legal trade in ivory over the next three years.
- China brought in a ban on trade in ivory and ivory products in December 2017, meaning all trade in ivory is now illegal, except for what it calls "genuine antiques". China's efforts appear already to have dampened demand – Chinese state media reports that raw ivory prices had fallen by 65% by the end of 2017.
- The US has implemented an updated ivory ban under the Endangered Species Act, which effectively outlaws most ivory commerce by limiting imports, exports and sales across state lines.
- The UK is in the process of adopting a near-total ban on ivory sales, which will prohibit domestic ivory sales, as well as the import and export of ivory for sale to and from the UK (including trade with other EU countries), subject to "strictly limited exemptions", such as trade in musical instruments containing ivory and sale of ivory to museums.

Countries around the world are not just shutting down their ivory markets – they are calling for Europe to do the same. China has called for the EU to "take credible steps to effectively ban illegal trade in ivory". In March, 32 African elephant range states, including three African heads – from Uganda, Gabon, and Botswana – formally joined the Avaaz campaign calling for the closure of Europe's ivory markets.[7] The Avaaz campaign has been signed by over 1 million people worldwide, and more than 100,000 Avaaz members responded to European Commission's public consultation to call for an ivory trade ban. The European Parliament is advocating for a ban on ivory trade in Europe, most recently in a resolution passed in November 2016.[8] And now EU member states including the UK and France are pushing for further restrictions on the EU ivory trade. Finally, with the tide turning against the trade in ivory, Europe is now the focus of global concern.

The president of Botswana signing the Avaaz petition to urge the EU to shut down its ivory trade

[7] *https://www.independent.co.uk/news/world/africa/vory-trade-eu-ban-african-countries-elephant-poaching-demand-animal-welfare-rights-a8259936.html*
[8] *http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+TA+P8-TA-2016-0454+0+DOC+XML+V0//EN*

Conclusion and Recommendations

This study makes clear that the European status quo cannot continue. Europe's domestic ivory market is providing cover for the illegal trade in ivory, including from elephants killed as part of the current poaching crisis. Urgent action is now required.

The European Commision is expected to announce further restrictions on the ivory trade in the coming months. These restrictions will only be effective if they shut down the 'antique' ivory loophole that is currently being used to flout EU law all over Europe. There should be no unrestricted trade in ivory in Europe, even for antiques, because of the difficulties for law enforcement to accurately date ivory without sophisticated testing of the type carried out for this study.

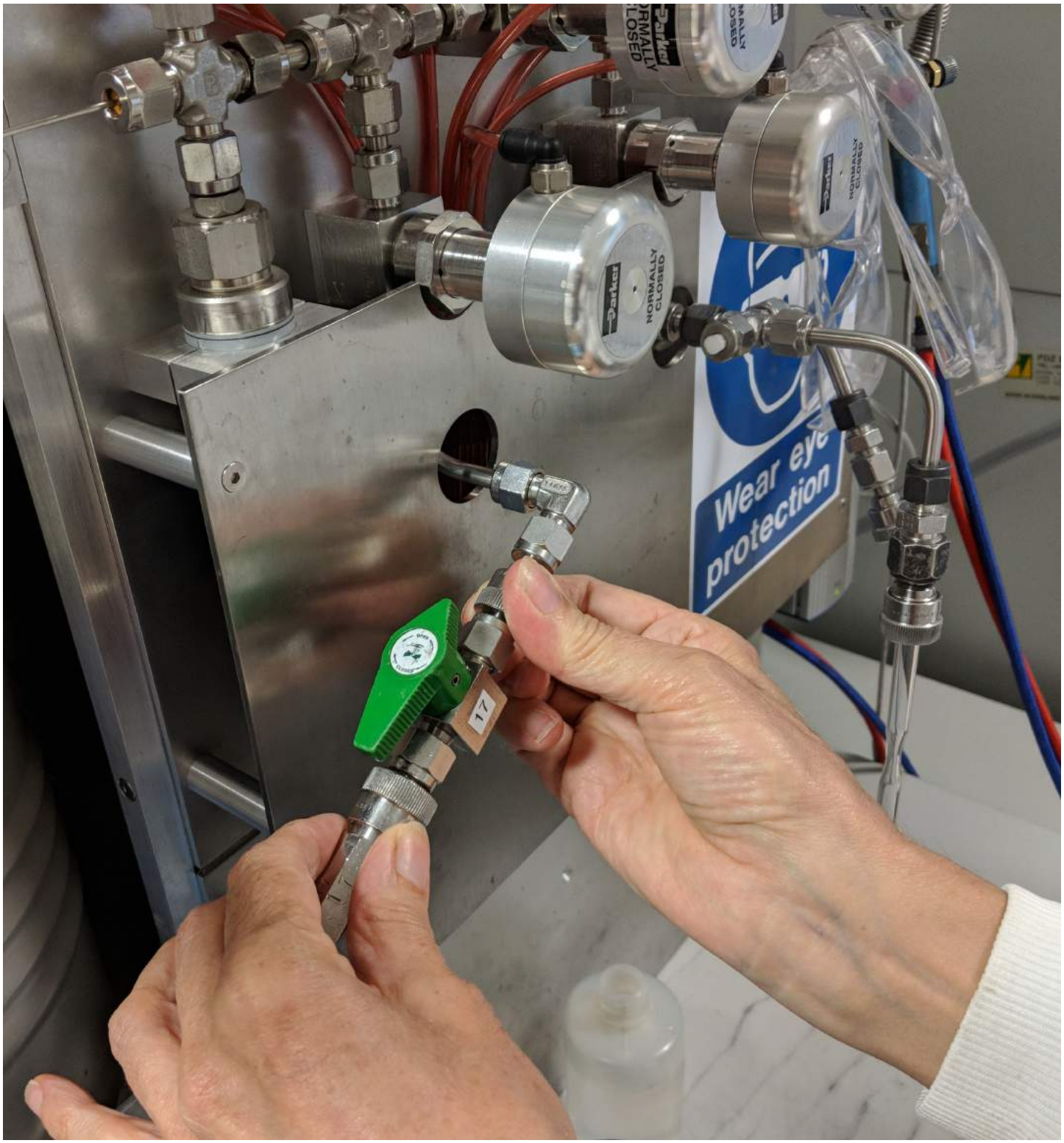
The ban on ivory trading currently being implemented in the UK provides an excellent model that could be adopted by Europe. This outlaws all trade in ivory, with the following exceptions:

- Items comprised less than 10% ivory (by volume) and made before 1947.
- Musical instruments made before 1975 and comprised of less than 20% ivory.
- Rare or important items, at least 100 years old, will be assessed by specialist institutions before exemption permits are issued.
- Specific exemptions for portrait miniatures painted on thin ivory bases and for commercial activity between accredited museums.

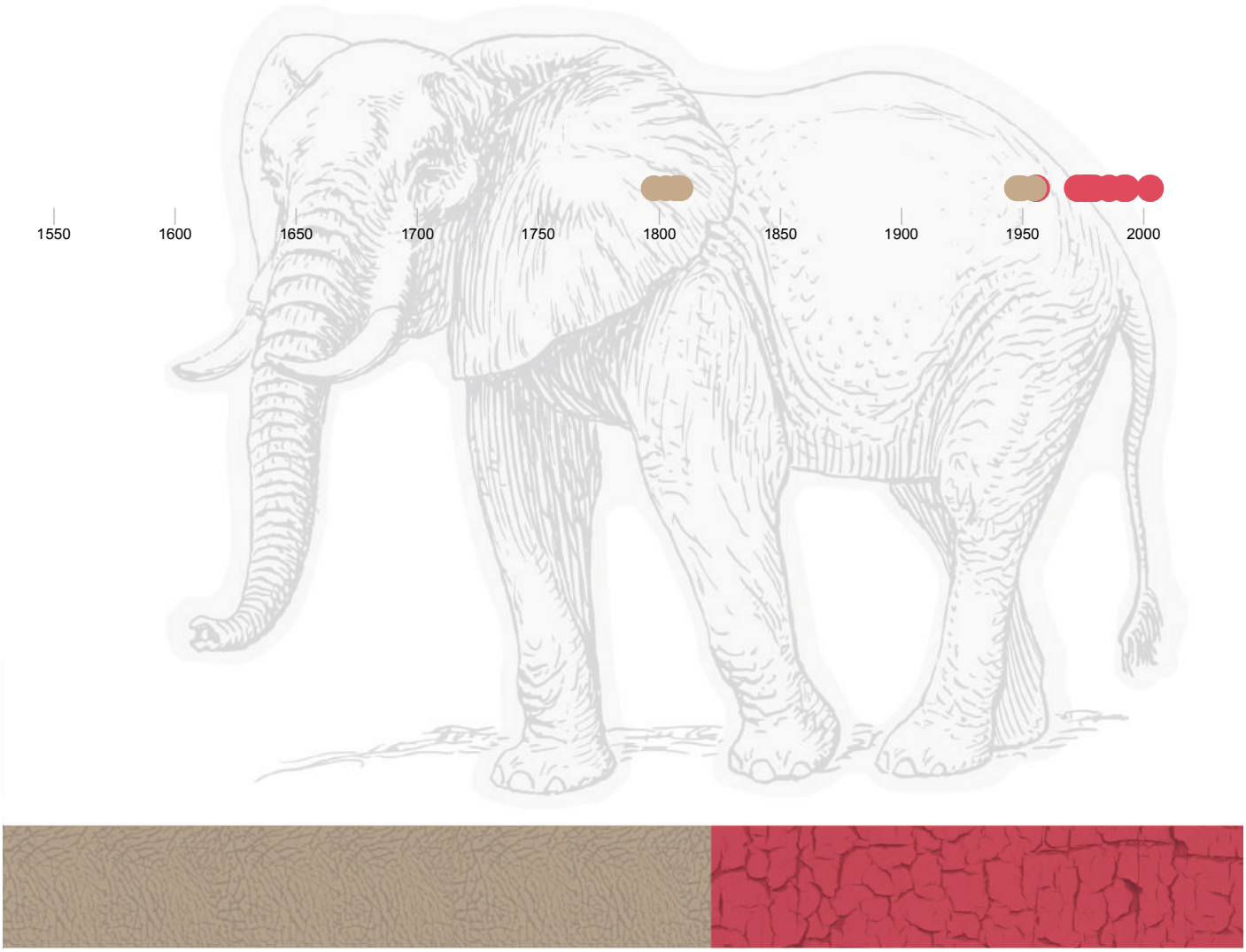
There is widespread concern that Europe's ivory exports are stoking demand for ivory and further exacerbating the poaching crisis. It is also undermining Europe's leadership on the wildlife trade on the global stage, and should be ended immediately, with the current guidance against the export of raw ivory upgraded to cover all ivory.

The full results

These following tables show the most probable date range that the ivory grew. Where an item has more than one possible date range, the most likely range appears on top. For simplicity, date ranges with less than 10% probability are not shown in these tables. For full calibrated age ranges please refer to Oxford's report p.44.



BELGIUM



42.9% antique **57.1% illegal**

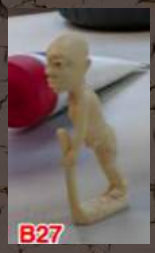
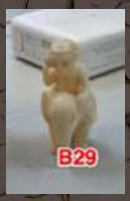
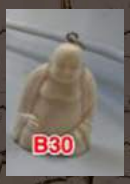
BELGIUM

Specimen	IMAGE	Seller	DATE-RANGE	STATUS
BE01		*Private seller on www.2dehands.be*	1699–1948	**ANTIQUE**
BE02		*Private seller on www.2dehands.be*	1686–1950	**ANTIQUE**
BE03		*Private seller on www.2dehands.be*	1649–1807	**ANTIQUE**
BE04		*Private seller on www.2dehands.be*	1653–1803	**ANTIQUE**
BE05		*Private seller on www.2dehands.be*	1669–1955	**ANTIQUE**
BE06		*Antique shop*	1975–1976	**ILLEGAL**
BE07		*Antique shop*	1954–1956	**ILLEGAL**

BELGIUM

Specimen	IMAGE	Seller	DATE-RANGE	STATUS
BE08		*Antique shop*	1963–1976	**ILLEGAL**
BE17		*Private seller on www.2dehands.be*	1963-1977	**ILLEGAL**
BE18		*Private seller on www.2dehands.be*	1989–1993	**ILLEGAL**
BE19		*Private seller on www.2dehands.be*	1978–1980	**ILLEGAL**
BE20		*Stall in Ghent flea market*	1971–1973	**ILLEGAL**
BE21		*Private seller on www.2dehands.be*	1999–2003	**ILLEGAL**

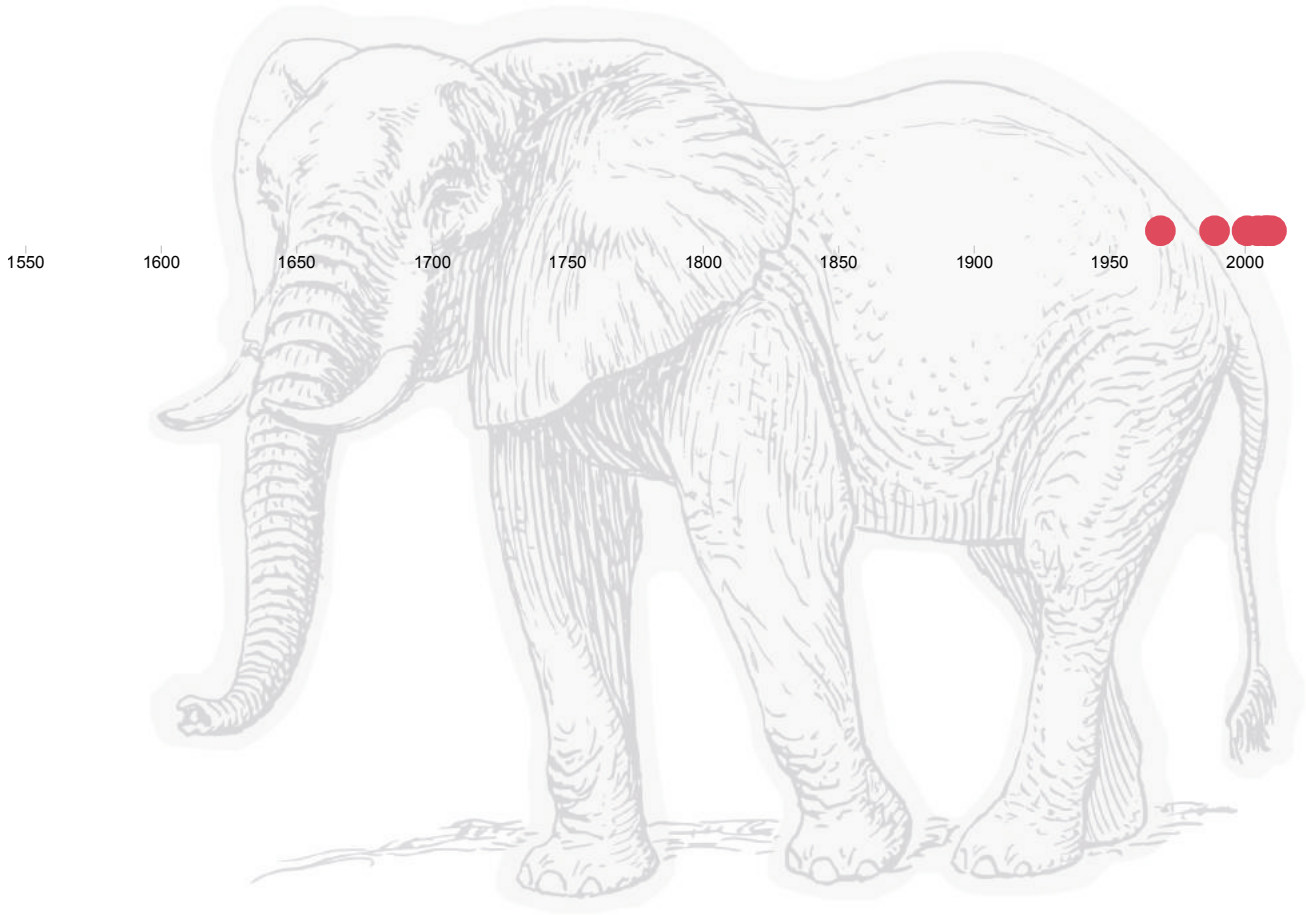
BELGIUM

Specimen	IMAGE	Seller	DATE-RANGE	STATUS
BE27		*Private seller on www.2dehands.be*	1667–1955	**ANTIQUE**
BE28		*Private seller on www.2dehands.be*	1627–1798	**ANTIQUE**
BE29		*Private seller on www.2dehands.be*	1649–1809	**ANTIQUE**
BE30		*Private seller on www.2dehands.be*	1976–1978	**ILLEGAL**
BE31		*Private seller on www.2dehands.be*	1988–1992 1959–1960	**ILLEGAL**
BE32		*Private seller on www.naturabuy.fr*	1697–1949	**ANTIQUE**

BELGIUM

Specimen	IMAGE	Seller	DATE-RANGE	STATUS
BE33		*Private seller on www.naturabuy.fr*	1975–1976	**ILLEGAL**
BE39	N/A	*Private seller on www.naturabuy.fr*	1984–1986, 1961–1963	**ILLEGAL**

BULGARIA



100% illegal

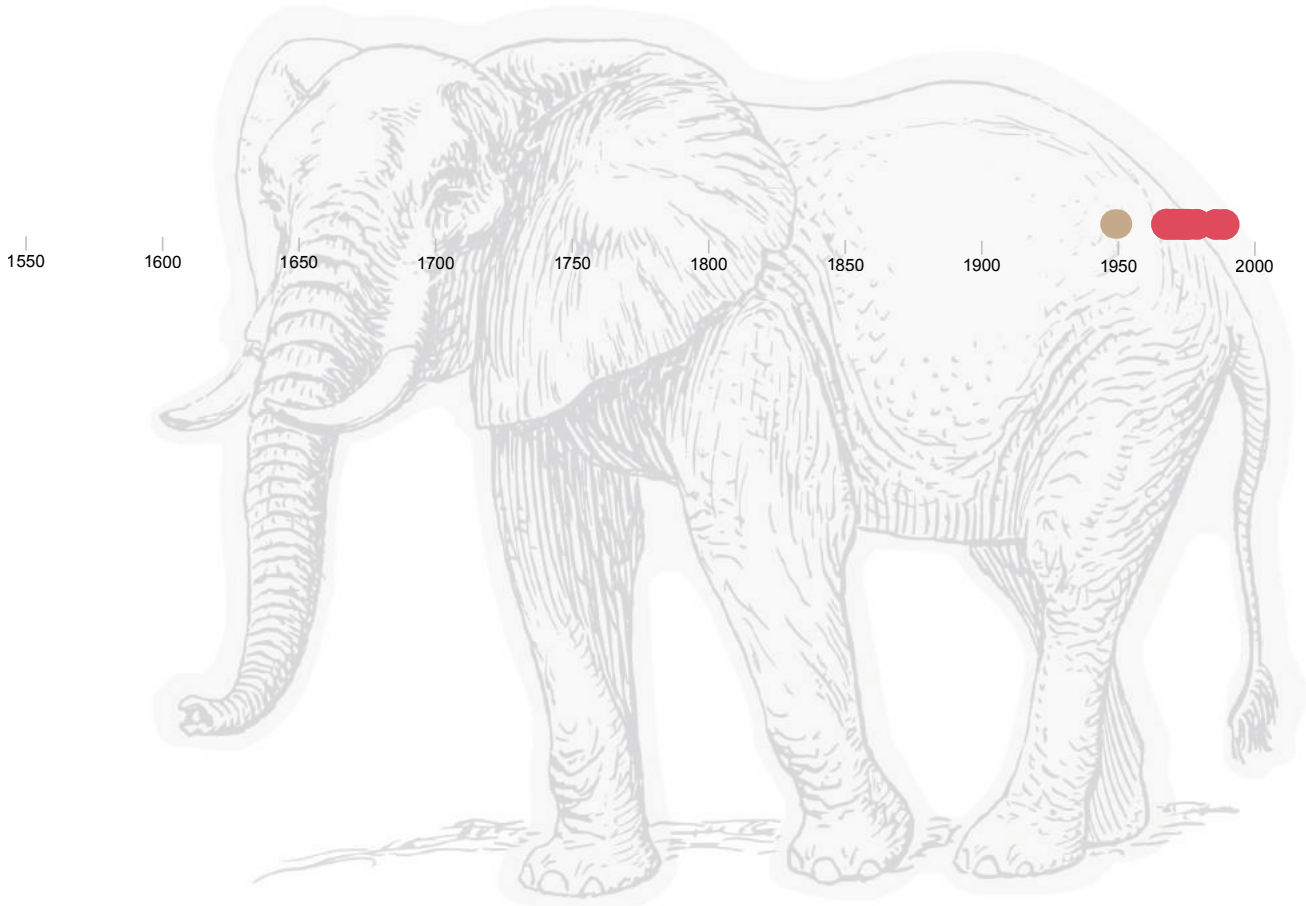
BULGARIA

Specimen	IMAGE	Seller	DATE-RANGE	STATUS
BU01a		*Private seller on www.olx.bg*	1998–2001	**ILLEGAL**
BU02		*Private seller on www.olx.bg*	1964-1969	**ILLEGAL**
BU03		*Private seller on www.olx.bg*	1986–1989, 1959–1963	**ILLEGAL**
BU04		*Private seller on www.balkan.auction*	2003–2005, 1957–1958	**ILLEGAL**
BU05a		*Private seller on www.balkan.auction*	2004–2008	**ILLEGAL**

BULGARIA

Specimen	IMAGE	Seller	DATE-RANGE	STATUS
BU05b (Tusk-shaped pendant)		*Private seller on www.balkan.auction*	2005–2010	**ILLEGAL**
BU07		*Private seller on www.olx.bg*	2004–2008	**ILLEGAL**

FRANCE



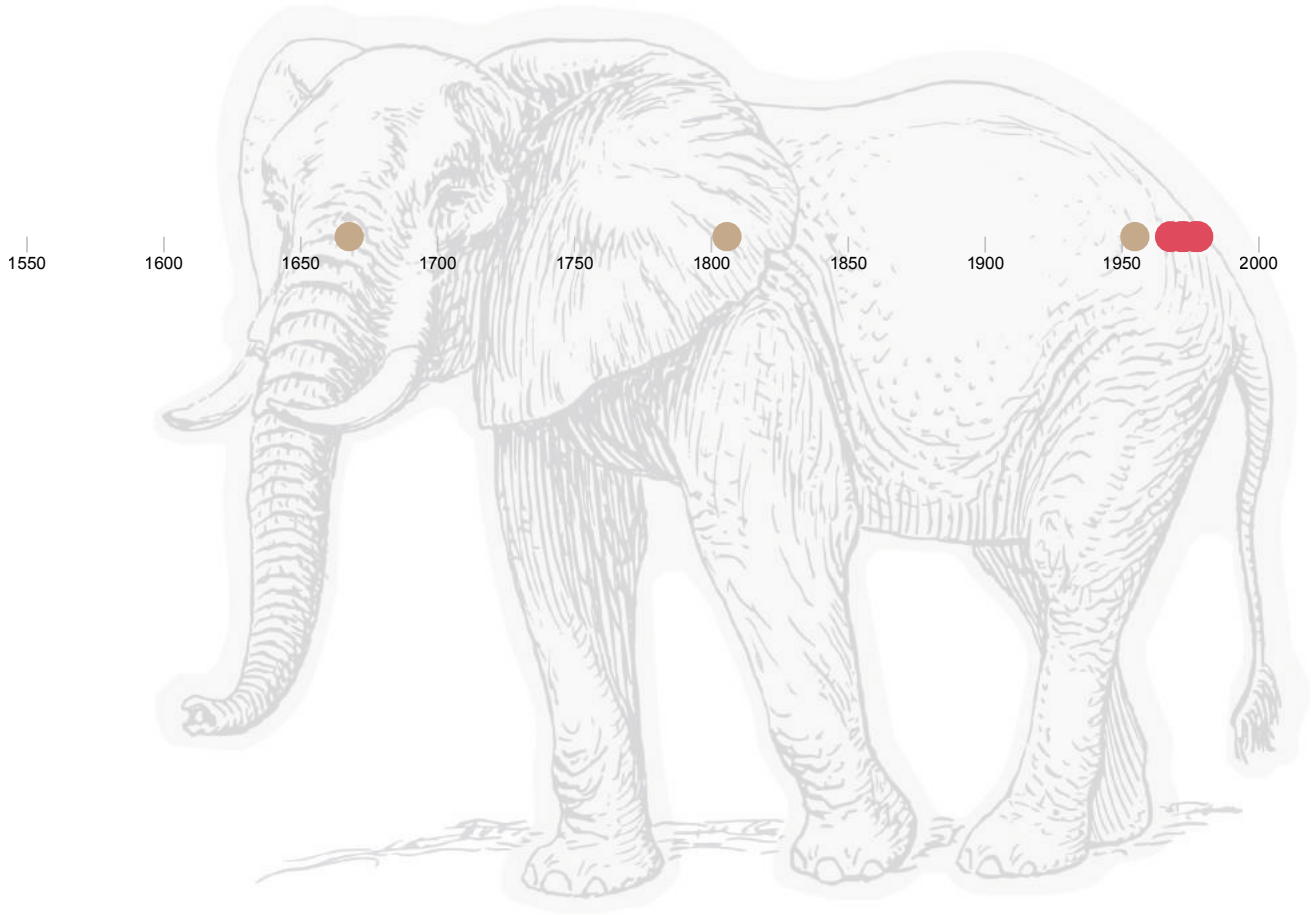
15.4% antique 84.6% illegal

FRANCE

Specimen	IMAGE	Seller	DATE-RANGE	STATUS
FR0003		*Private seller on www.naturabuy.fr*	1691–1950	**ANTIQUE**
FR0006		*Private seller on www.naturabuy.fr*	1987–1989, 1959–1960	**ILLEGAL**
FR0007		*Private seller on www.naturabuy.fr*	1977–1979	**ILLEGAL**
FR0008		*Private seller on www.naturabuy.fr*	1973–1974	**ILLEGAL**
FR0009			1984–1986, 1961–1962	**ILLEGAL**

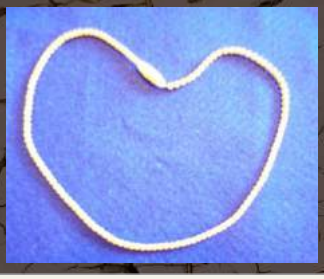
Specimen	IMAGE	Seller	DATE-RANGE	STATUS
FR0010		*Private seller on www.naturabuy.fr*	1967–1968	**ILLEGAL**
FR0011		*Private seller on www.naturabuy.fr*	1972–1973	**ILLEGAL**
FR01		*Private seller on www.naturabuy.fr*	1967–1968	**ILLEGAL**
FR02		*Private seller on www.naturabuy.fr*	1698–1949	**ANTIQUE**
FR03		*Private seller on www.naturabuy.fr*	1974–1975, 1963–1964	**ILLEGAL**
FR04		*Private seller on www.naturabuy.fr*	1975–1976, 1963	**ILLEGAL**
FR05.1		*Private seller on www.naturabuy.fr*	1969–1971	**ILLEGAL**
FR06		*Private seller on www.naturabuy.fr*	1969–1970	**ILLEGAL**

GERMANY



44.4% antique 55.6% illegal

GERMANY

Specimen	IMAGE	Seller	DATE-RANGE	STATUS
GE02		*Antique shop*	1667–1955	**ANTIQUE**
GE03		*Private seller on www.oldthing.de*	1971–1973	**ILLEGAL**
GE04		*Private seller on www.oldthing.de*	1503–1668	**ANTIQUE**
GE05		*Private seller on www.oldthing.de*	1648–1806	**ANTIQUE**
GE06	N/A	*Private seller on www.oldthing.de*	1964–1968	**ILLEGAL**
GE07		*Private seller on www.oldthing.de*	1667–1955	**ANTIQUE**
GE08		*Private seller on www.oldthing.de*	1976–1978	**ILLEGAL**

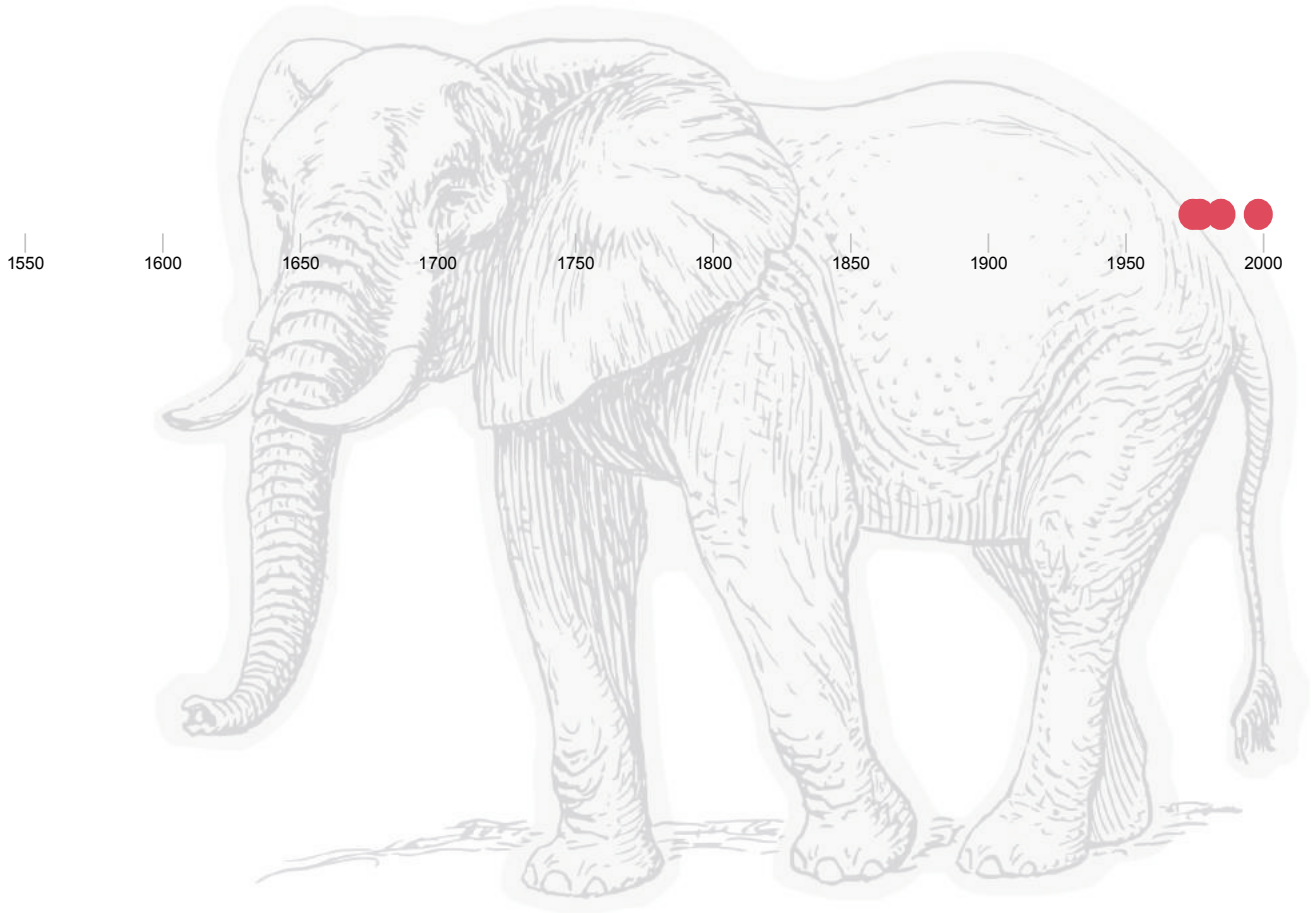
GERMANY

Specimen	IMAGE	*Seller*	DATE-RANGE	**STATUS**
GE09		*Private seller on www.oldthing.de*	1970–1972	**ILLEGAL**
GE10		*Private seller on www.oldthing.de*	1975–1977, 1963	**ILLEGAL**

IRELAND

Specimen	IMAGE	*Seller*	DATE-RANGE	**STATUS**
IR0001		*Antique shop*	1657–1809	**ANTIQUE**

ITALY

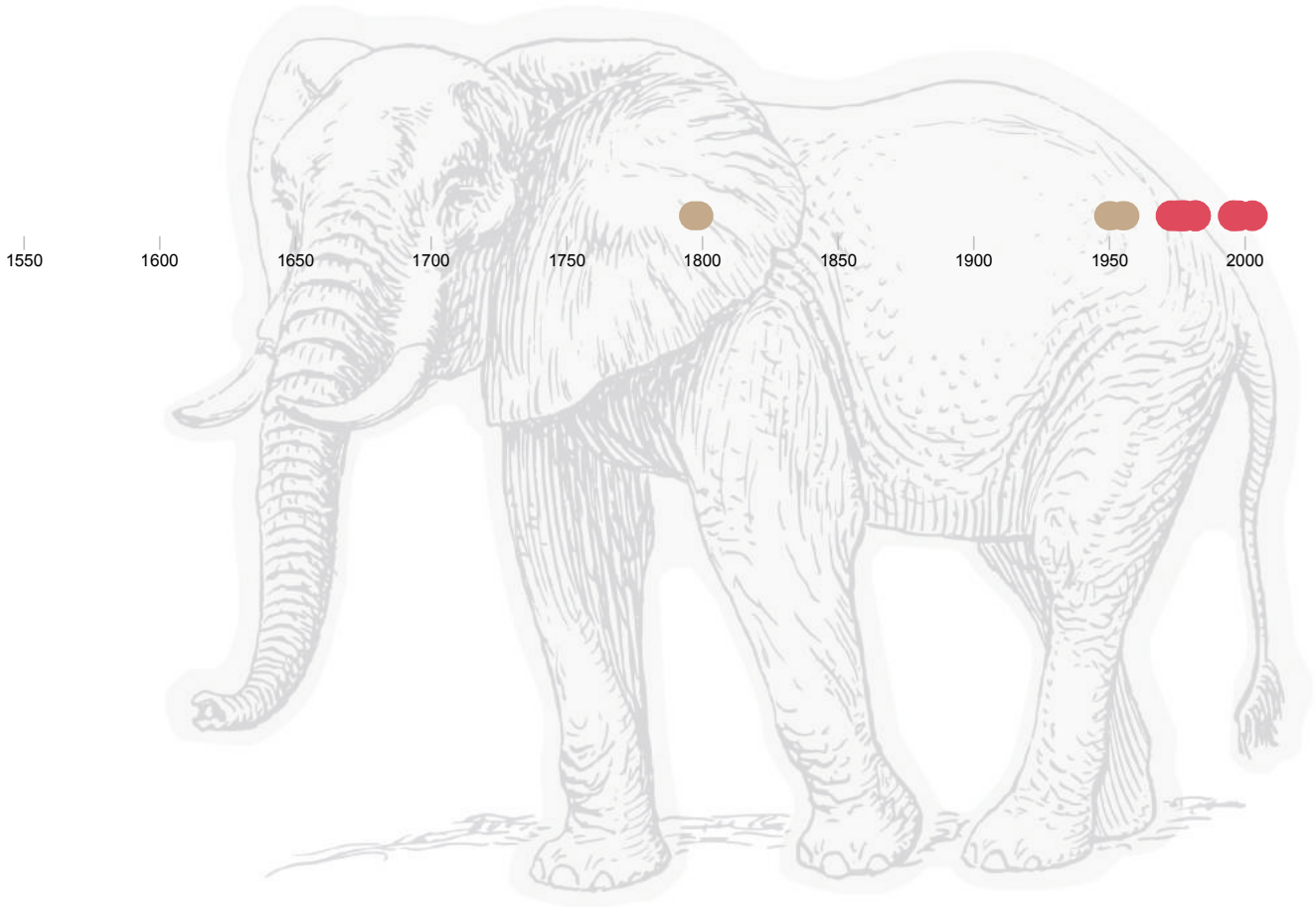


100% illegal

ITALY

Specimen	IMAGE	Seller	DATE-RANGE	STATUS
IT01		*Private seller on www.kijiji.it*	1972–1973	**ILLEGAL**
IT02		*Private seller on www.kijiji.it*	1995–1998	**ILLEGAL**
IT03		*Private seller on www.ebay.it*	1980–1982	**ILLEGAL**
IT04		*Private seller on www.ebay.it*	1968–1970, 1964	**ILLEGAL**

NETHERLANDS



31.6% antique, 68.4% illegal

NETHERLANDS

Specimen	IMAGE	Seller	DATE-RANGE	STATUS
N01		*Antique shop*	1814–1956	**ANTIQUE**
N02		*Antique shop*	1994–1998	**ILLEGAL**
N03		*Antique shop*	1980–1982, 1962–1963	**ILLEGAL**
N04		*Antique shop*	1688–1950	**ANTIQUE**

NETHERLANDS

Specimen	IMAGE	Seller	DATE-RANGE	STATUS
N05		*Private seller on www.marktplaats.nl*	2000–2003	**ILLEGAL**
N06		*Private seller on www.marktplaats.nl*	1980–1982, 1962–1963	**ILLEGAL**
N07a		*Private seller on www.marktplaats.nl*	1993–1996	**ILLEGAL**
N07b		*Private seller on www.marktplaats.nl*	1993–1996	**ILLEGAL**
N08		*Private seller on www.marktplaats.nl*	1645–1799	**ANTIQUE**
N09		*Private seller on www.marktplaats.nl*	1976–1978	**ILLEGAL**
N10		*Private seller on www.marktplaats.nl*	1513–1797	**ANTIQUE**

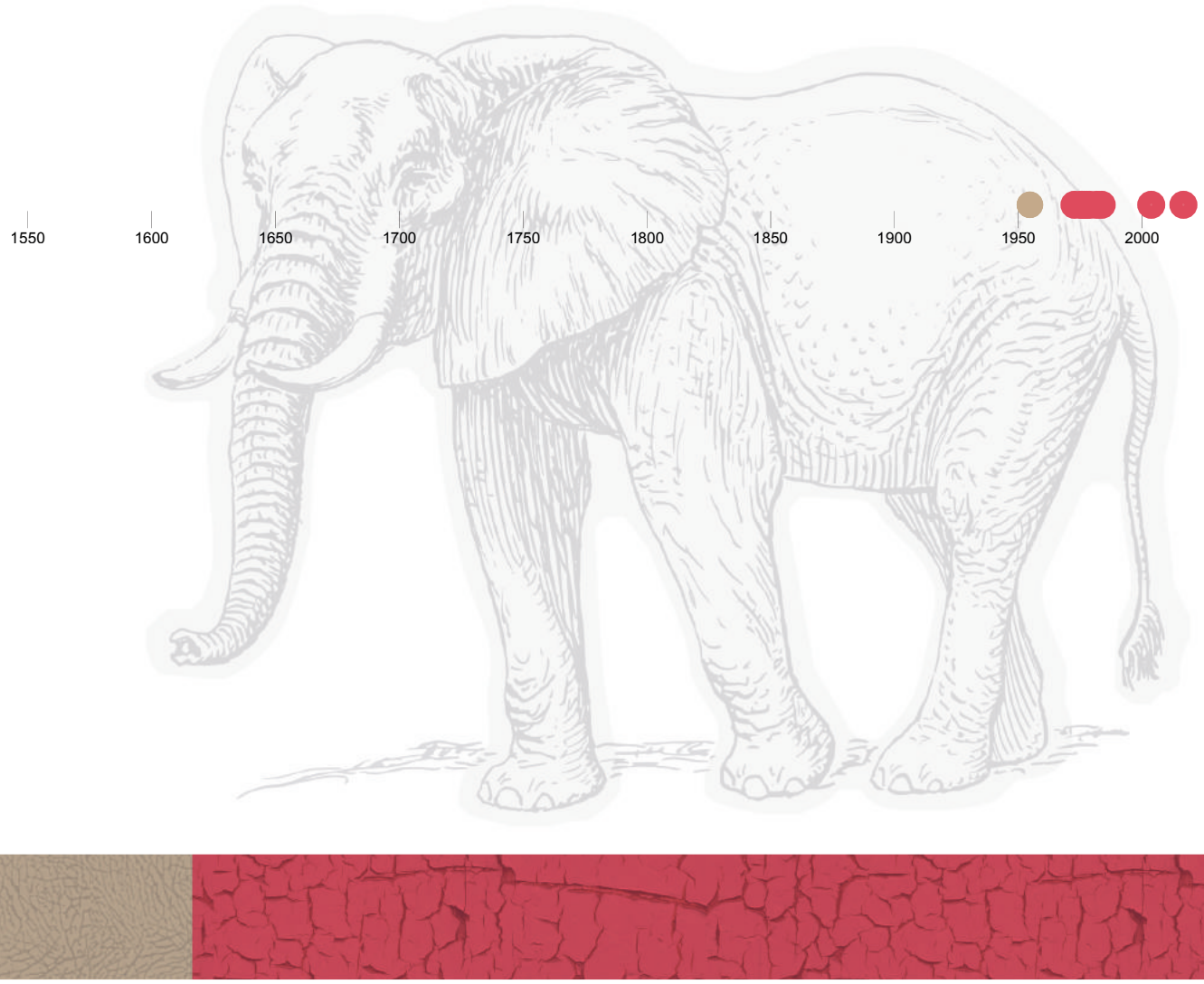
NETHERLANDS

Specimen	IMAGE	Seller	DATE-RANGE	STATUS
N11		*Private seller on www.marktplaats.nl*	1975–1976, 1963–1964	**ILLEGAL**
N12		*Private seller on www.marktplaats.nl*	1980–1982, 1962–1963	**ILLEGAL**
N13		*Private seller on www.marktplaats.nl*	1676–1951	**ANTIQUE**
N14		*Private seller on www.marktplaats.nl*	1667–1955	**ANTIQUE**
N15	N/A	*Private seller on www.marktplaats.nl*	1976–1978	**ILLEGAL**
N16		*Private seller on www.marktplaats.nl*	1974–1975	**ILLEGAL**

NETHERLANDS

Specimen	IMAGE	*Seller*	DATE-RANGE	**STATUS**
N17		*Private seller on www.marktplaats.nl*	1975–1977, 1963	**ILLEGAL**
N18		*Private seller on www.marktplaats.nl*	1972–1973	**ILLEGAL**

PORTUGAL

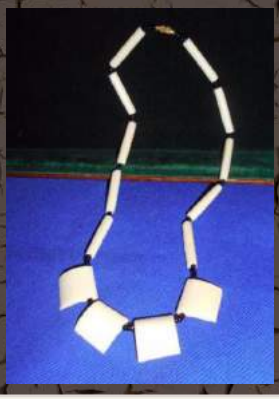


16.7% antique, 83.3% illegal

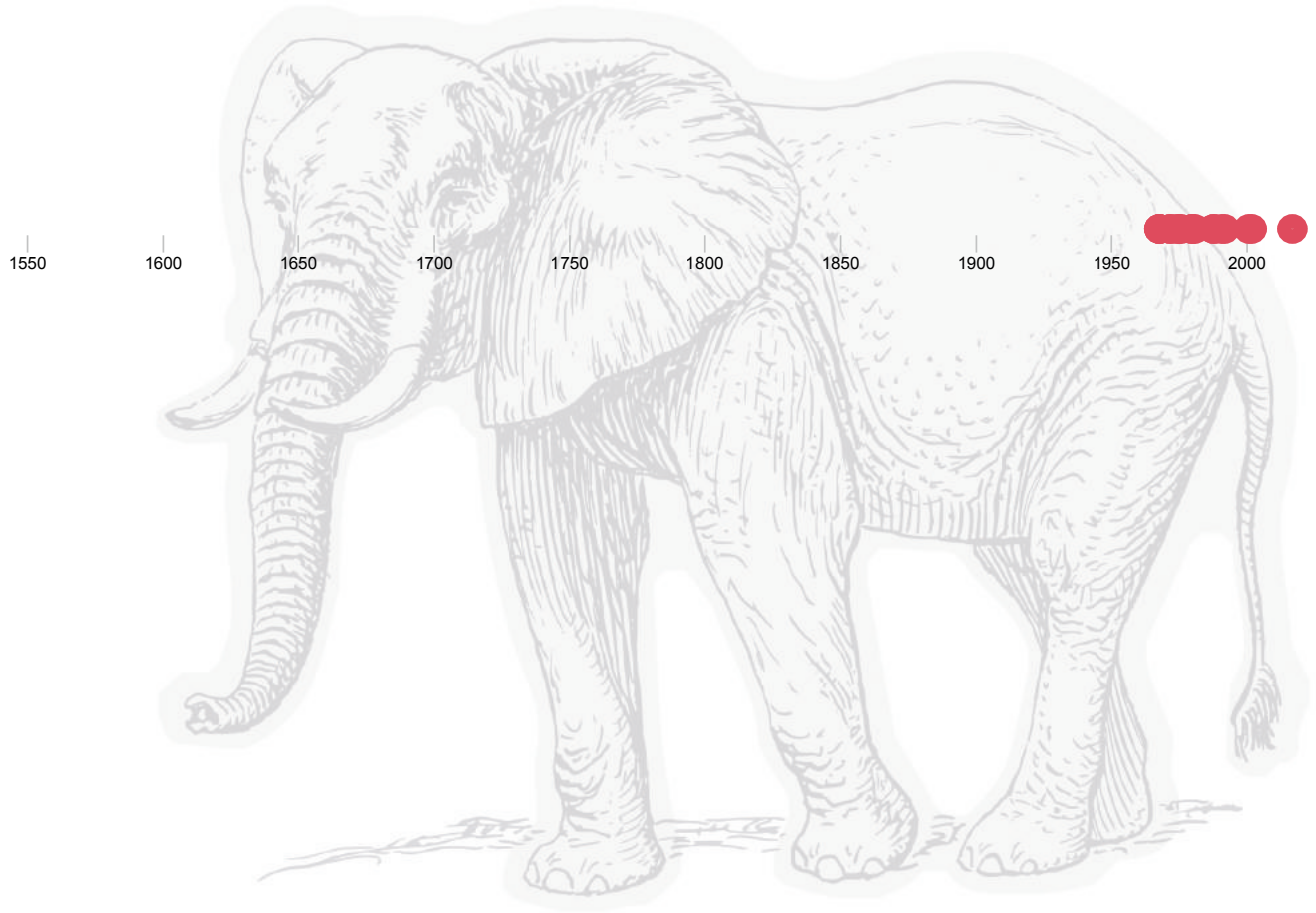
PORTUGAL

Specimen	IMAGE	Seller	DATE-RANGE	STATUS
PO01		*Private seller on www.olx.pt*	1977–1979	**ILLEGAL**
PO02		*Private seller on www.olx.pt*	1982–1984	**ILLEGAL**
PO03		*Private seller on www.olx.pt*	1980–1982, 1962–1963	**ILLEGAL**
PO04		*Private seller on www.olx.pt*	1976–1977, 1963	**ILLEGAL**
PO05		*Private seller on www.olx.pt*	1976–1978	**ILLEGAL**
PO11	N/A	*Private seller on www.olx.pt*	1975–1976	**ILLEGAL**
PO12		*Private seller on www.olx.pt*	1972–1973	**ILLEGAL**
PO13		*Private seller on www.olx.pt*	1975–1976 1963–1964	**ILLEGAL**
PO14		*Private seller on www.olx.pt*	1673–1955	**ANTIQUE**
PO17		*Private seller on www.olx.pt*	Post 2010	**ILLEGAL**

PORTUGAL

Specimen	IMAGE	*Seller*	DATE-RANGE	**STATUS**
PO18		*Private seller on www.olx.pt*	1670–1955	**ANTIQUE**
PO19		Private seller on www.olx.pt	2001–2004	**ILLEGAL**

SPAIN



100% illegal

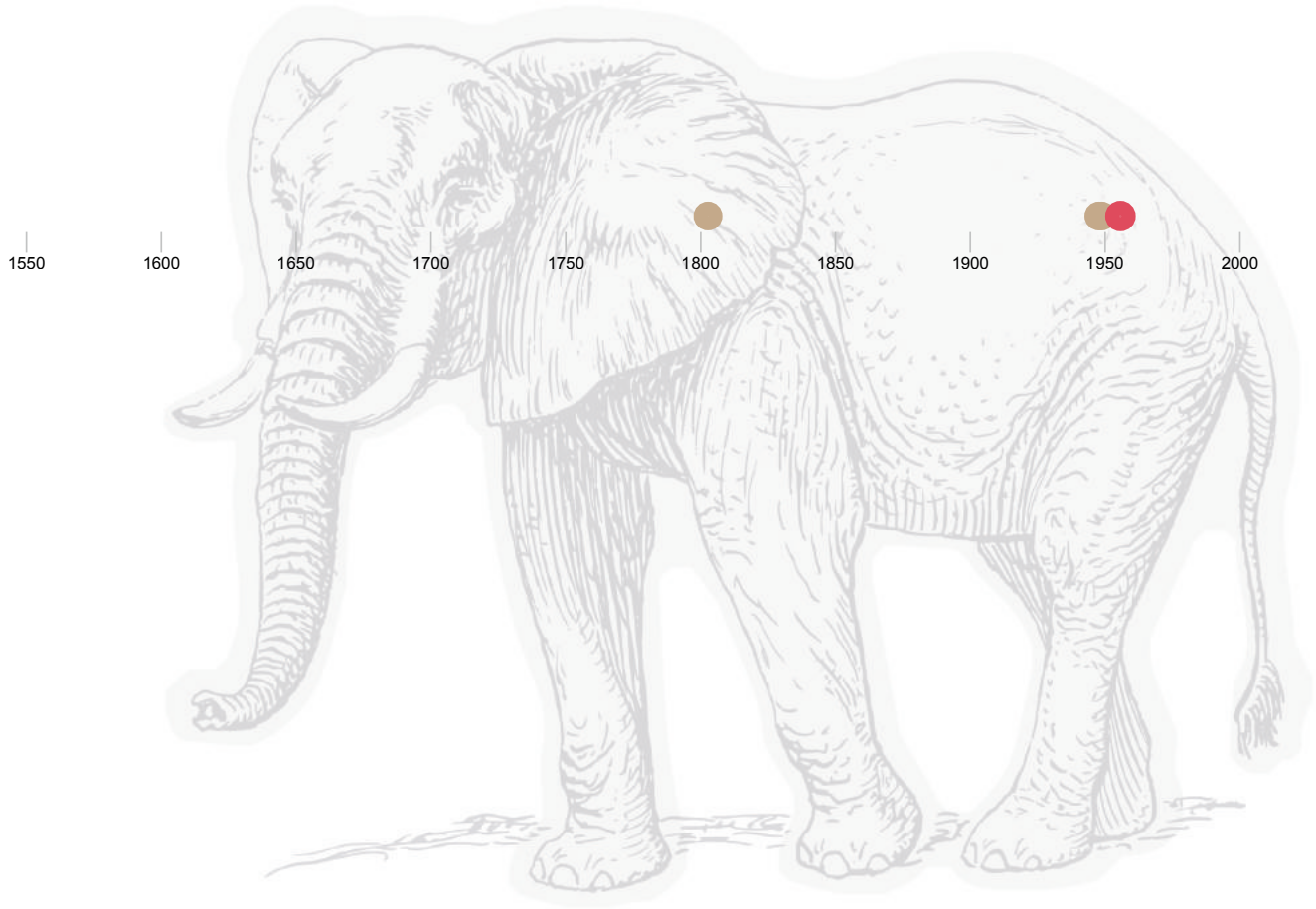
SPAIN

Specimen	IMAGE	Seller	DATE-RANGE	STATUS
S01		*Private seller on www.todocoleccion.net*	1975–1976, 1963–1964	**ILLEGAL**
S02		*Antique shop*	1959–1962, 1986–1988	**ILLEGAL**
S03		*Antique shop*	1970–1972	**ILLEGAL**
S04		*Antique shop*	1978–1980	**ILLEGAL**
S05		*Antique shop*	1970–1972	**ILLEGAL**
S06		*Antique shop*	1974–1975, 1963–1964	**ILLEGAL**

Specimen	IMAGE	Seller	DATE-RANGE	STATUS
S07		*Antique shop*	1988–1991, 1959–1960	**ILLEGAL**
S08		*Antique shop*	1967–1968	**ILLEGAL**
S09		*Private seller on www.todocoleccion.net*	1967–1968, 1964	**ILLEGAL**
S11		*Antique shop*	1986–1988, 1959–1962	**ILLEGAL**
S12	N/A	*Antique shop*	Post-2010	**ILLEGAL**
S13		*Antique shop*	1974–1975, 1963–1964	**ILLEGAL**
S14		*Antique shop*	1988–1992	**ILLEGAL**

Specimen	IMAGE	Seller	DATE-RANGE	STATUS
S15		*Private seller on www.todocoleccion.net*	1980–1981, 1962–1963	**ILLEGAL**
S17		*Private seller on www.todocoleccion.net*	1978–1980	**ILLEGAL**
S18a		*Antique shop*	1997–2001	**ILLEGAL**
S18b		*Antique shop*	1998–2002	**ILLEGAL**
S19		*Antique shop*	1967–1968, 1964	**ILLEGAL**

UK



80% antique 20% illegal

Specimen	IMAGE	Seller	DATE-RANGE	STATUS
UK0002		*Antique shop*	1697–1949	**ANTIQUE**
UK0004		*Antique shop*	1954–1956	**ILLEGAL**
UK0005		*Antique shop*	1650–1803	**ANTIQUE**
UK0012		*Antique shop*	1697–1948	**ANTIQUE**
UK0013		*Antique shop*	1668–1955	**ANTIQUE**

Oxford University Report

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Radiocarbon dating of worked ivory specimens for Avaaz

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1 Summary

The Oxford Radiocarbon Accelerator Unit has dated 109 worked ivory specimens for Avaaz. These specimens were purchased in ten European Union (EU) countries.

The trade of *Loxodonta africana* and *Elephas maximus* ivory within the EU is governed by European Commission Regulations 338/97 and 865/06. These regulations prohibit intra-EU trade of ivory specimens which have been significantly altered from their natural or raw state after 3rd March 1947.

Radiocarbon dating determines the age of formation of ivory; that is, the year during which grew the part of the tusk that was sampled for analysis. Because of the lifespan of elephants, ivory may be formed many years before the death of an elephant. Even where the radiocarbon age of the ivory sample is consistent with it being formed prior to 1947 this does exclude the death of the animal that produced the ivory occurring after 1947 or that the ivory was worked after 1947.

Of the 109 specimens dated, 81 (74%) have radiocarbon ages inconsistent with the ivory being formed prior to 1947.

12 (57%) of 21 specimens purchased in **Belgium** have radiocarbon ages inconsistent with the ivory being formed prior to 1947.

7 (100%) of 7 specimens purchased in **Bulgaria** have radiocarbon ages inconsistent with the ivory being formed prior to 1947. The ivory in four of these specimens is likely to have been formed after 2000.

11 (86%) of 13 specimens purchased in **France** have radiocarbon ages inconsistent with the ivory being formed prior to 1947.

5 (56%) of 9 specimens purchased in **Germany** have radiocarbon ages inconsistent with the ivory being formed prior to 1947.

4 (100%) of 4 specimens purchased in **Italy** have radiocarbon ages inconsistent with the ivory being formed prior to 1947.

1 specimen was purchased in **Ireland**. This specimen had a radiocarbon age consistent with the ivory being formed prior to 1947.

13 (68%) of 19 specimens purchased in the **Netherlands** have radiocarbon ages inconsistent with the ivory being formed prior to 1947.

10 (83%) of 12 specimens purchased in **Portugal** have radiocarbon ages inconsistent with the ivory being formed prior to 1947. The ivory from one of these specimens may have been formed after 2010.

18 (100%) of 18 specimens purchased in **Spain** have radiocarbon ages inconsistent with the ivory being formed prior to 1947. The ivory from one of these specimens may have been formed after 2010.

One (20%) of 5 specimens purchased in the **United Kingdom** had a radiocarbon age inconsistent with the ivory being formed prior to 1947.

2 Background to radiocarbon dating ivory

Radiocarbon dating can be applied to most organic materials and can be used to date material which formed during the last 50,000 years. It is a useful technique to identify ivory which was formed after 1947 as this date is close to the large increase in atmospheric radiocarbon associated with atomic bomb testing in the 1950s and 1960s. This bomb radiocarbon can be clearly detected in objects of biological origin which were formed from the mid-1950s onwards.

Radiocarbon, a radioactive isotope of carbon, is continually naturally produced in the upper atmosphere as part of a cascade of reactions caused by cosmic ray bombardment. Newly formed radiocarbon is quickly oxidised to carbon dioxide which becomes distributed throughout the atmosphere and oceans. Plants incorporate carbon dioxide through photosynthesis and animals incorporate carbon by ingesting plants.

Once carbon is isolated from the atmosphere, for example within the collagen molecules in an elephant tusk, no new radiocarbon can be added. Because radiocarbon is radioactive — decaying with a half-life of 5,730 years — as time passes the abundance of radiocarbon in the ivory decreases, but the abundance of stable carbon isotopes remains constant. So, by measuring the abundance of radiocarbon relative to that of stable carbon isotopes, it is possible to calculate how long ago the ivory was formed.

A complication of radiocarbon dating is the variation over time of the concentration of radiocarbon in the atmosphere. This affects the initial relative abundance of radiocarbon as a material is formed and therefore affects its measured radiocarbon age. To deal with this complication, radiocarbon measurements are calibrated to give the calendar age of a sample. This is done using a calibration curve which is constructed by measuring the radiocarbon content of materials which formed at a known ages, such as tree rings independently dated using dendrochronology.

Prior to 1950 there is a period where the atmospheric concentration of radiocarbon was decreasing at a similar rate to the half-life of the isotope, creating a plateau in the radiocarbon calibration curve. This means that it is not possible to use radiocarbon dating to precisely date material which formed between around 1650 and 1950.

Between the mid-1950s and mid-1960s the concentration of radiocarbon in the atmosphere almost doubled due to atomic bomb testing. Since then, the atmospheric concentration of radiocarbon has declined as carbon is exported from the atmosphere into the oceans and biosphere. This rapid increase and subsequent decrease in atmospheric radiocarbon concentration allows radiocarbon dating to be used for precise age determinations for material formed since the mid-1950s.

Any radiocarbon measurement on material from this bomb period will have two possible calibrated calendar ages: one corresponding to an earlier part of the bomb peak as the radiocarbon concentration in the atmosphere was increasing and the other to a latter part of the bomb peak as the radiocarbon concentration was decreasing. For a given radiocarbon age, the latter of these two possible calendar ages is typically more likely.

The event which the radiocarbon technique dates is the year of ivory formation. Tusks are modified incisors which grow continually throughout the life of an elephant, which means that ivory from the proximal end of a tusk will have a radiocarbon age closer to the date of death of the elephant than the distal end. For this reason, it is important to take ivory samples for dating from as close to the proximal end of the tusk as possible. However, in many of the highly worked specimens analysed here it was not always possible to determine the proximal end of the tusk. As such, the calendar ages presented should be considered as the earliest possible date for the death of the animal. The actual date of death of the animal may be several decades later.

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3 Results

3.0 Explanation of results

The radiocarbon ages of the 109 worked ivory specimens are grouped by the country in which the specimens were purchased.

For each group, results are presented in a table as well as two types of plot: one showing the calibrated calendar ages of all samples from that country and the other the individual calibration plots for each sample.

The plots of calibrated calendar ages and the individual calibration plots both display the probability distributions of the calibrated ages as histograms. The ages under the highest part of these histograms are the most likely calendar age for a given radiocarbon determination. The brackets under the histograms show the range of the 95.4% confidence interval (this is the interval which, based on the radiocarbon determination and calibration curve used, gives a 95.4% probability of containing the true age of the specimen).

The individual calibration plots display the radiocarbon determination (shown in red), the calibration curve (shown in blue) and the probability distribution of the calibrated calendar age. Where the 95.4% confidence interval is split over two or more ranges the text on the plots gives the probability of the true age of the sample falling within each range. For example, based on the radiocarbon determination for sample BE06 there is a 5% probability that the ivory was formed during 1963, but a 90% probability it formed between 1975 and 1976.

Radiocarbon determinations are presented as $F^{14}C$. $F^{14}C = 1$ for a sample formed in 1950 (in the northern hemisphere); with values of $F^{14}C < 1$ for ages before 1950 and $F^{14}C > 1$ for ages after.

By convention, each radiocarbon determination is assigned a laboratory code. For radiocarbon determinations made at the Oxford Radiocarbon Accelerator Unit, the laboratory code has the prefix OxA.

The tables also contain data about the stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope composition of the collagen extracted from the ivory and used for dating. These provide information about the diet and habitat of the elephants. Very broadly, more negative $\delta^{13}C$ (ca. -23‰ or lower) suggests the elephant browsed exclusively in closed canopy forest, whereas less negative $\delta^{13}C$ (ca. -13‰) suggests the elephant browsed exclusively in open grassland. Higher $\delta^{15}N$ suggests feeding in a drier habitat and lower values a more humid habitat. (For a more detailed explanation of stable isotopes in elephant collagen see, for example, Van der Merwe et al., 1990)

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3.1 Belgium

12 (57%) of 21 specimens purchased in Belgium display radiocarbon ages inconsistent with the ivory being formed pre-1947.

Most of the post-1947 samples likely date from the 1970s. The most recent specimen is BE21 where there is a 93% probability that the ivory was formed between 1999 and 2003.

Table 1. Radiocarbon determinations, stable carbon and nitrogen isotope compositions and 95.4% confidence intervals of the calibrated ages for worked ivory specimens purchased in Belgium.

Specimen	Laboratory code	$F^{14}C$	$\delta^{13}C$ / ‰	$\delta^{15}N$ / ‰	Calibrated age, 95.4% confidence interval / cal AD
BE01	OxA-36985	0.98644 ± 0.00275	-22.6	+10.1	1699–1955
BE02	OxA-36999	0.98244 ± 0.00327	-20.9	+8.1	1686–1950
BE03	OxA-37030	0.97280 ± 0.00310	-22.9	+11.0	1649–1955
BE04	OxA-36987	0.97244 ± 0.00276	-23.5	+10.6	1651–1954
BE05	OxA-36988	0.97752 ± 0.00273	-26.0	+10.9	1669–1955
BE06	OxA-37008	1.36824 ± 0.00384	-22.2	+5.7	1963, 1975–1976
BE06 (duplicate measurement)	OxA-37009	1.36634 ± 0.00391	-21.3	+5.6	1963, 1975–1976
BE07	OxA-37006	1.00530 ± 0.00337	-21.5	+7.8	1954–1956
BE08	OxA-36949	1.35840 ± 0.00353	-18.8	+8.2	1963, 1975–1977
BE17	OxA-36992	1.35247 ± 0.00341	-26.4	+12.3	1963, 1976–1977
BE18	OxA-36983	1.15945 ± 0.00308	-25.2	+8.4	1959, 1988–1993
BE19	OxA-37029	1.29966 ± 0.00359	-25.1	+12.9	1963, 1978–1980
BE20	OxA-36920	1.47853 ± 0.00371	-23.0	+12.4	1963–1964, 1971–1973
BE21	OxA-36989	1.09203 ± 0.00497	-22.8	+8.8	1958, 1999–2003
BE27	OxA-37020	0.97714 ± 0.00320	-20.9	+7.9	1667–1955
BE28	OxA-37022	0.96730 ± 0.00325	-21.9	+6.5	1627–1954
BE29	OxA-37021	0.97335 ± 0.00314	-24.8	+10.1	1649–1955
BE30	OxA-37033	1.33577 ± 0.00369	-19.9	+7.5	1963, 1976–1978
BE31	OxA-37034	1.16830 ± 0.00342	-25.3	+12.2	1959–1960, 1988–1992
BE32	OxA-37045	0.98516 ± 0.00311	-22.9	+6.6	1697–1955
BE33	OxA-37049	1.36614 ± 0.00386	-26.5	+11.5	1963, 1975–1976
BE39	OxA-37035	1.20932 ± 0.00354	-25.6	+11.6	1961–1963, 1984–1986

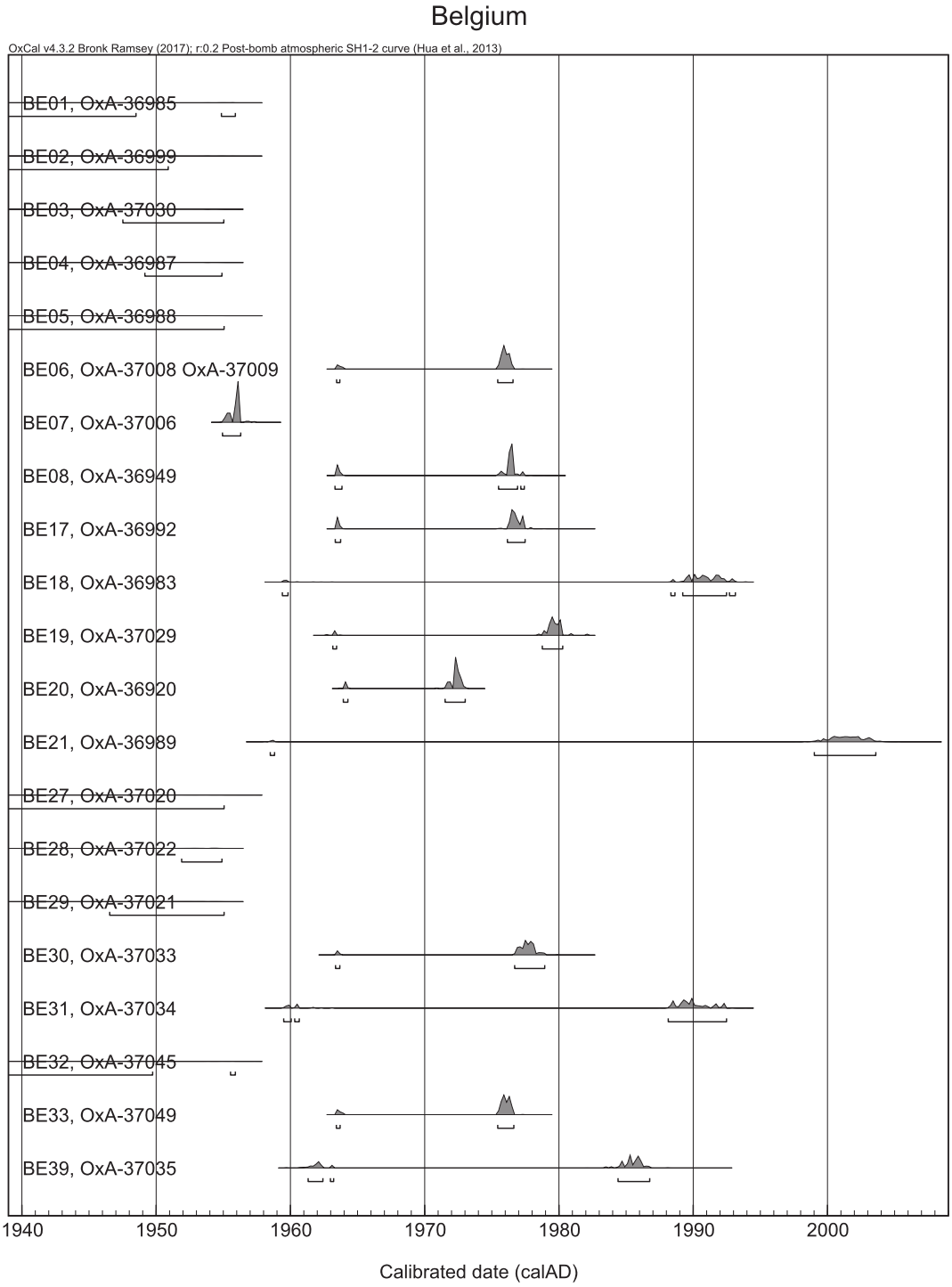
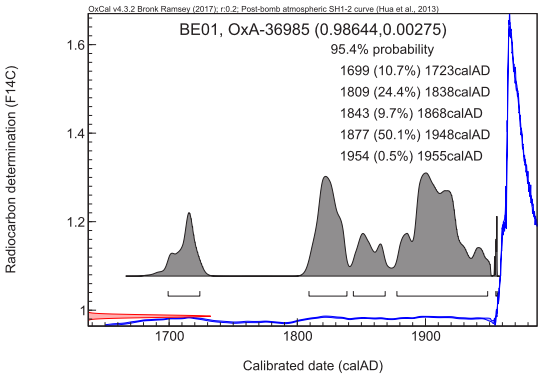
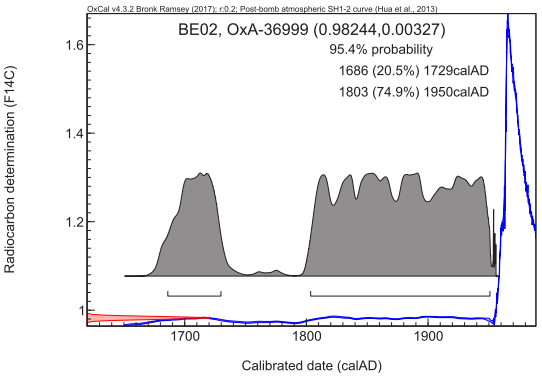
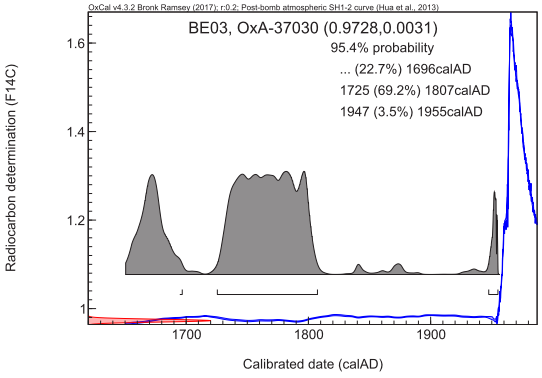


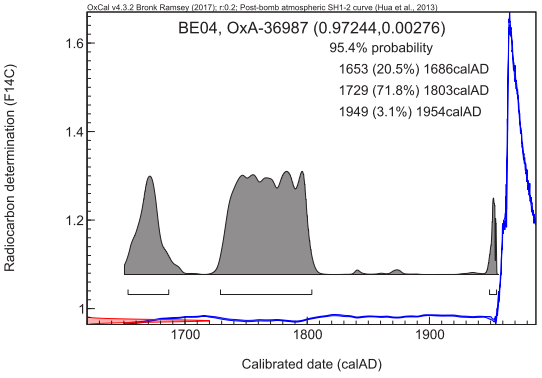
Figure 1. Probability distributions for the calibrated calendar ages of worked ivory specimens purchased in Belgium. The brackets under each distribution show 95.4% confidence intervals.

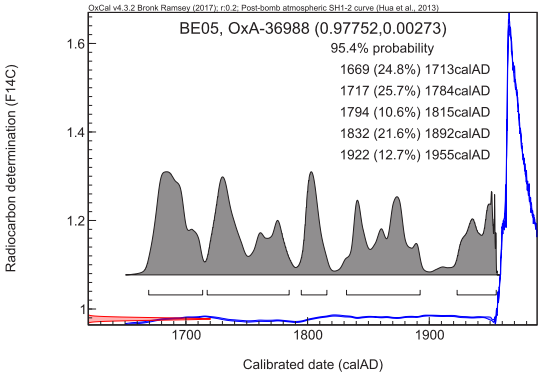
Following three pages: Figure 2. Calibration plots for radiocarbon determinations of worked ivory specimens purchased in Belgium.


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BE01, OxA-36985 (0.98644,0.00275)
95.4% probability
1699 (10.7%) 1723calAD
1809 (24.4%) 1838calAD
1843 (9.7%) 1868calAD
1877 (50.1%) 1948calAD
1954 (0.5%) 1955calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BE02, OxA-36999 (0.98244,0.00327)
95.4% probability
1686 (20.5%) 1729calAD
1803 (74.9%) 1950calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BE03, OxA-37030 (0.9728,0.0031)
95.4% probability
... (22.7%) 1696calAD
1725 (69.2%) 1807calAD
1947 (3.5%) 1955calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BE04, OxA-36987 (0.97244,0.00276)
95.4% probability
1653 (20.5%) 1686calAD
1729 (71.8%) 1803calAD
1949 (3.1%) 1954calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)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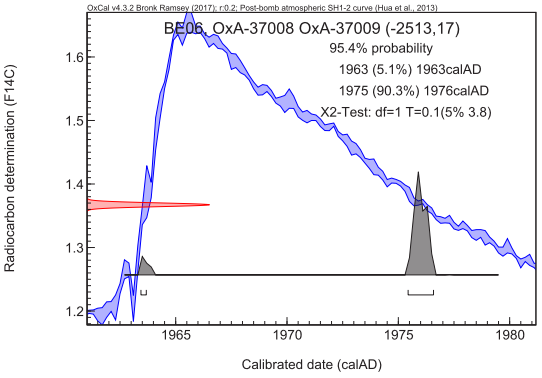
BE05, OxA-36988 (0.97752,0.00273)
95.4% probability
1669 (24.8%) 1713calAD
1717 (25.7%) 1784calAD
1794 (10.6%) 1815calAD
1832 (21.6%) 1892calAD
1922 (12.7%) 1955calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)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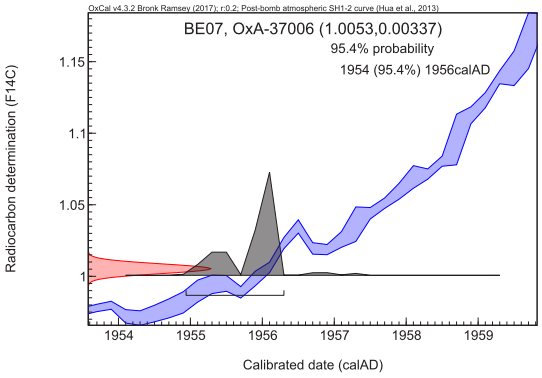
BE06, OxA-37008 OxA-37009 (-2513,17)
95.4% probability
1963 (5.1%) 1963calAD
1975 (90.3%) 1976calAD
X2-Test: df=1 T=0.1(5% 3.8)
Radiocarbon determination (F14C)
Calibrated date (calAD)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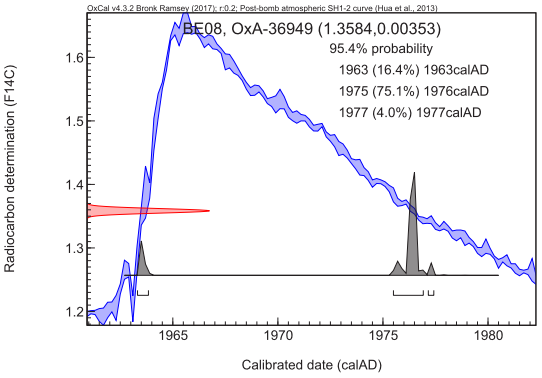
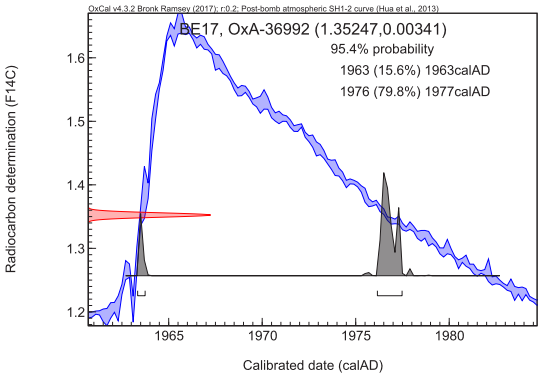
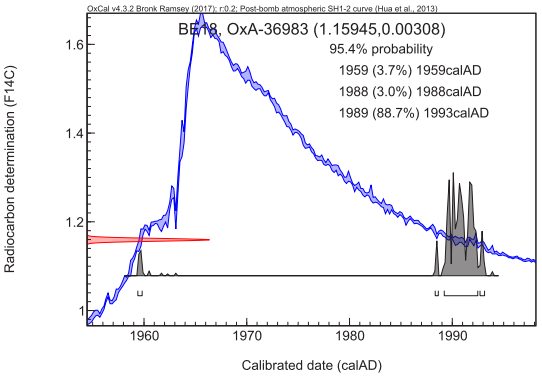
BE07, OxA-37006 (1.0053,0.00337)
95.4% probability
1954 (95.4%) 1956calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BE08, OxA-36949 (1.3584,0.00353)
95.4% probability
1963 (16.4%) 1963calAD
1975 (75.1%) 1976calAD
1977 (4.0%) 1977calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BE17, OxA-36992 (1.35247,0.00341)
95.4% probability
1963 (15.6%) 1963calAD
1976 (79.8%) 1977calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)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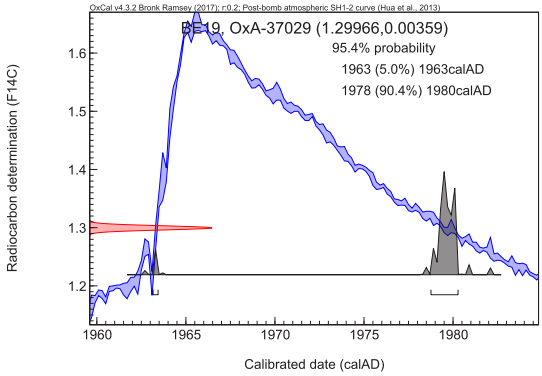
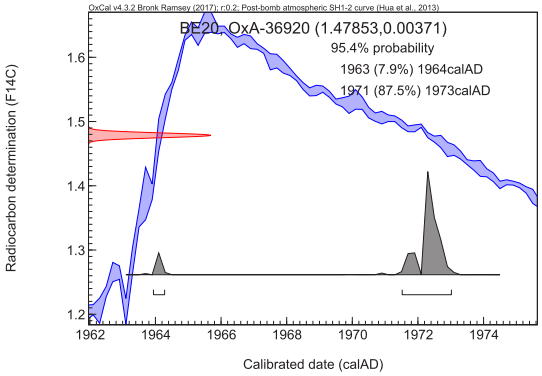
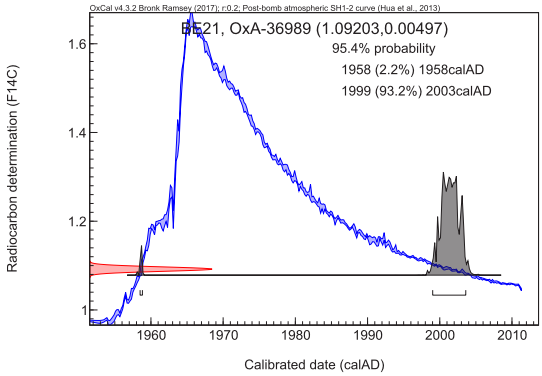
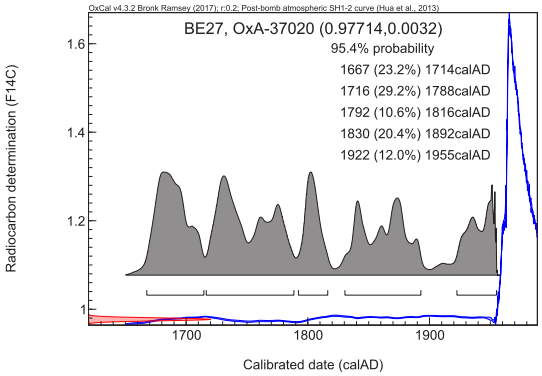
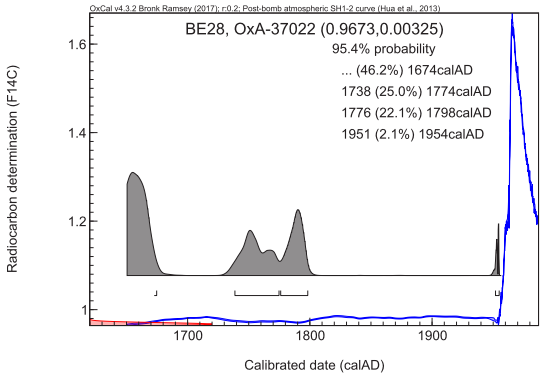
BE18, OxA-36983 (1.15945,0.00308)
95.4% probability
1959 (3.7%) 1959calAD
1988 (3.0%) 1988calAD
1989 (88.7%) 1993calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

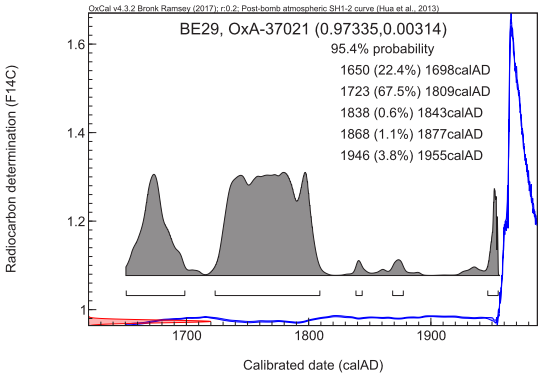

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BE19, OxA-37029 (1.29966,0.00359)
95.4% probability
1963 (5.0%) 1963calAD
1978 (90.4%) 1980calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

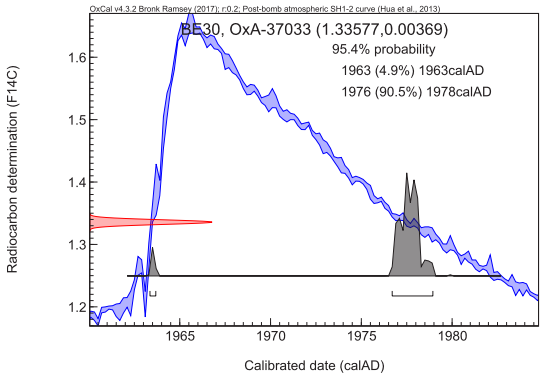

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BE20, OxA-36920 (1.47853,0.00371)
95.4% probability
1963 (7.9%) 1964calAD
1971 (87.5%) 1973calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

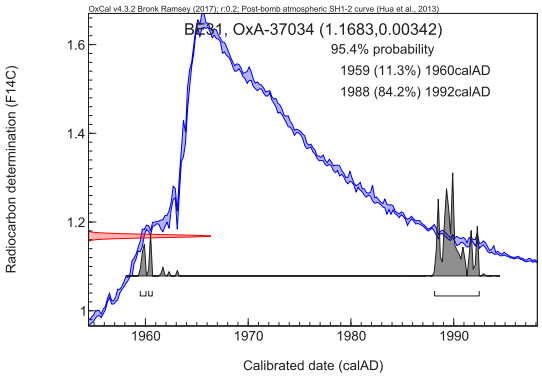

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BE21, OxA-36989 (1.09203,0.00497)
95.4% probability
1958 (2.2%) 1958calAD
1999 (93.2%) 2003calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

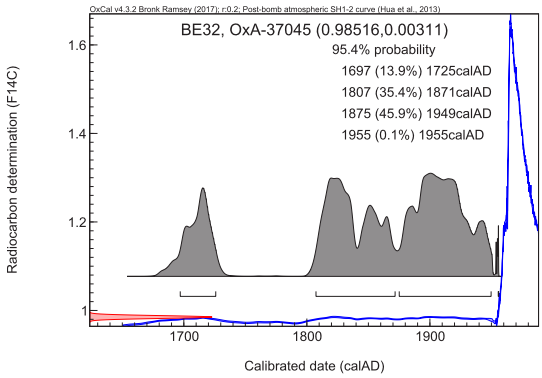

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BE27, OxA-37020 (0.97714,0.0032)
95.4% probability
1667 (23.2%) 1714calAD
1716 (29.2%) 1788calAD
1792 (10.6%) 1816calAD
1830 (20.4%) 1892calAD
1922 (12.0%) 1955calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

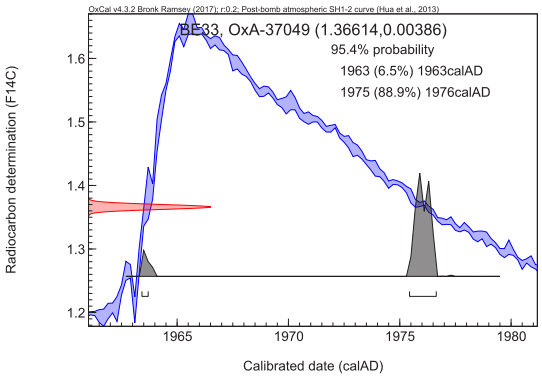

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BE28, OxA-37022 (0.9673,0.00325)
95.4% probability
... (46.2%) 1674calAD
1738 (25.0%) 1774calAD
1776 (22.1%) 1798calAD
1951 (2.1%) 1954calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

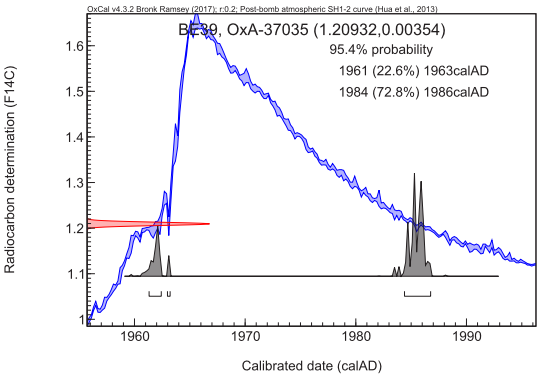

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BE29, OxA-37021 (0.97335,0.00314)
95.4% probability
1650 (22.4%) 1698calAD
1723 (67.5%) 1809calAD
1838 (0.6%) 1843calAD
1868 (1.1%) 1877calAD
1946 (3.8%) 1955calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BE30, OxA-37033 (1.33577,0.00369)
95.4% probability
1963 (4.9%) 1963calAD
1976 (90.5%) 1978calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BE31, OxA-37034 (1.1683,0.00342)
95.4% probability
1959 (11.3%) 1960calAD
1988 (84.2%) 1992calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BE32, OxA-37045 (0.98516,0.00311)
95.4% probability
1697 (13.9%) 1725calAD
1807 (35.4%) 1871calAD
1875 (45.9%) 1949calAD
1955 (0.1%) 1955calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BE33, OxA-37049 (1.36614,0.00386)
95.4% probability
1963 (6.5%) 1963calAD
1975 (88.9%) 1976calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BE39, OxA-37035 (1.20932,0.00354)
95.4% probability
1961 (22.6%) 1963calAD
1984 (72.8%) 1986calAD
Radiocarbon determination (F14C)
1.6
1.5
1.4
1.3
1.2
1.1
1
1960
1970
1980
1990
Calibrated date (calAD)

3.2 Bulgaria

All of the seven specimens purchased in Bulgaria have radiocarbon determinations inconsistent with the ivory being formed before 1947.

The ivory in five of these specimens was likely formed in 2000 or later, with the ivory from samples BU04, BU05a, BU05b and BU07 being similar in age.

Table 2. Radiocarbon determinations, stable carbon and nitrogen isotope compositions and 95.4% confidence intervals of the calibrated ages for worked ivory specimens purchased in Bulgaria.

Specimen	Laboratory code	$F^{14}C$	$\delta^{13}C$ / ‰	$\delta^{15}N$ / ‰	Calibrated age, 95.4% confidence interval / cal AD
BU01a	OxA-37048	1.09874 ± 0.00325	-20.3	+8.1	1958, 1998–2001
BU02	OxA-37060	1.56384 ± 0.00418	-21.2	+7.1	1964, 1967–1970
BU03	OxA-37043	1.18793 ± 0.00362	-19.4	+7.5	1959–1963, 1985–1989
BU04	OxA-37055	1.07835 ± 0.00337	-26.4	+10.8	1957–1958, 2002–2005
BU05a (Heart-shaped pendant)	OxA-37056	1.07057 ± 0.00335	-26.9	+12.8	1957–1958, 2004–2008
BU05b (Tusk-shaped pendant)	OxA-37059	1.06305 ± 0.00350	-26.7	+11.9	1957–1958, 2005–2010
BU07	OxA-37050	1.06919 ± 0.00342	-19.0	+4.7	1957–1958, 2004–2008

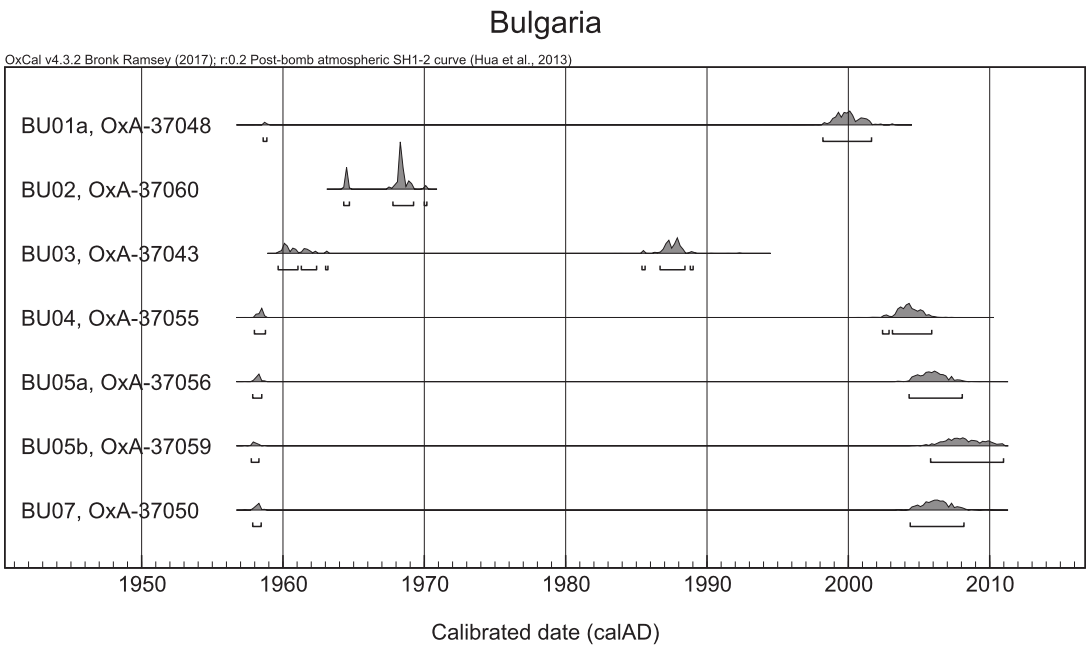
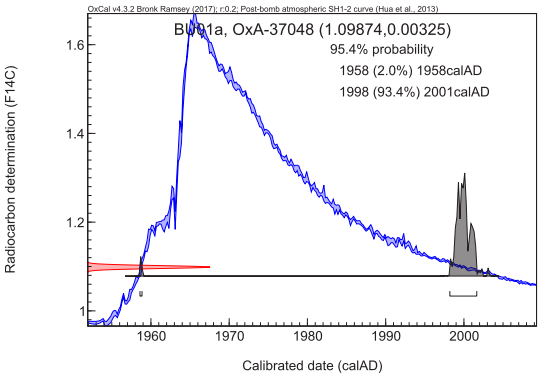
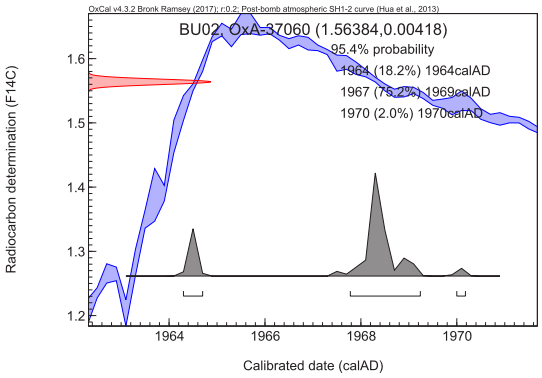
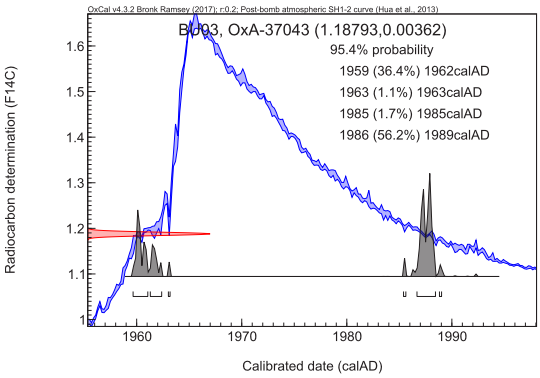


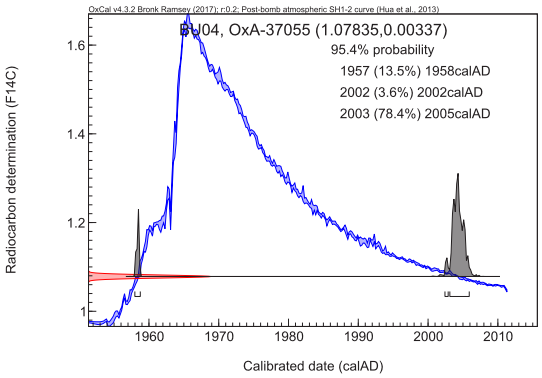
Figure 3. Probability distributions for the calibrated calendar ages of worked ivory specimens purchased in Bulgaria. The brackets under each distribution show 95.4% confidence intervals.

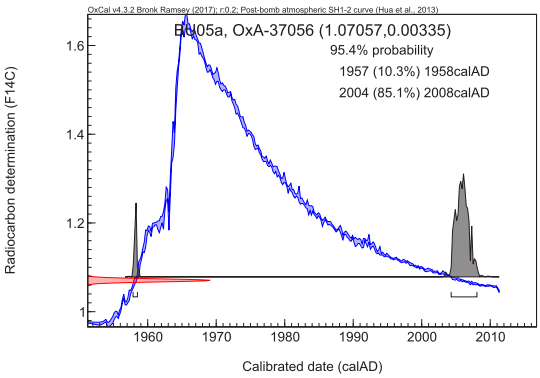
Following page: Figure 4. Calibration plots for radiocarbon determinations of worked ivory specimens purchased in Bulgaria.

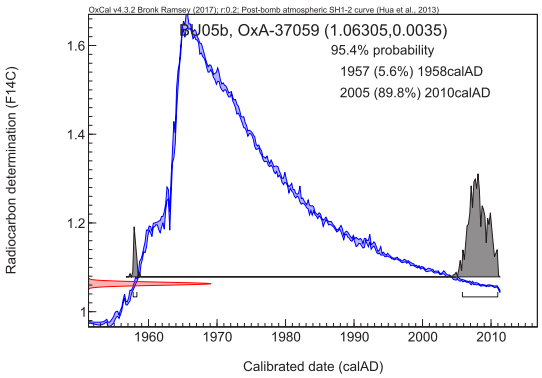

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BU01a, OxA-37048 (1.09874,0.00325)
95.4% probability
1958 (2.0%) 1958calAD
1998 (93.4%) 2001calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

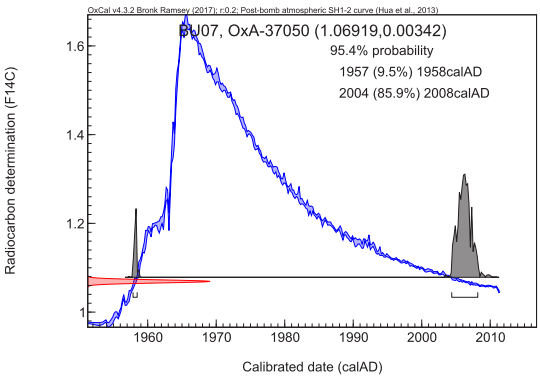

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BU02, OxA-37060 (1.56384,0.00418)
95.4% probability
1964 (18.2%) 1964calAD
1967 (75.2%) 1969calAD
1970 (2.0%) 1970calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

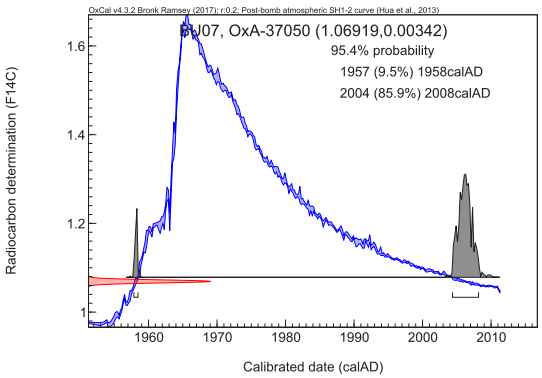

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BU03, OxA-37043 (1.18793,0.00362)
95.4% probability
1959 (36.4%) 1962calAD
1963 (1.1%) 1963calAD
1985 (1.7%) 1985calAD
1986 (56.2%) 1989calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BU04, OxA-37055 (1.07835,0.00337)
95.4% probability
1957 (13.5%) 1958calAD
2002 (3.6%) 2002calAD
2003 (78.4%) 2005calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BU05a, OxA-37056 (1.07057,0.00335)
95.4% probability
1957 (10.3%) 1958calAD
2004 (85.1%) 2008calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BU05b, OxA-37059 (1.06305,0.0035)
95.4% probability
1957 (5.6%) 1958calAD
2005 (89.8%) 2010calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BU07, OxA-37050 (1.06919,0.00342)
95.4% probability
1957 (9.5%) 1958calAD
2004 (85.9%) 2008calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
BU07, OxA-37050 (1.06919,0.00342)
95.4% probability
1957 (9.5%) 1958calAD
2004 (85.9%) 2008calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

3.3 France

All but two of the thirteen specimens purchased in France display radiocarbon ages inconsistent with the ivory being formed prior to 1947.

The ivory in the post-1947 specimens spans a range of most likely dates from the late 1960s to late 1980s.

Table 3. Radiocarbon determinations, stable carbon and nitrogen isotope compositions and 95.4% confidence intervals of the calibrated ages for worked ivory specimens purchased in France.

Specimen	Laboratory code	$F^{14}C$	$\delta^{13}C$ / ‰	$\delta^{15}N$ / ‰	Calibrated age, 95.4% confidence interval / cal AD
FR0003 Letter opener	OxA-36317	0.98326 ± 0.00308	-23.7	+11.3	1691–1950
FR0006 African figure (small)	OxA-36446	1.18303 ± 0.00317	-24.9	+11.9	1959–1963, 1987–1989
FR0007 African figure (large)	OxA-36447	1.32286 ± 0.00342	-26.6	+11.3	1977–1979
FR0008 Bracelet	OxA-36448	1.42336 ± 0.00346	-21.6	+6.3	1963, 1973–1974
FR0009 Bracelet	OxA-36449	1.21343 ± 0.00319	-19.8	+9.5	1961–1963, 1983–1986
FR0010 Chinese-style carving	OxA-36450	1.57564 ± 0.00385	-19.6	+7.3	1964, 1967–1968
FR0011 Trinket	OxA-36451	1.45275 ± 0.00356	-13.0	+7.9	1963–1964, 1972–1973
FR01	OxA-37046	1.57549 ± 0.00416	-17.8	+8.3	1964, 1967–1968
FR01 (duplicate measurement)	OxA-37047	1.56705 ± 0.00407	-17.3	+8.5	1964, 1967–1970
FR02	OxA-37054	0.98683 ± 0.00319	-21.2	+4.2	1698–1955
FR03	OxA-37061	1.39416 ± 0.00377	-20.4	+6.8	1963–1964, 1974–1975
FR04	OxA-36951	1.36081 ± 0.00335	-15.3	+7.2	1963, 1975–1976
FR05.1	OxA-37052	1.51885 ± 0.00412	-25.6	+11.7	1964, 1969–1971
FR06	OxA-37058	1.53124 ± 0.00413	-26.1	+6.8	1964, 1968–1970

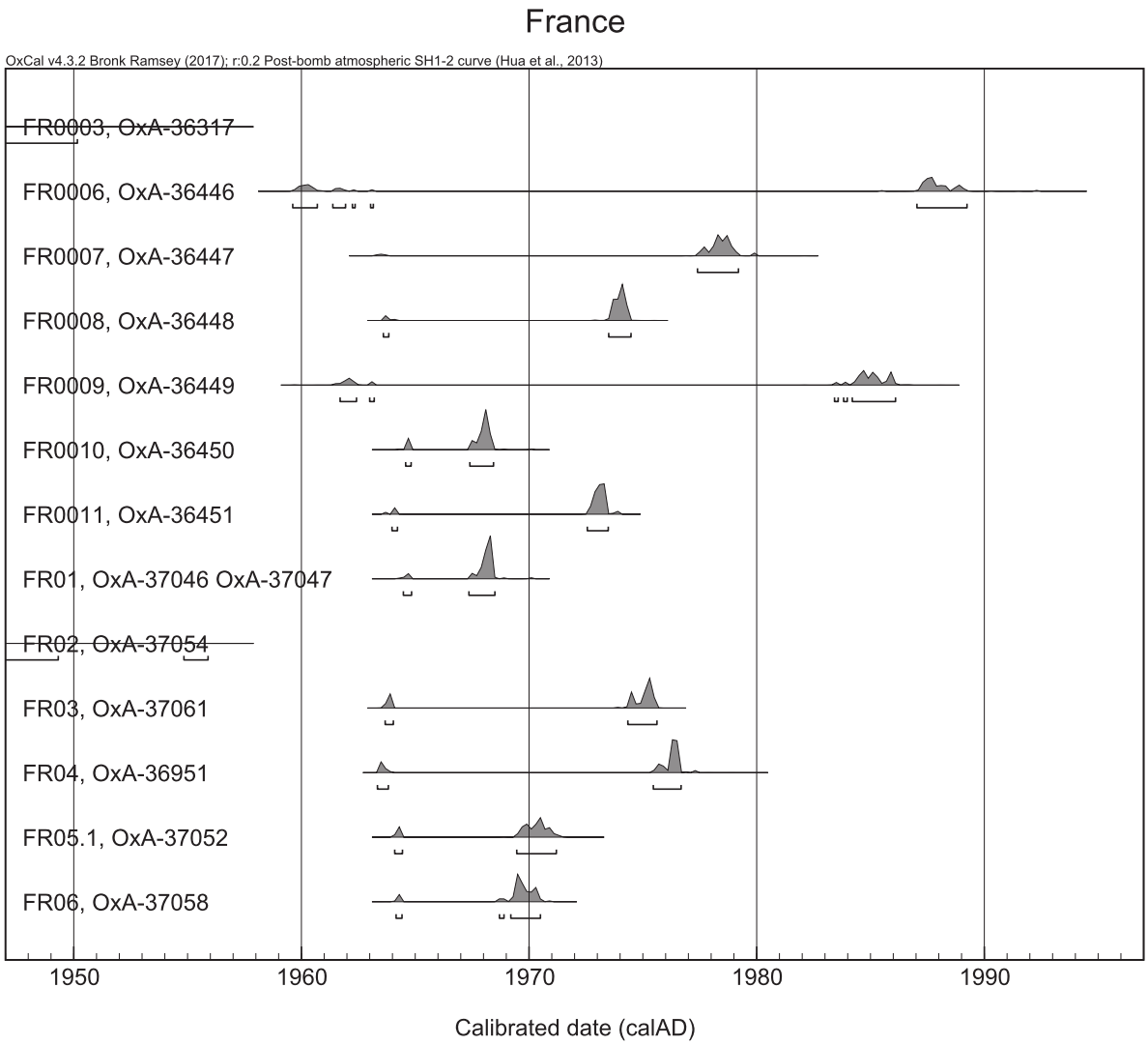
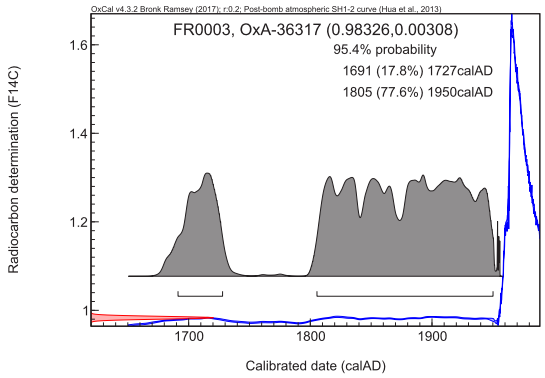
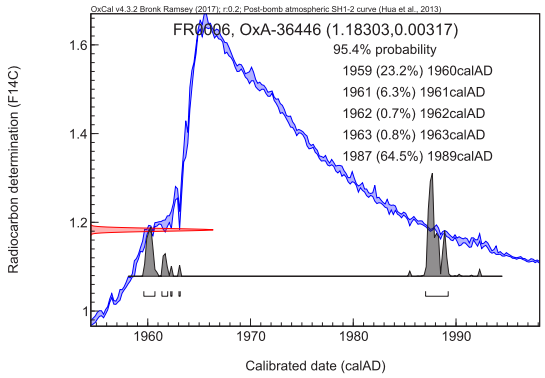
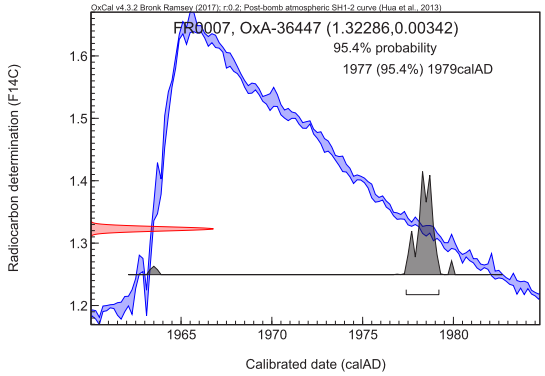


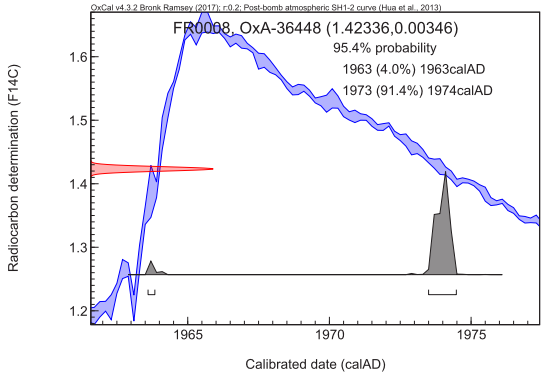
Figure 5. Probability distributions for the calibrated calendar ages of worked ivory specimens purchased in France. The brackets under each distribution show 95.4% confidence intervals.

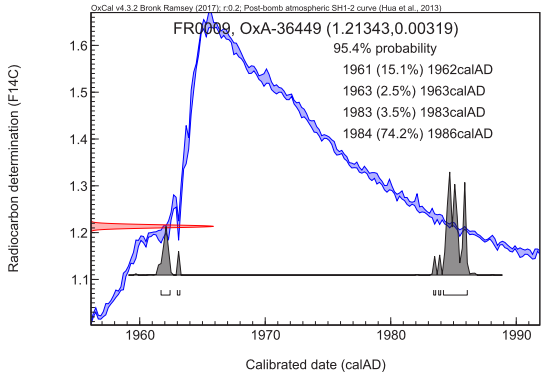
Following two pages: Figure 6. Calibration plots for radiocarbon determinations of worked ivory specimens purchased in France

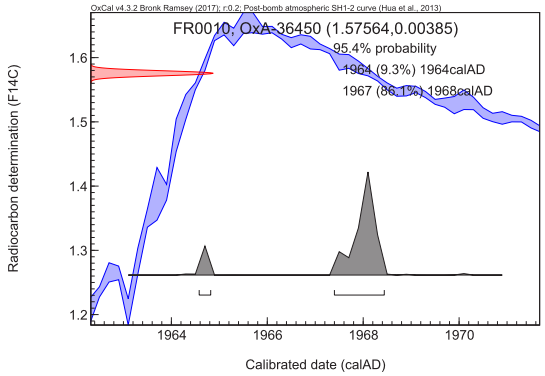

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
FR0003, OxA-36317 (0.98326,0.00308)
95.4% probability
1691 (17.8%) 1727calAD
1805 (77.6%) 1950calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

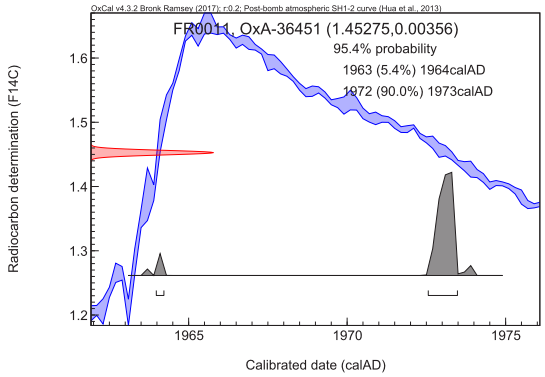

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
FR0006, OxA-36446 (1.18303,0.00317)
95.4% probability
1959 (23.2%) 1960calAD
1961 (6.3%) 1961calAD
1962 (0.7%) 1962calAD
1963 (0.8%) 1963calAD
1987 (64.5%) 1989calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

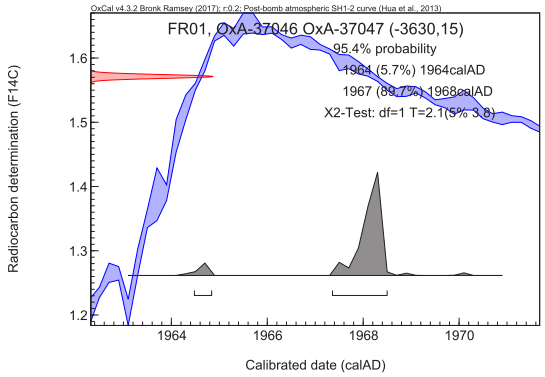

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
FR0007, OxA-36447 (1.32286,0.00342)
95.4% probability
1977 (95.4%) 1979calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

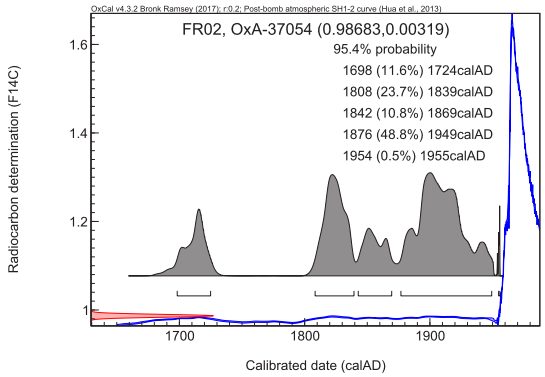

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
FR0008, OxA-36448 (1.42336,0.00346)
95.4% probability
1963 (4.0%) 1963calAD
1973 (91.4%) 1974calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

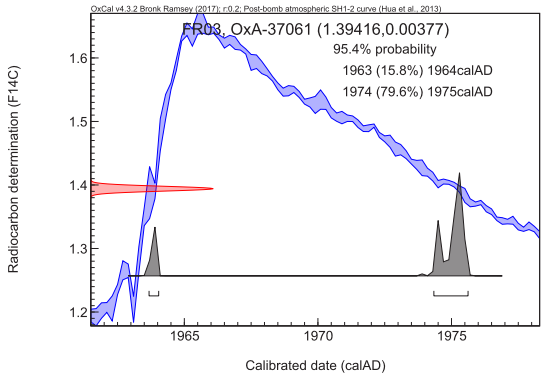

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
FR0009, OxA-36449 (1.21343,0.00319)
95.4% probability
1961 (15.1%) 1962calAD
1963 (2.5%) 1963calAD
1983 (3.5%) 1983calAD
1984 (74.2%) 1986calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

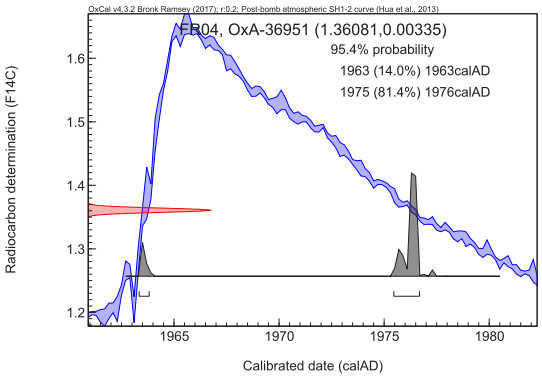

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
FR0010, OxA-36450 (1.57564,0.00385)
95.4% probability
1964 (9.3%) 1964calAD
1967 (86.1%) 1968calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

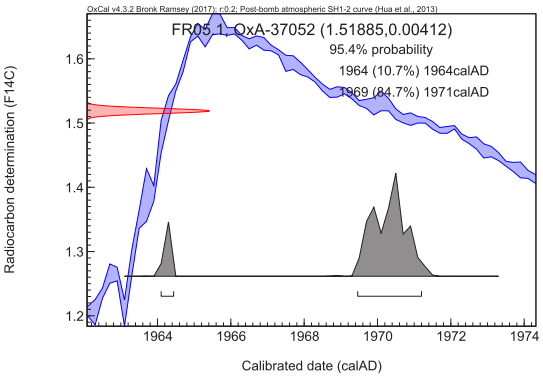

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
FR0011, OxA-36451 (1.45275,0.00356)
95.4% probability
1963 (5.4%) 1964calAD
1972 (90.0%) 1973calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

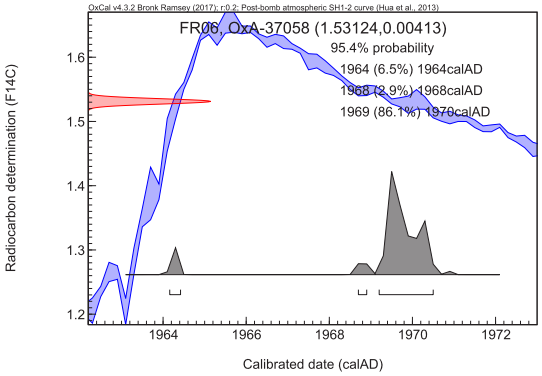

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
FR01, OxA-37046 OxA-37047 (-3630,15)
95.4% probability
1964 (5.7%) 1964calAD
1967 (89.7%) 1968calAD
X2-Test: df=1 T=2.1(5% 3.8)
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
FR02, OxA-37054 (0.98683,0.00319)
95.4% probability
1698 (11.6%) 1724calAD
1808 (23.7%) 1839calAD
1842 (10.8%) 1869calAD
1876 (48.8%) 1949calAD
1954 (0.5%) 1955calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
FR03, OxA-37061 (1.39416,0.00377)
95.4% probability
1963 (15.8%) 1964calAD
1974 (79.6%) 1975calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
FR04, OxA-36951 (1.36081,0.00335)
95.4% probability
1963 (14.0%) 1963calAD
1975 (81.4%) 1976calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
FR05.1, OxA-37052 (1.51885,0.00412)
95.4% probability
1964 (10.7%) 1964calAD
1969 (84.7%) 1971calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
FR06, OxA-37058 (1.53124,0.00413)
95.4% probability
1964 (6.5%) 1964calAD
1968 (2.9%) 1968calAD
1969 (86.1%) 1970calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

3.4 Germany

Five of the nine specimens purchased in Germany contained ivory formed after 1947. These specimens give a range of likely dates of formation during the 1960s and 1970s.

Table 4. Radiocarbon determinations, stable carbon and nitrogen isotope compositions and 95.4% confidence intervals of the calibrated ages for worked ivory specimens purchased in Germany.

Specimen	Laboratory code	$F^{14}C$	$\delta^{13}C$ / ‰	$\delta^{15}N$ / ‰	Calibrated age, 95.4% confidence interval / cal AD
GE02	OxA-37066	0.97678 ± 0.00314	-22.9	+8.0	1666–1955
GE03	OxA-37062	1.47871 ± 0.00413	-18.0	+6.8	1963–1964, 1971–1973
GE04	OxA-37063	0.96221 ± 0.00344	-8.3	+5.6	1503–1668
GE05	OxA-37064	0.97243 ± 0.00320	-19.8	+8.7	1648–1954
GE06	OxA-37070	1.57849 ± 0.00429	-24.2	+12.0	1964, 1967–1968
GE07	OxA-37067	0.97683 ± 0.00323	-19.0	+8.7	1667–1955
GE08	OxA-37069	1.33470 ± 0.00401	-18.6	+7.0	1963, 1976–1978
GE09	OxA-37068	1.48904 ± 0.00414	-20.0	+10.5	1963–1964, 1970–1972
GE10	OxA-37065	1.35718 ± 0.00387	-19.2	+7.8	1963, 1975–1977

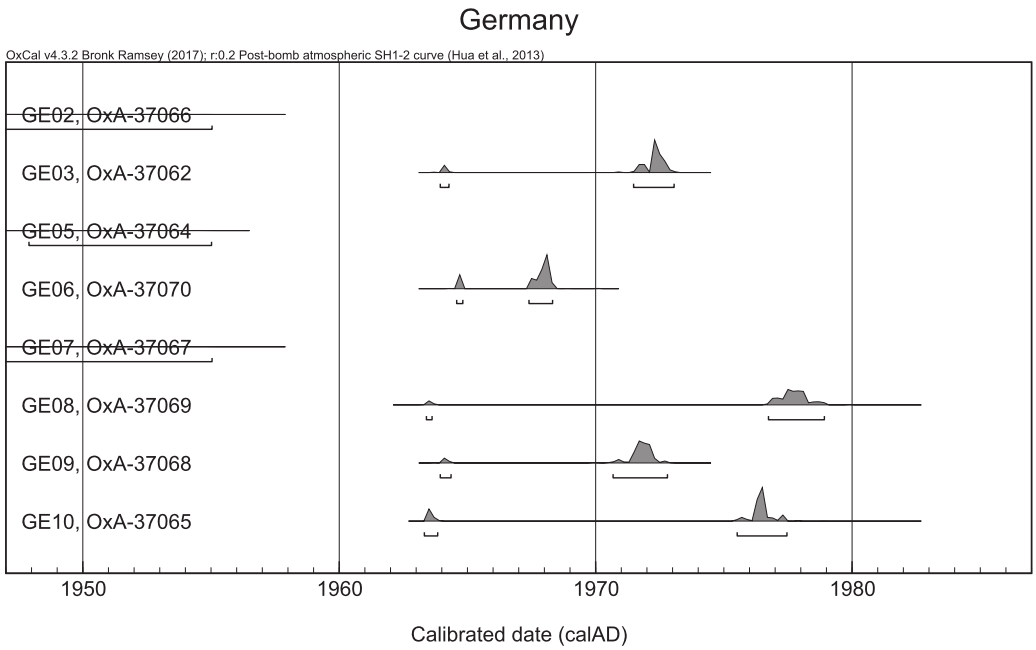
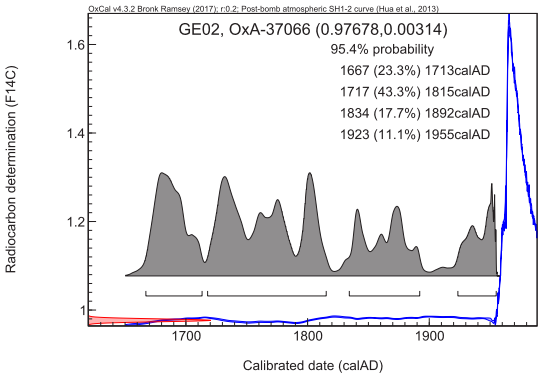
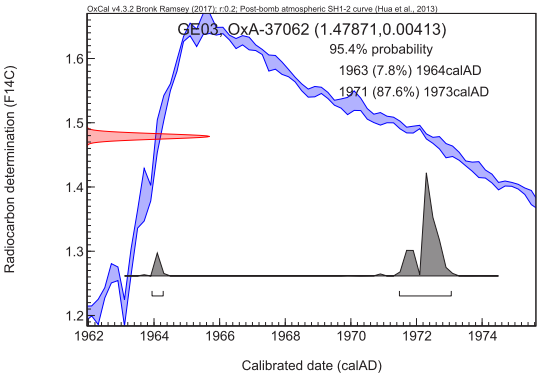
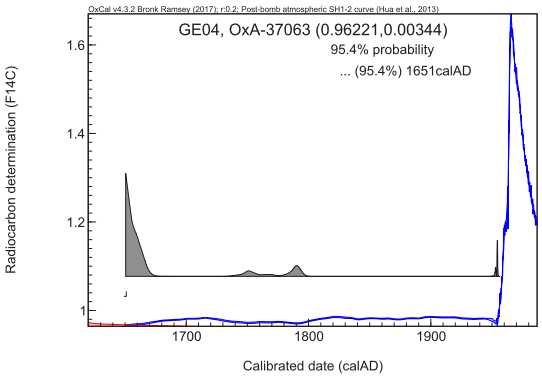


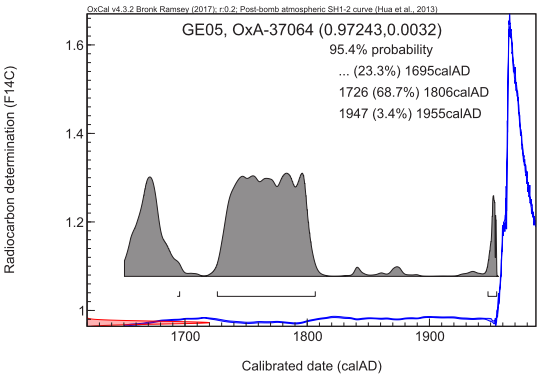
Figure 7. Probability distributions for the calibrated calendar ages of worked ivory specimens purchased in Germany. The brackets under each distribution show 95.4% confidence intervals.

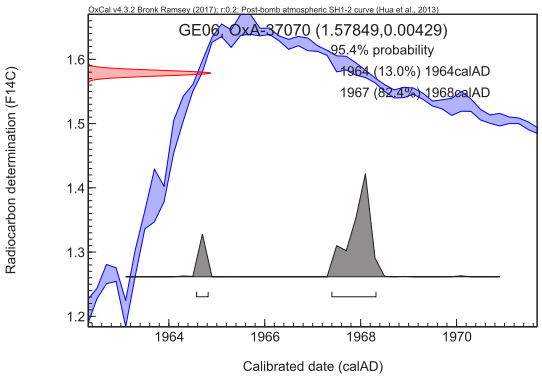
Following page: Figure 8. Calibration plots for radiocarbon determinations of worked ivory specimens purchased in Germany.

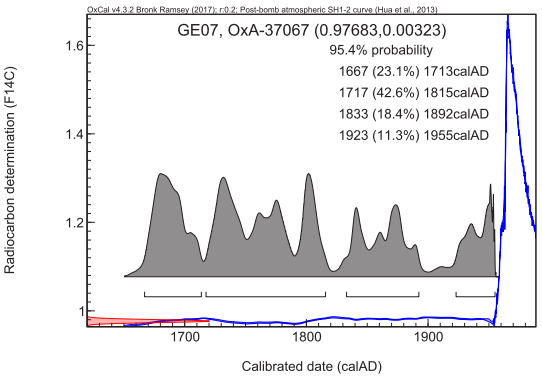

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
GE02, OxA-37066 (0.97678,0.00314)
95.4% probability
1667 (23.3%) 1713calAD
1717 (43.3%) 1815calAD
1834 (17.7%) 1892calAD
1923 (11.1%) 1955calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

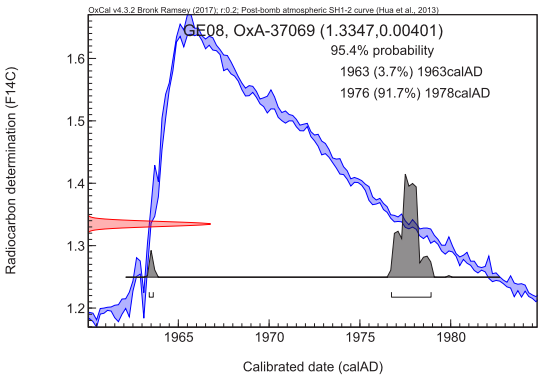

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
GE03, OxA-37062 (1.47871,0.00413)
95.4% probability
1963 (7.8%) 1964calAD
1971 (87.6%) 1973calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

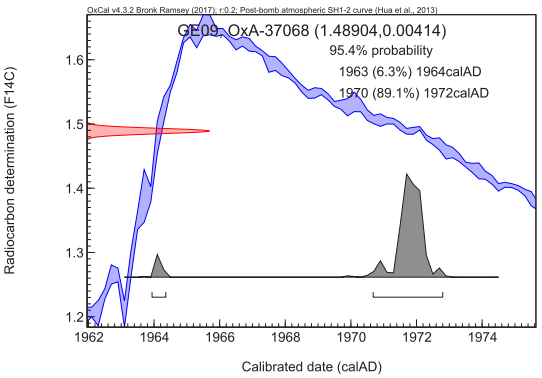

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
GE04, OxA-37063 (0.96221,0.00344)
95.4% probability
... (95.4%) 1651calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

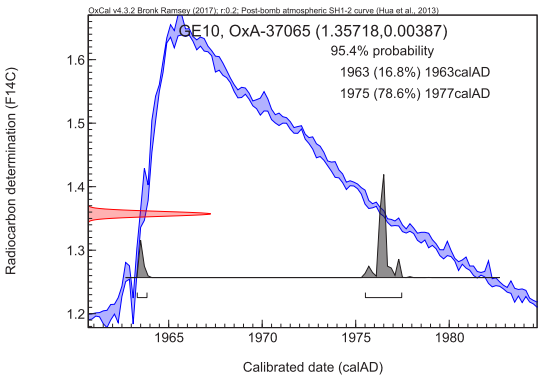

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
GE05, OxA-37064 (0.97243,0.0032)
95.4% probability
... (23.3%) 1695calAD
1726 (68.7%) 1806calAD
1947 (3.4%) 1955calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
GE06, OxA-37070 (1.57849,0.00429)
95.4% probability
1964 (13.0%) 1964calAD
1967 (82.4%) 1968calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
GE07, OxA-37067 (0.97683,0.00323)
95.4% probability
1667 (23.1%) 1713calAD
1717 (42.6%) 1815calAD
1833 (18.4%) 1892calAD
1923 (11.3%) 1955calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
GE08, OxA-37069 (1.3347,0.00401)
95.4% probability
1963 (3.7%) 1963calAD
1976 (91.7%) 1978calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
GE09, OxA-37068 (1.48904,0.00414)
95.4% probability
1963 (6.3%) 1964calAD
1970 (89.1%) 1972calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
GE10, OxA-37065 (1.35718,0.00387)
95.4% probability
1963 (16.8%) 1963calAD
1975 (78.6%) 1977calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

3.5 Ireland

One specimen was purchased in Ireland. This specimen gave a radiocarbon determination consistent with ivory being formed prior to 1947.

Table 5. Radiocarbon determination, stable carbon and nitrogen isotope compositions and 95.4% confidence interval of the calibrated ages for the worked ivory specimen purchased in Ireland.

Specimen	Laboratory code	$F^{14}C$	$\delta^{13}C$ / ‰	$\delta^{15}N$ / ‰	Calibrated age, 95.4% confidence interval / cal AD
IR0001 Carved tusk	OxA-36444	0.97445 ± 0.00259	-23.8	+9.7	1657–1955

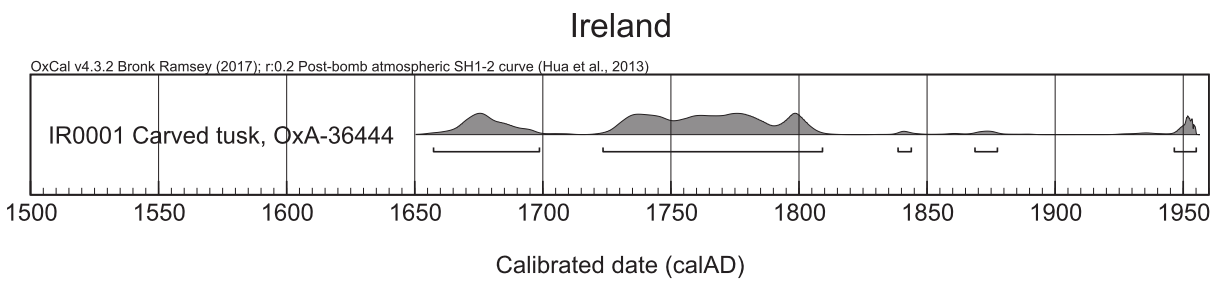


Figure 9. Probability distribution for the calibrated calendar ages of the worked ivory specimen purchased in Ireland. The brackets under the distribution show the 95.4% confidence interval.

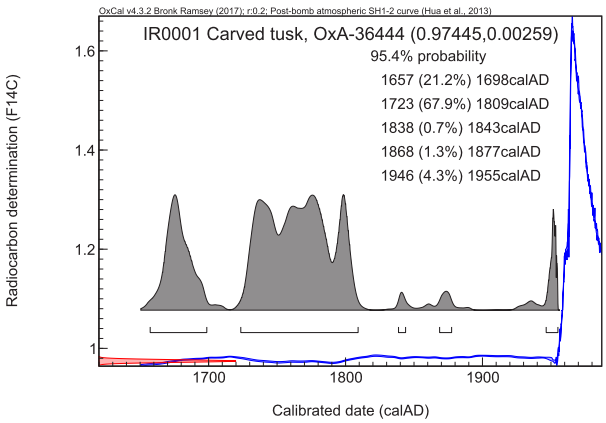


Figure 10. Calibration plot for the radiocarbon determination of the worked ivory specimen purchased in Ireland.

3.6 Italy

All four of the specimens purchased in Italy gave radiocarbon determinations consistent with the ivory being formed after 1947. The ivory in IT02 most likely formed between 1995 and 1998.

Table 6. Radiocarbon determinations, stable carbon and nitrogen isotope compositions and 95.4% confidence intervals of the calibrated ages for worked ivory specimens purchased in Italy.

Specimen	Laboratory code	$F^{14}C$	$\delta^{13}C$ / ‰	$\delta^{15}N$ / ‰	Calibrated age, 95.4% confidence interval / cal AD
IT01	OxA-37005	1.45508 ± 0.00408	-20.7	+6.9	1963–1964, 1972–1973
IT02	OxA-37032	1.11407 ± 0.00349	-21.5	+8.3	1958–1959, 1995–1998
IT03	OxA-37076	1.26870 ± 0.00381	-17.8	+15.1	1962–1963, 1980–1982
IT04	OxA-37004	1.55557 ± 0.00410	-8.1	+5.2	1964, 1968–1970

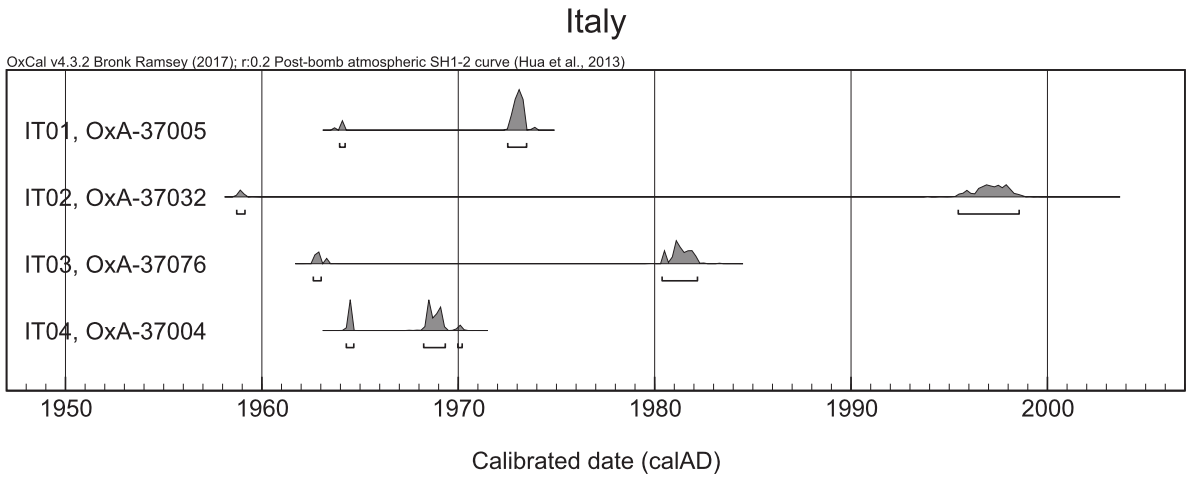
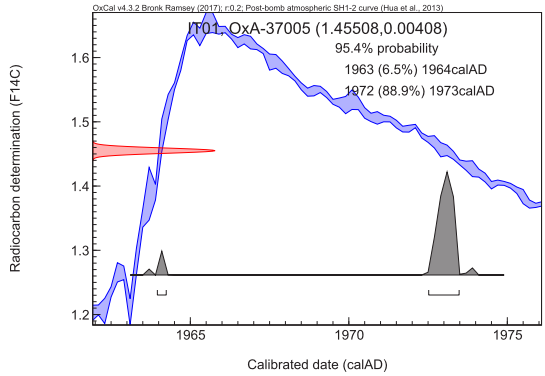
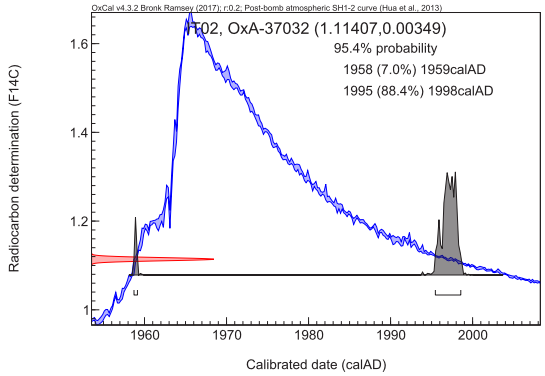
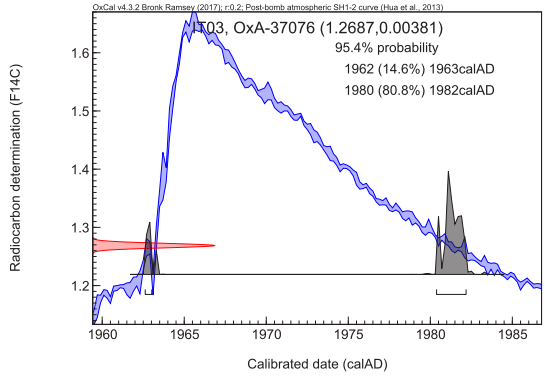


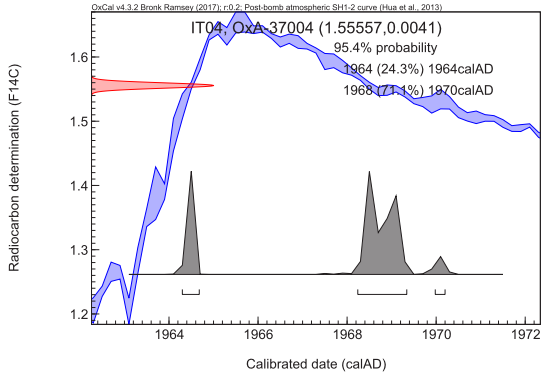
Figure 11. Probability distributions for the calibrated calendar ages of worked ivory specimens purchased in Italy. The brackets under each distribution show 95.4% confidence intervals.

Following page: Figure 12. Calibration plots for radiocarbon determinations of worked ivory specimens purchased in Italy.


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
IT01, OxA-37005 (1.45508,0.00408)
95.4% probability
1963 (6.5%) 1964calAD
1972 (88.9%) 1973calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
IT02, OxA-37032 (1.11407,0.00349)
95.4% probability
1958 (7.0%) 1959calAD
1995 (88.4%) 1998calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
IT03, OxA-37076 (1.2687,0.00381)
95.4% probability
1962 (14.6%) 1963calAD
1980 (80.8%) 1982calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
IT04, OxA-37004 (1.55557,0.0041)
95.4% probability
1964 (24.3%) 1964calAD
1968 (71.1%) 1970calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

3.7 Netherlands

13 of the 19 worked ivory specimens purchased in the Netherlands have radiocarbon ages consistent with the ivory being formed after 1947. Most of these specimens contain ivory likely formed during the 1970s, but four specimens contain ivory likely formed after 1990, one of which contains ivory likely formed between 2000 and 2003.

Table 7. Radiocarbon determinations, stable carbon and nitrogen isotope compositions and 95.4% confidence intervals of the calibrated ages for worked ivory specimens purchased in the Netherlands.

Specimen	Laboratory code	$F^{14}C$	$\delta^{13}C$ / ‰	$\delta^{15}N$ / ‰	Calibrated age, 95.4% confidence interval / cal AD
N01	OxA-36879	0.99332 ± 0.00275	-21.2	+6.1	1714–1956
N02	OxA-36917	1.11989 ± 0.00306	-12.9	+4.3	1958–1959, 1994–1998
N03	OxA-36880	1.27007 ± 0.00340	-25.5	+10.8	1962–1963, 1980–1982
N04	OxA-36918	0.98229 ± 0.00277	-22.6	+9.3	1688–1950
N05	OxA-36881	1.09110 ± 0.00309	-8.4	+6.9	2000–2003
N06	OxA-36919	1.27512 ± 0.00329	-22.0	+6.9	1962–1963, 1980–1982
N07a	OxA-37036	1.12443 ± 0.0034	-12.1	+5.8	1958–1959, 1993–1996
N07b	OxA-37037	1.12425 ± 0.00354	-11.1	+6.0	1958–1959, 1993–1997
N07b (duplicate measurement)	OxA-37038	1.12819 ± 0.00337	-10.9	+6.0	1958–1959, 1993–1996
N08	OxA-37042	0.96986 ± 0.00300	-19.8	+9.2	1645–1954
N09	OxA-36878	1.3424 ± 0.00347	-27.2	+10.9	1963–1964, 1976–1978
N10	OxA-37040	0.96577 ± 0.00298	-20.9	+7.1	1513–1954
N11	OxA-37041	1.38153 ± 0.00415	-12.4	+7.3	1963–1964, 1975–1976
N12	OxA-37003	1.26246 ± 0.00361	-15.2	+7.0	1962–1963, 1980–1982
N13	OxA-36996	0.98018 ± 0.00302	-10.2	+8.6	1676–1954
N14	OxA-36997	0.97717 ± 0.00312	-11.5	+8.0	1667–1955
N15	OxA-36877	1.34737 ± 0.00345	-26.5	+11.6	1963, 1976–1978
N16	OxA-37007	1.40489 ± 0.0040	-12.8	+4.0	1963–1964, 1974–1975
N17	OxA-37044	1.35708 ± 0.00377	-12.8	+7.5	1963, 1975–1977
N18	OxA-37051	1.46404 ± 0.00399	-15.0	+6.7	1963–1964, 1972–1973

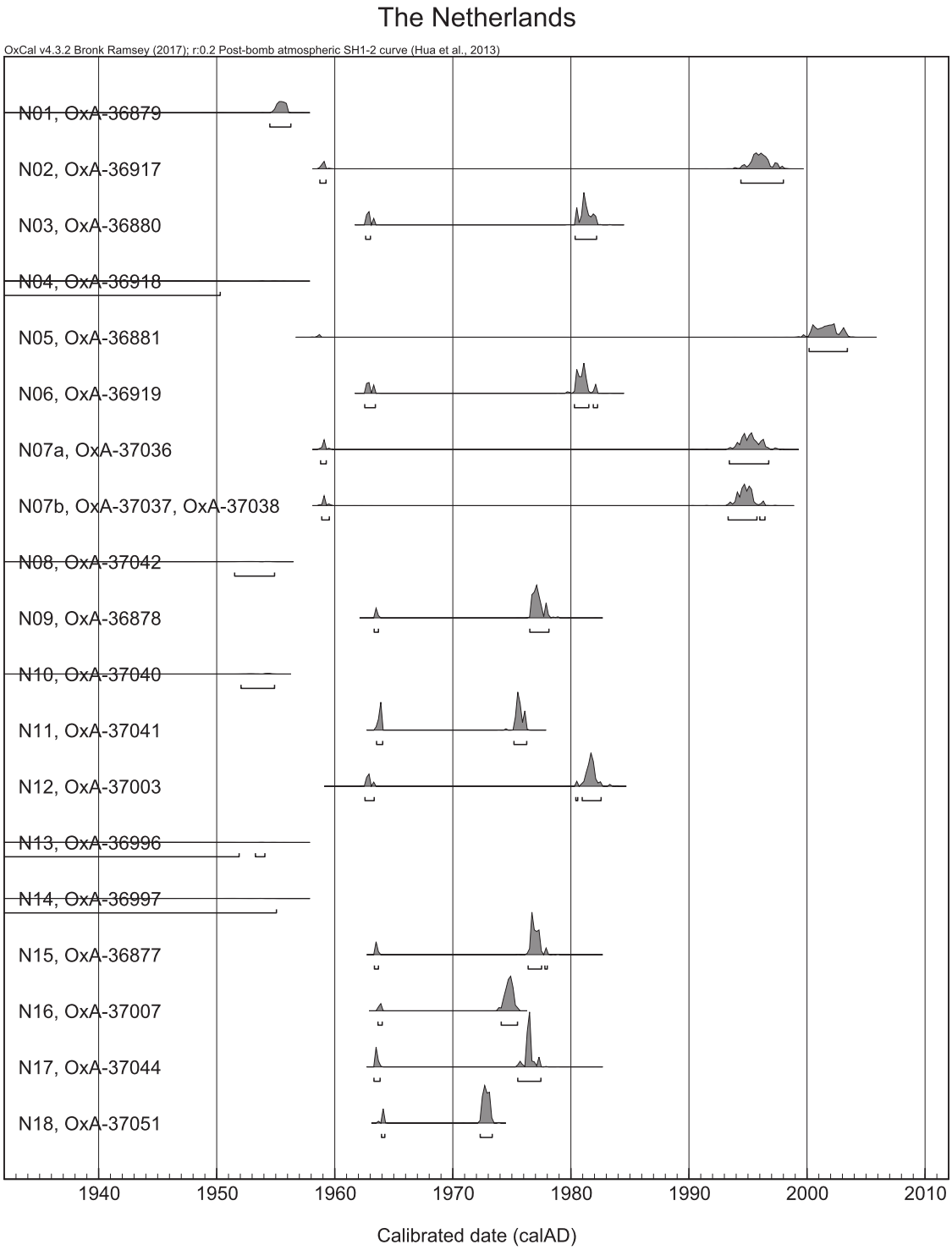
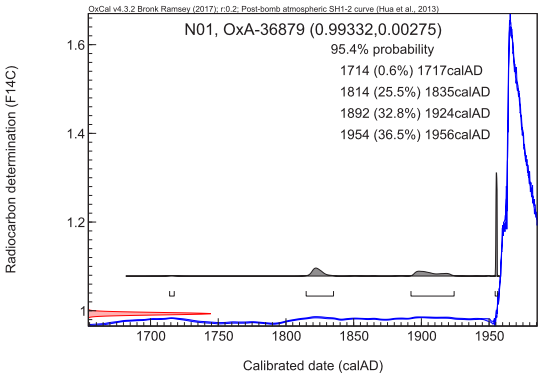
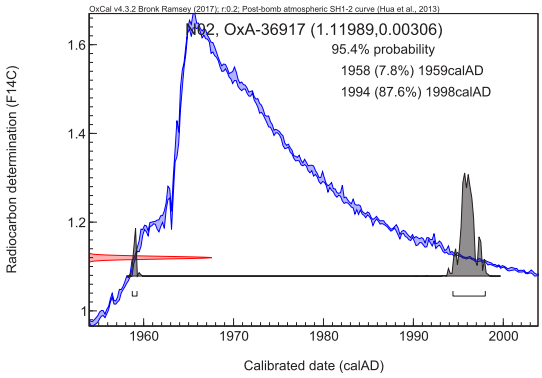
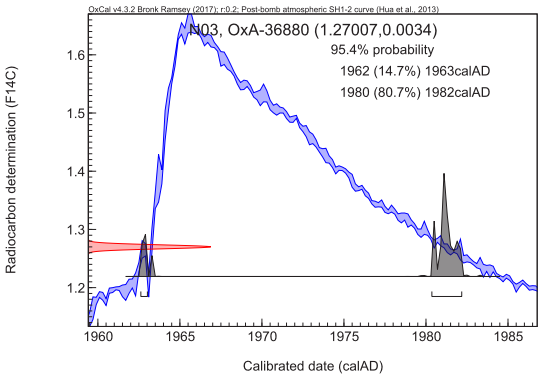


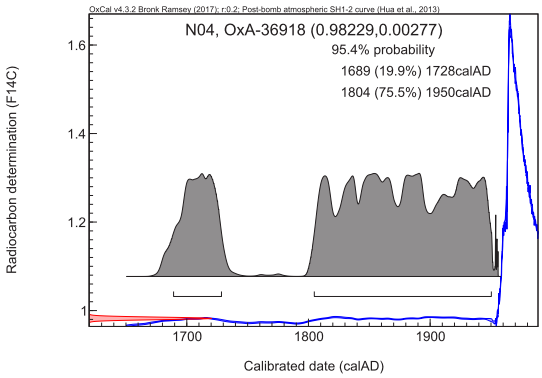
Figure 13. Probability distributions for the calibrated calendar ages of worked ivory specimens purchased in the Netherlands. The brackets under each distribution show 95.4% confidence intervals.

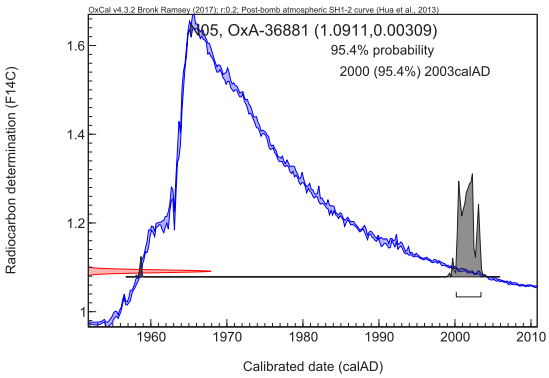
Following two pages: Figure 14. Calibration plots for radiocarbon determinations of worked ivory specimens purchased in the Netherlands.

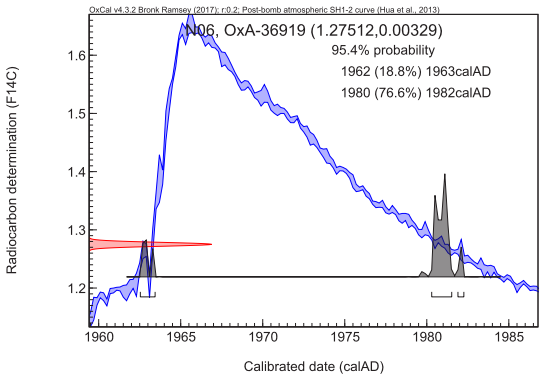

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
N01, OxA-36879 (0.99332,0.00275)
95.4% probability
1714 (0.6%) 1717calAD
1814 (25.5%) 1835calAD
1892 (32.8%) 1924calAD
1954 (36.5%) 1956calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

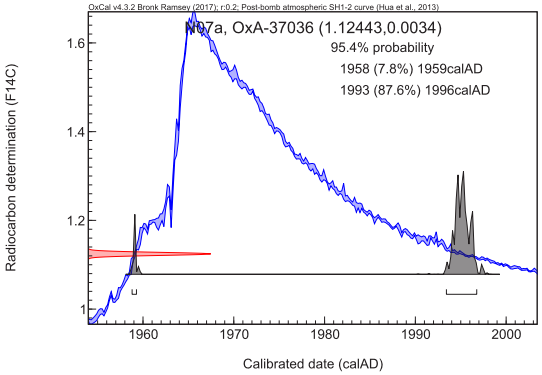

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
N02, OxA-36917 (1.11989,0.00306)
95.4% probability
1958 (7.8%) 1959calAD
1994 (87.6%) 1998calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

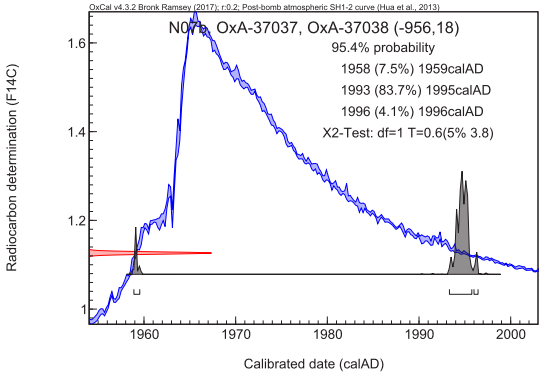

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
N03, OxA-36880 (1.27007,0.0034)
95.4% probability
1962 (14.7%) 1963calAD
1980 (80.7%) 1982calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

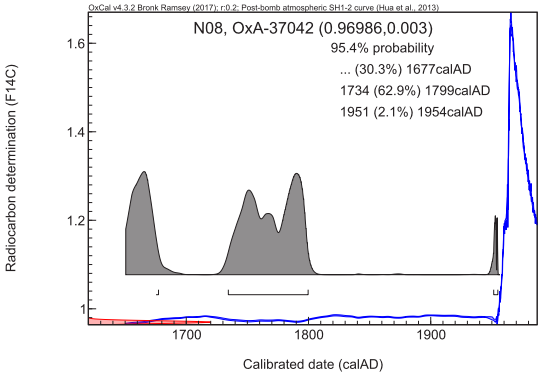

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
N04, OxA-36918 (0.98229,0.00277)
95.4% probability
1689 (19.9%) 1728calAD
1804 (75.5%) 1950calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

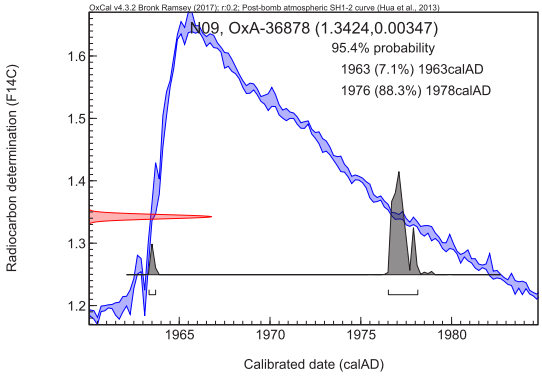

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
N05, OxA-36881 (1.0911,0.00309)
95.4% probability
2000 (95.4%) 2003calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

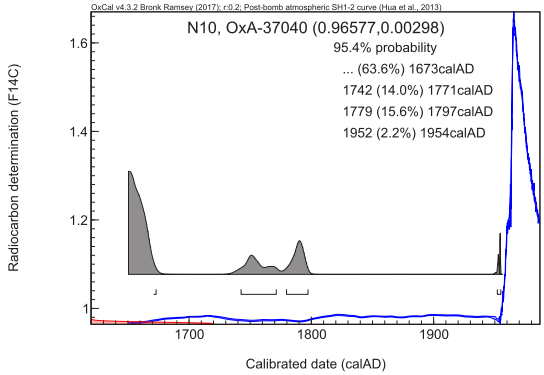

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
N06, OxA-36919 (1.27512,0.00329)
95.4% probability
1962 (18.8%) 1963calAD
1980 (76.6%) 1982calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

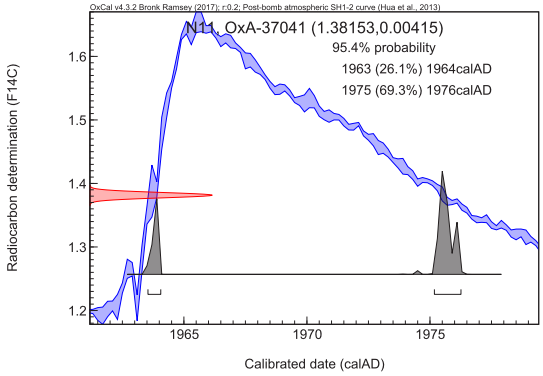

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
N07a, OxA-37036 (1.12443,0.0034)
95.4% probability
1958 (7.8%) 1959calAD
1993 (87.6%) 1996calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

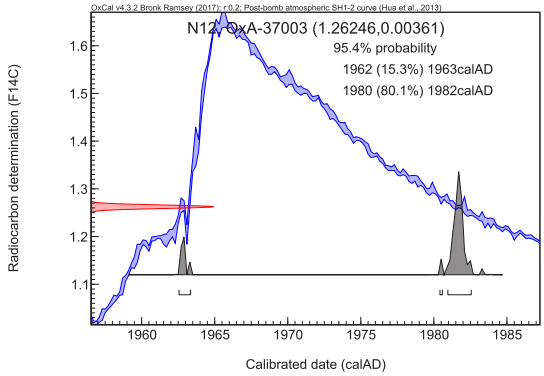

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
N07b, OxA-37037, OxA-37038 (-956,18)
95.4% probability
1958 (7.5%) 1959calAD
1993 (83.7%) 1995calAD
1996 (4.1%) 1996calAD
X2-Test: df=1 T=0.6(5% 3.8)
Radiocarbon determination (F14C)
Calibrated date (calAD)

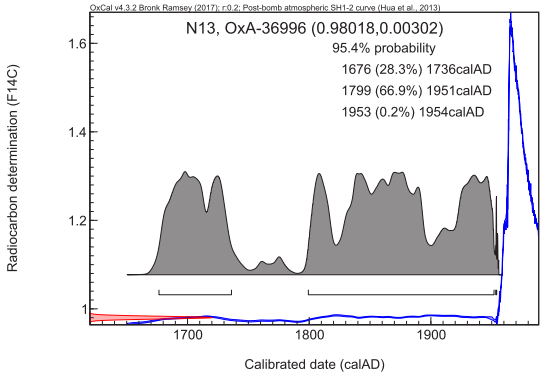

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
N08, OxA-37042 (0.96986,0.003)
95.4% probability
... (30.3%) 1677calAD
1734 (62.9%) 1799calAD
1951 (2.1%) 1954calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

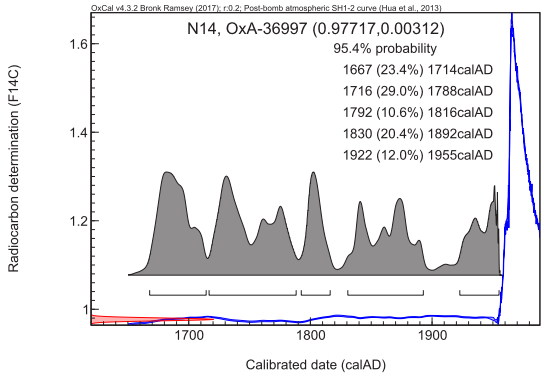

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
N09, OxA-36878 (1.3424,0.00347)
95.4% probability
1963 (7.1%) 1963calAD
1976 (88.3%) 1978calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

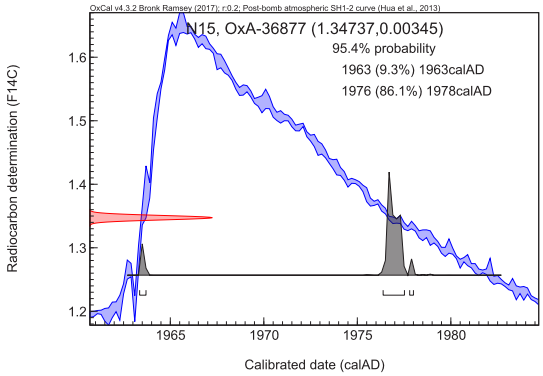

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
N10, OxA-37040 (0.96577,0.00298)
95.4% probability
... (63.6%) 1673calAD
1742 (14.0%) 1771calAD
1779 (15.6%) 1797calAD
1952 (2.2%) 1954calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

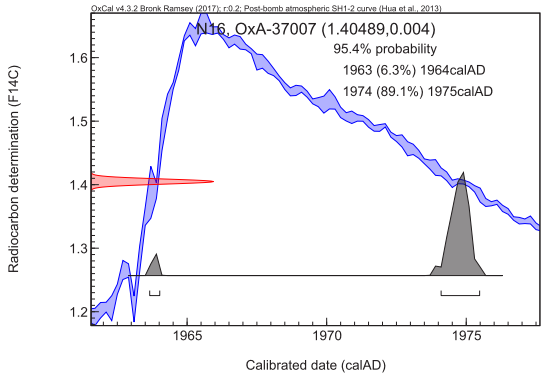

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
N11, OxA-37041 (1.38153,0.00415)
95.4% probability
1963 (26.1%) 1964calAD
1975 (69.3%) 1976calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

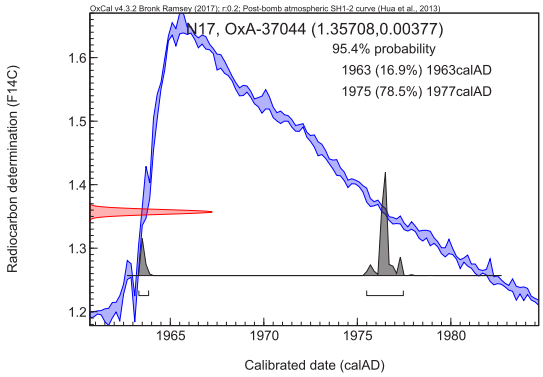

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
N12, OxA-37003 (1.26246,0.00361)
95.4% probability
1962 (15.3%) 1963calAD
1980 (80.1%) 1982calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

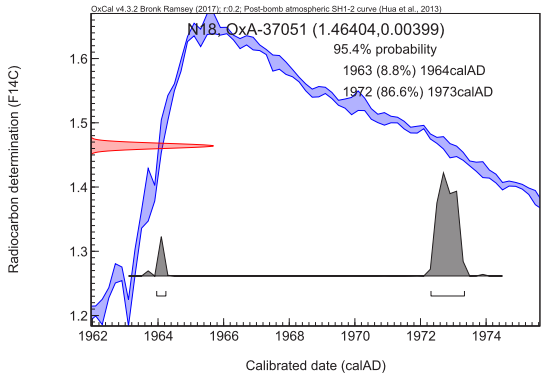

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
N13, OxA-36996 (0.98018,0.00302)
95.4% probability
1676 (28.3%) 1736calAD
1799 (66.9%) 1951calAD
1953 (0.2%) 1954calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
N14, OxA-36997 (0.97717,0.00312)
95.4% probability
1667 (23.4%) 1714calAD
1716 (29.0%) 1788calAD
1792 (10.6%) 1816calAD
1830 (20.4%) 1892calAD
1922 (12.0%) 1955calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
N15, OxA-36877 (1.34737,0.00345)
95.4% probability
1963 (9.3%) 1963calAD
1976 (86.1%) 1978calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
N16, OxA-37007 (1.40489,0.004)
95.4% probability
1963 (6.3%) 1964calAD
1974 (89.1%) 1975calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
N17, OxA-37044 (1.35708,0.00377)
95.4% probability
1963 (16.9%) 1963calAD
1975 (78.5%) 1977calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
N18, OxA-37051 (1.46404,0.00399)
95.4% probability
1963 (8.8%) 1964calAD
1972 (86.6%) 1973calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

3.8 Portugal

10 of 12 specimens purchased in Portugal contain ivory with radiocarbon ages consistent with the ivory being formed after 1947.

The calibration curves used to calculate calibrated calendar ages from radiocarbon determinations are updated periodically. The most recent curve extends to 2010. The radiocarbon determination for the ivory in specimen PO17 is consistent with the later of the two post-bomb calibrated age ranges being after 2010, which is more recent than the latest data in the calibration curve. For this reason, only one post-bomb calibrated age range is provided rather than the usual two.

A second specimen with a very recent age is PO19, the ivory in which was likely formed between 2000 and 2004.

Table 8. Radiocarbon determinations, stable carbon and nitrogen isotope compositions and 95.4% confidence intervals of the calibrated ages for worked ivory specimens purchased in Portugal.

Specimen	Laboratory code	$F^{14}C$	$\delta^{13}C$ / ‰	$\delta^{15}N$ / ‰	Calibrated age, 95.4% confidence interval / cal AD
PO01	OxA-37010	1.32228 ± 0.00402	-10.8	+4.4	1977–1979
PO02	OxA-37013	1.24406 ± 0.00376	-28.2	+11.2	1962, 1982–1984
PO03	OxA-37015	1.26926 ± 0.00375	-25.6	+9.3	1962–1963, 1980–1982
PO04	OxA-37018	1.35542 ± 0.00390	-20.7	+4.7	1963, 1975–1977
PO05	OxA-37017	1.33391 ± 0.00382	-24.3	+8.5	1963, 1976–1978
PO11	OxA-37011	1.37168 ± 0.00402	-16.0	+8.1	1963, 1975–1976
PO12	OxA-37014	1.46968 ± 0.00407	-21.9	+8.4	1964, 1972–1973
PO13	OxA-37016	1.38319 ± 0.00394	-22.2	+8.6	1963–1964, 1975–1976
PO14	OxA-37019	0.97958 ± 0.00322	-10.6	+8.2	1673–1955
PO17	OxA-37012	1.0303 ± 0.00334	-21.3	+7.6	1956–1957, (post-2010)
PO18	OxA-37053	0.97848 ± 0.00323	-25.1	+10.0	1670–1955
PO19	OxA-37057	1.08508 ± 0.00328	-10.3	+8.2	1958, 2000–2004

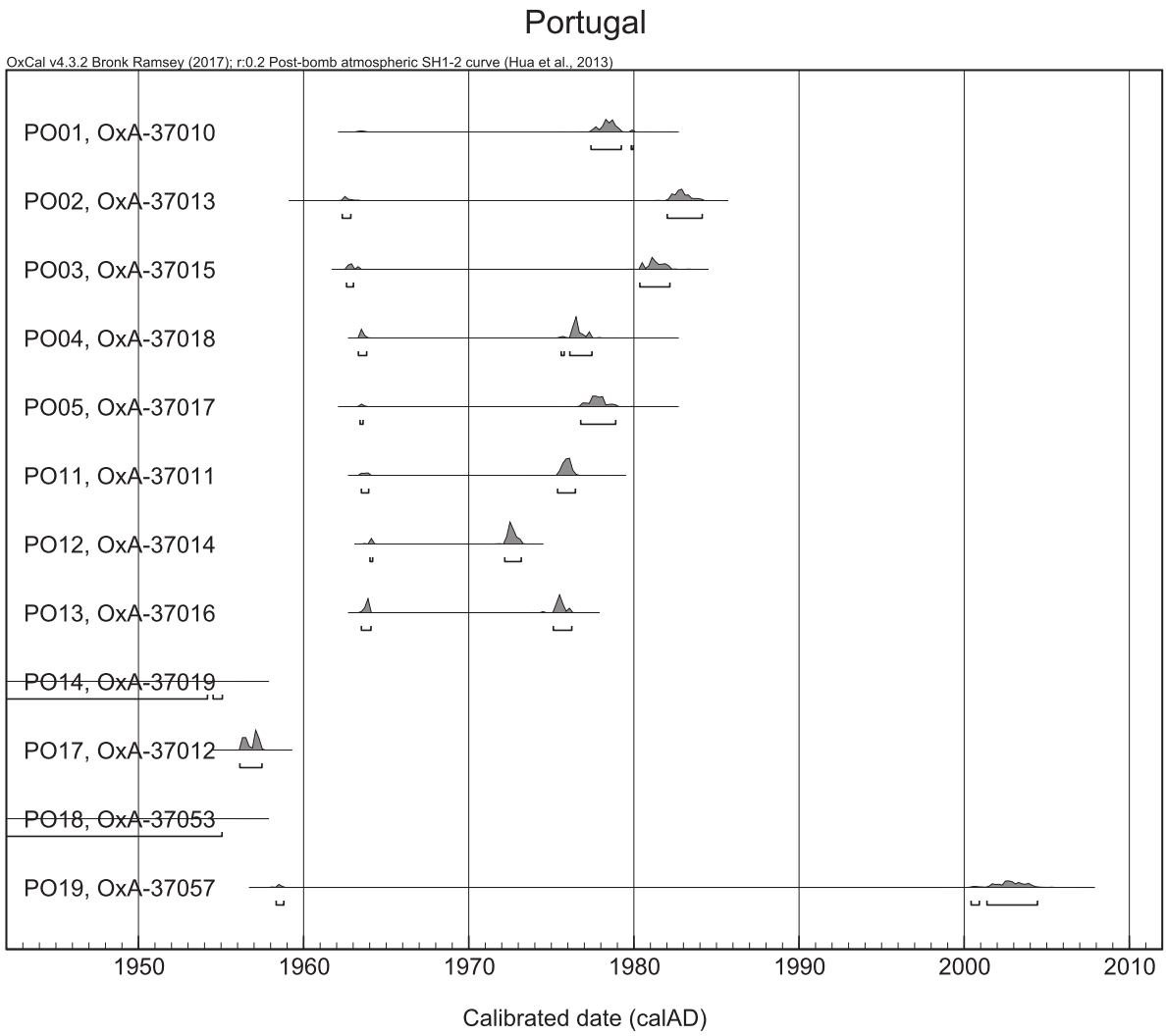
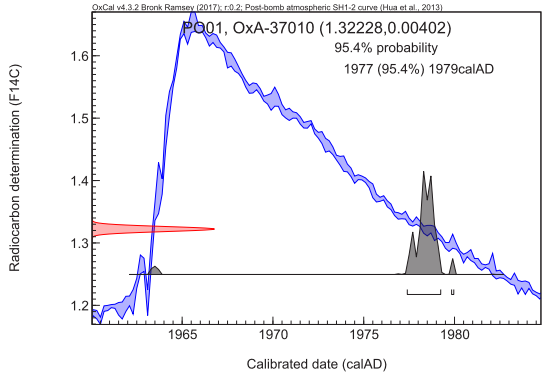
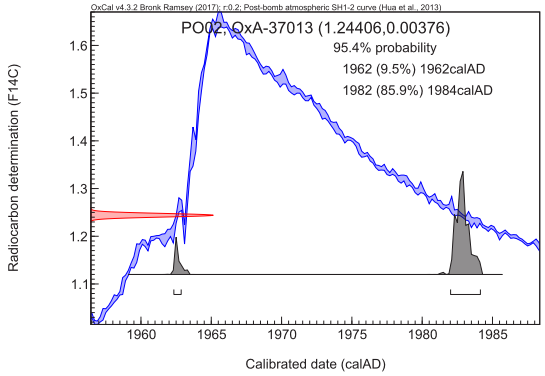
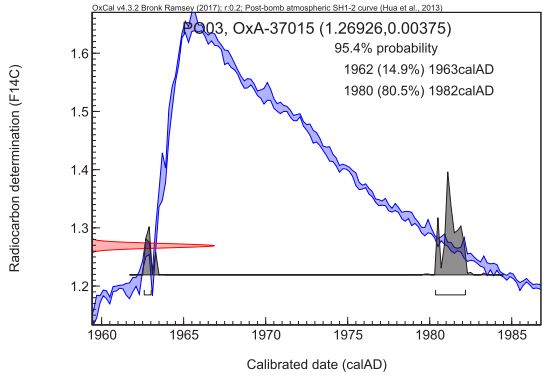


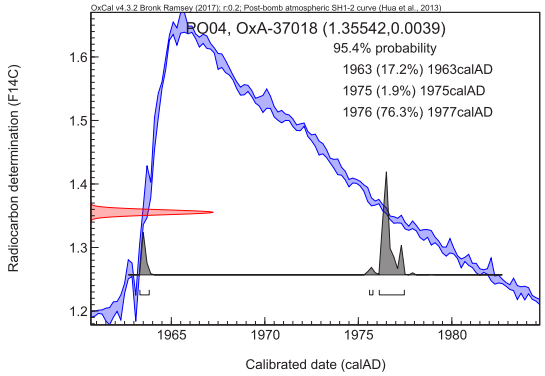
Figure 15. Probability distributions for the calibrated calendar ages of worked ivory specimens purchased in Portugal. The brackets under each distribution show 95.4% confidence intervals.

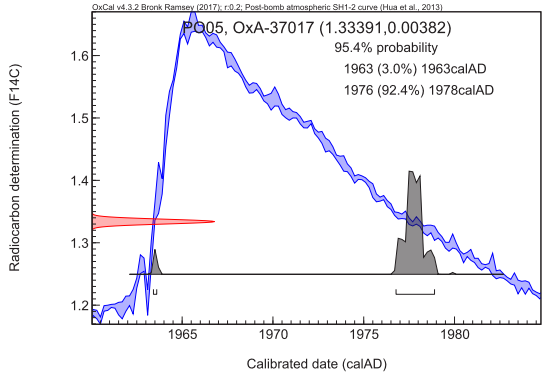
Following two pages: Figure 16. Calibration plots for radiocarbon determinations of worked ivory specimens purchased in Portugal.

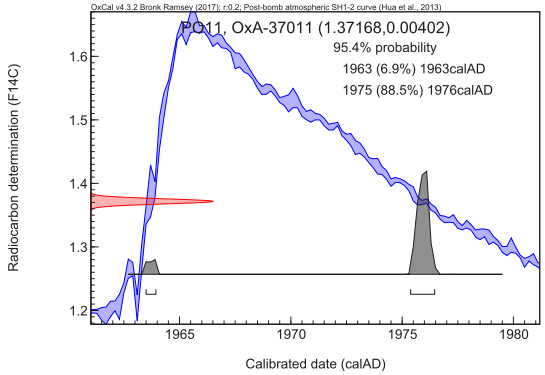

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
PO01, OxA-37010 (1.32228,0.00402)
95.4% probability
1977 (95.4%) 1979calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

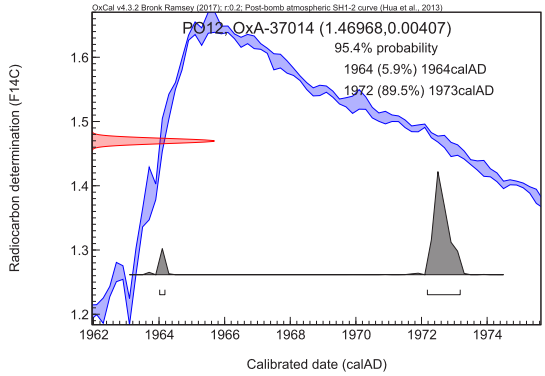

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
PO02, OxA-37013 (1.24406,0.00376)
95.4% probability
1962 (9.5%) 1962calAD
1982 (85.9%) 1984calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

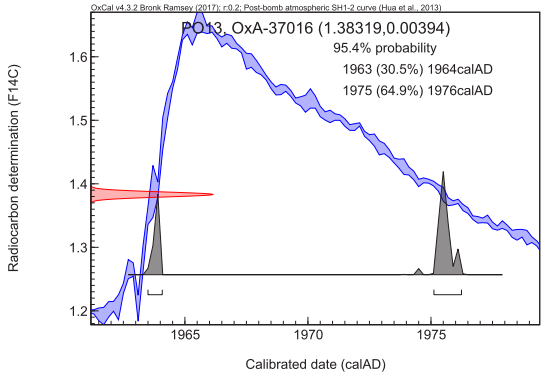

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
PO03, OxA-37015 (1.26926,0.00375)
95.4% probability
1962 (14.9%) 1963calAD
1980 (80.5%) 1982calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

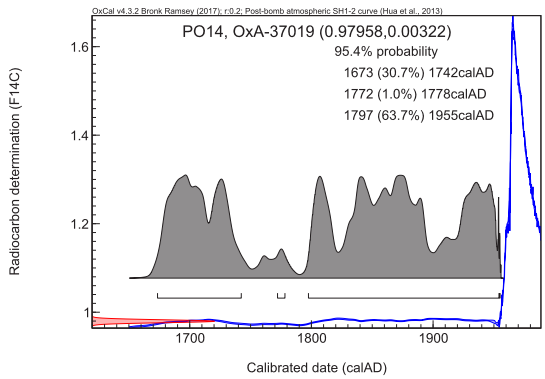

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
PO04, OxA-37018 (1.35542,0.0039)
95.4% probability
1963 (17.2%) 1963calAD
1975 (1.9%) 1975calAD
1976 (76.3%) 1977calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

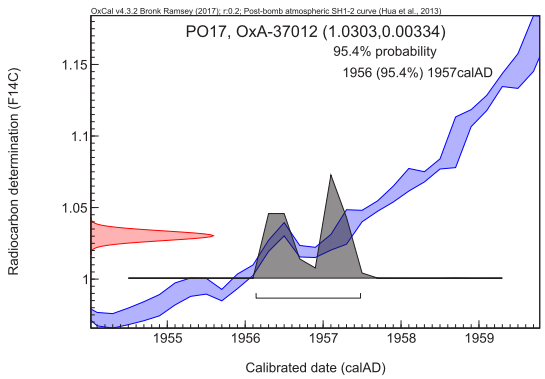

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
PO05, OxA-37017 (1.33391,0.00382)
95.4% probability
1963 (3.0%) 1963calAD
1976 (92.4%) 1978calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

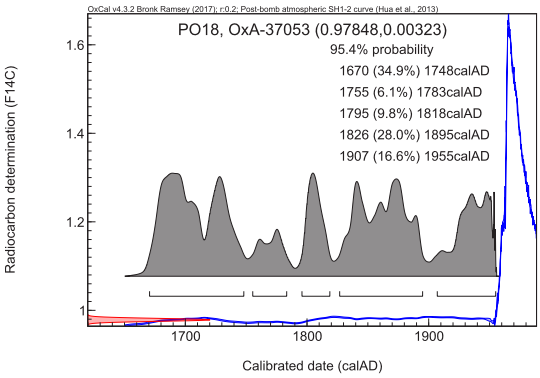

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
PO11, OxA-37011 (1.37168,0.00402)
95.4% probability
1963 (6.9%) 1963calAD
1975 (88.5%) 1976calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

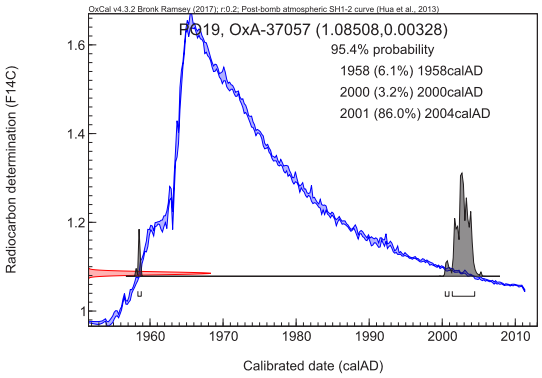

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
PO12, OxA-37014 (1.46968,0.00407)
95.4% probability
1964 (5.9%) 1964calAD
1972 (89.5%) 1973calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
PO13, OxA-37016 (1.38319,0.00394)
95.4% probability
1963 (30.5%) 1964calAD
1975 (64.9%) 1976calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
PO14, OxA-37019 (0.97958,0.00322)
95.4% probability
1673 (30.7%) 1742calAD
1772 (1.0%) 1778calAD
1797 (63.7%) 1955calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
PO17, OxA-37012 (1.0303,0.00334)
95.4% probability
1956 (95.4%) 1957calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
PO18, OxA-37053 (0.97848,0.00323)
95.4% probability
1670 (34.9%) 1748calAD
1755 (6.1%) 1783calAD
1795 (9.8%) 1818calAD
1826 (28.0%) 1895calAD
1907 (16.6%) 1955calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
PO19, OxA-37057 (1.08508,0.00328)
95.4% probability
1958 (6.1%) 1958calAD
2000 (3.2%) 2000calAD
2001 (86.0%) 2004calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

3.9 Spain

All 18 of the worked ivory specimens purchased in Spain display radiocarbon determinations inconsistent with the ivory being formed before 1947. The likely age of specimen S12 is more recent than the most recent limit of the latest calibration curve, which only extends to 2010. For this reason, only one post-bomb calibrated age range can be provided rather than the usual two.

Table 9. Radiocarbon determinations, stable carbon and nitrogen isotope compositions and 95.4% confidence intervals of the calibrated ages for worked ivory specimens purchased in Spain.

Specimen	Laboratory code	$F^{14}C$	$\delta^{13}C$ / ‰	$\delta^{15}N$ / ‰	Calibrated age, 95.4% confidence interval / cal AD
S01	OxA-37028	1.38457 ± 0.00386	-26.4	+10.8	1963–1964, 1975–1976
S02	OxA-37000	1.19419 ± 0.00372	-27.3	+9.9	1959–1963, 1985–1988
S03	OxA-36980	1.4908 ± 0.00357	-26.2	+9.6	1963–1964, 1970–1972
S04	OxA-37026	1.31113 ± 0.00366	-28.6	+9.4	1963–1963, 1978–1980
S05	OxA-36981	1.49509 ± 0.00352	-8.9	+7.4	1964, 1970–1972
S06	OxA-36979	1.39237 ± 0.00359	-27.1	+8.4	1963–1964, 1974–1975
S07	OxA-36977	1.16985 ± 0.00298	-21.3	+5.3	1959–1961, 1988–1992
S08	OxA-36986	1.56967 ± 0.00369	-22.9	+7.0	1964, 1967–1968
S09	OxA-37031	1.58620 ± 0.00427	-17.2	+6.7	1964, 1967–1968
S11	OxA-36982	1.19392 ± 0.00310	-18.0	+10.7	1959–1962, 1985–1988
S12	OxA-37027	1.03211 ± 0.00317	-21.2	+6.8	1956–1957, (post-2010)
S13	OxA-36998	1.39074 ± 0.00388	-20.0	+10.5	1963–1964, 1974–1975
S14	OxA-36984	1.16689 ± 0.00302	-20.3	+6.9	1959–1960, 1988–1992
S15	OxA-36976	1.27810 ± 0.00319	-25.5	+11.9	1962–1963, 1980–1982
S17	OxA-36978	1.30601 ± 0.00323	-24.6	+12.4	1963, 1978–1980
S18a	OxA-37002	1.10358 ± 0.00341	-18.4	+6.8	1958–1959, 1997–2001
S18b	OxA-37039	1.09630 ± 0.00352	-15.2	+7.5	1998–2003
S19	OxA-37001	1.58333 ± 0.00416	-11.8	+5.0	1964, 1967–1968

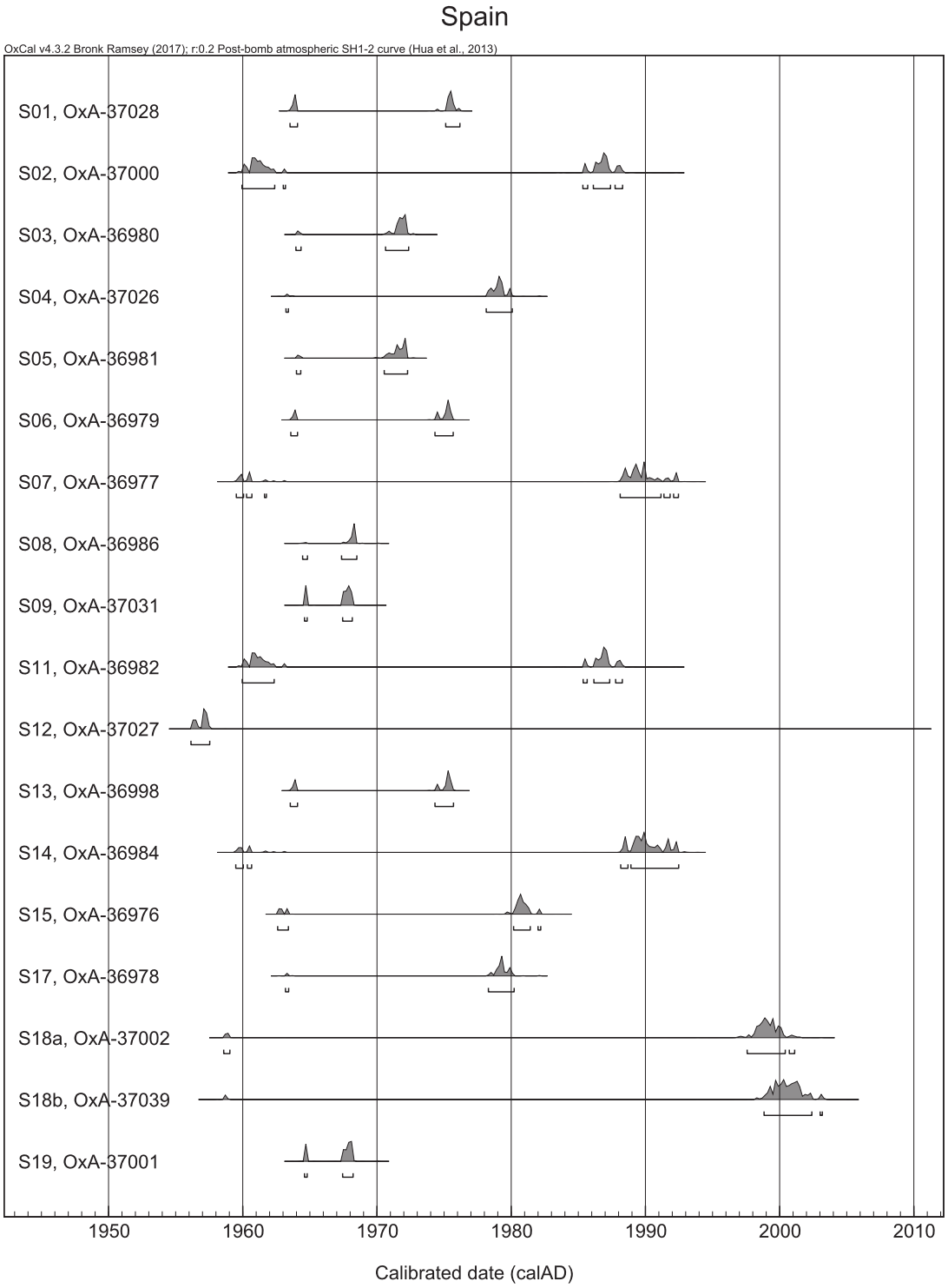
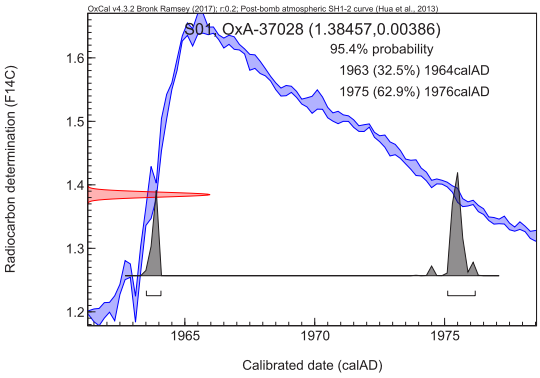
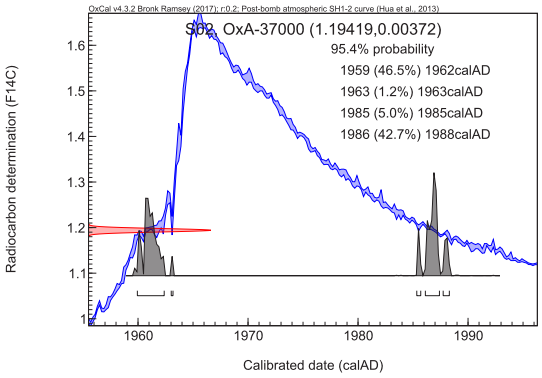
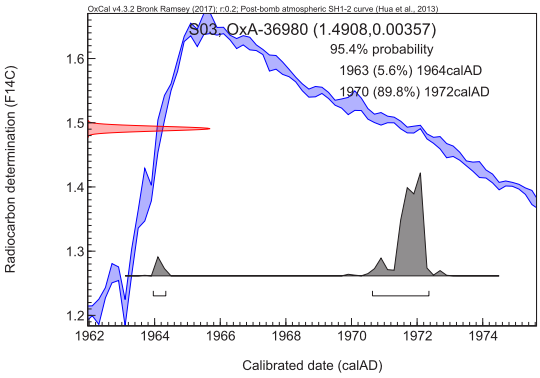


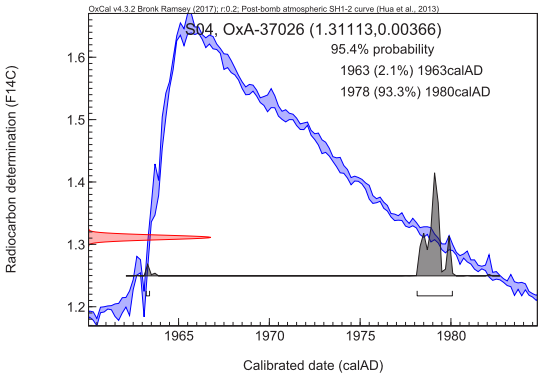
Figure 17. Probability distributions for the calibrated calendar ages of worked ivory specimens purchased in Spain. The brackets under each distribution show 95.4% confidence intervals.

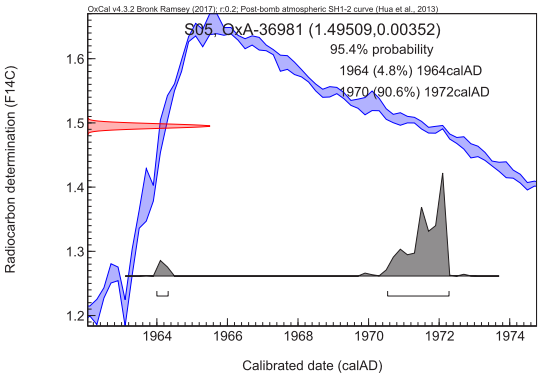
Following two pages: Figure 18. Calibration plots for radiocarbon determinations of worked ivory specimens purchased in Spain.

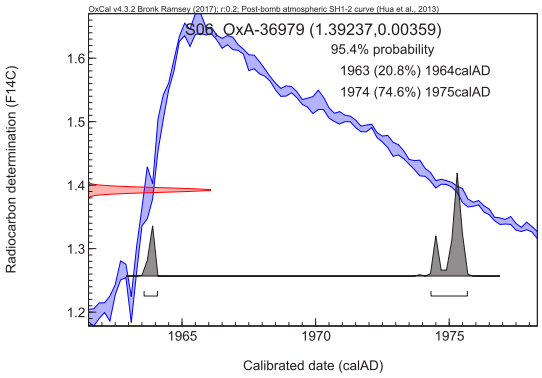

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
S01, OxA-37028 (1.38457,0.00386)
95.4% probability
1963 (32.5%) 1964calAD
1975 (62.9%) 1976calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

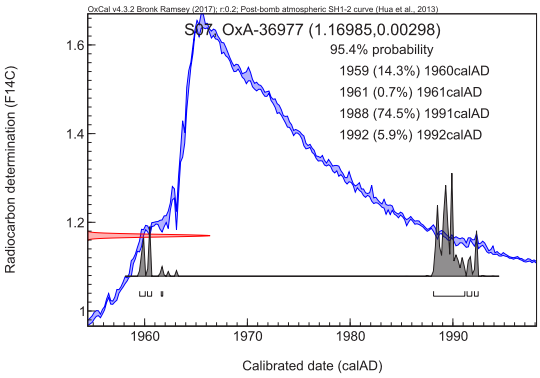

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
S02, OxA-37000 (1.19419,0.00372)
95.4% probability
1959 (46.5%) 1962calAD
1963 (1.2%) 1963calAD
1985 (5.0%) 1985calAD
1986 (42.7%) 1988calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

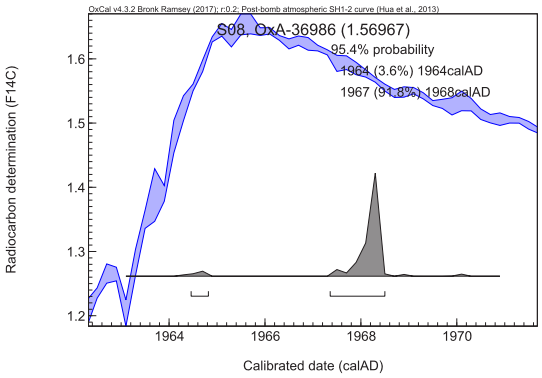

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
S03, OxA-36980 (1.4908,0.00357)
95.4% probability
1963 (5.6%) 1964calAD
1970 (89.8%) 1972calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

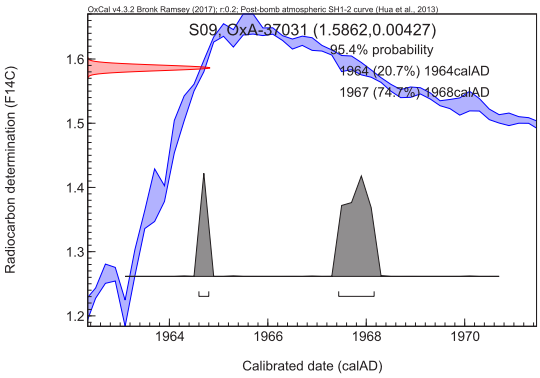

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
S04, OxA-37026 (1.31113,0.00366)
95.4% probability
1963 (2.1%) 1963calAD
1978 (93.3%) 1980calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

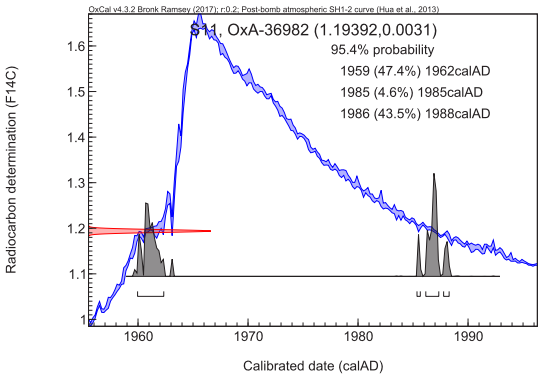

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
S05, OxA-36981 (1.49509,0.00352)
95.4% probability
1964 (4.8%) 1964calAD
1970 (90.6%) 1972calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

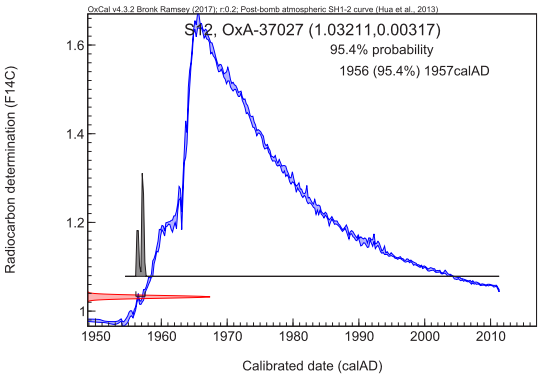

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
S06, OxA-36979 (1.39237,0.00359)
95.4% probability
1963 (20.8%) 1964calAD
1974 (74.6%) 1975calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

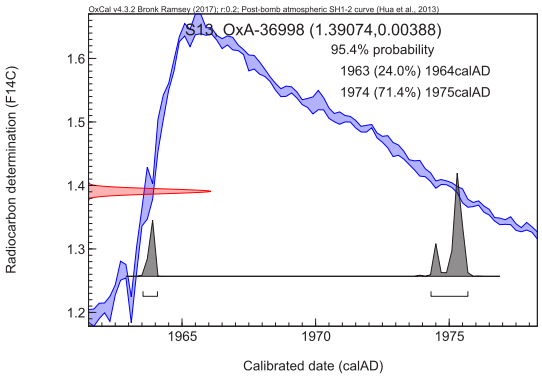

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
S07, OxA-36977 (1.16985,0.00298)
95.4% probability
1959 (14.3%) 1960calAD
1961 (0.7%) 1961calAD
1988 (74.5%) 1991calAD
1992 (5.9%) 1992calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

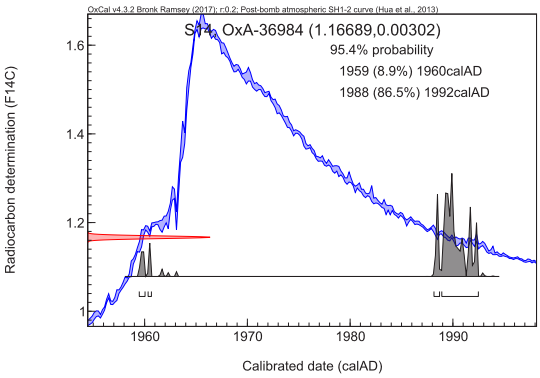

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
S08, OxA-36986 (1.56967)
95.4% probability
1964 (3.6%) 1964calAD
1967 (91.8%) 1968calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

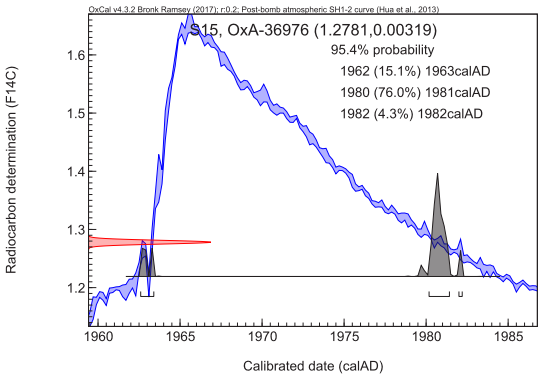

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
S09, OxA-37031 (1.5862,0.00427)
95.4% probability
1964 (20.7%) 1964calAD
1967 (74.7%) 1968calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

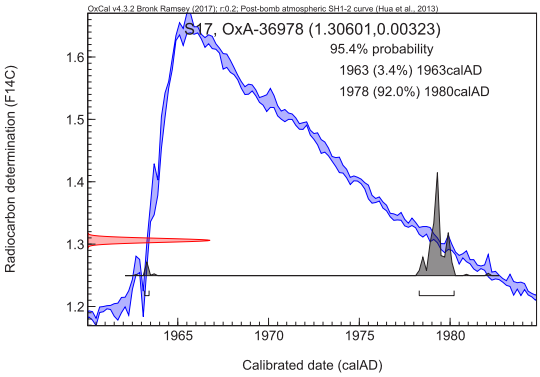

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
S11, OxA-36982 (1.19392,0.0031)
95.4% probability
1959 (47.4%) 1962calAD
1985 (4.6%) 1985calAD
1986 (43.5%) 1988calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

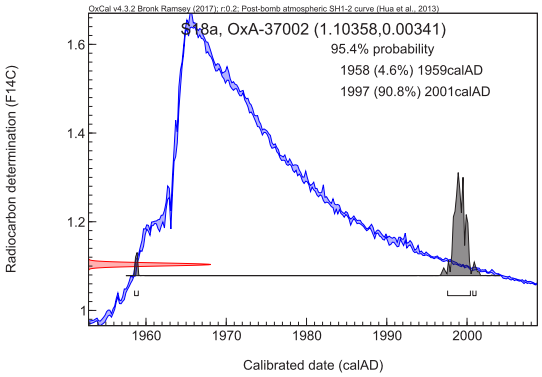

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
S12, OxA-37027 (1.03211,0.00317)
95.4% probability
1956 (95.4%) 1957calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

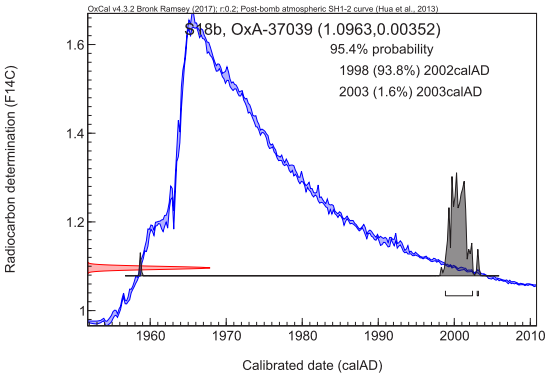

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
S13, OxA-36998 (1.39074,0.00388)
95.4% probability
1963 (24.0%) 1964calAD
1974 (71.4%) 1975calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

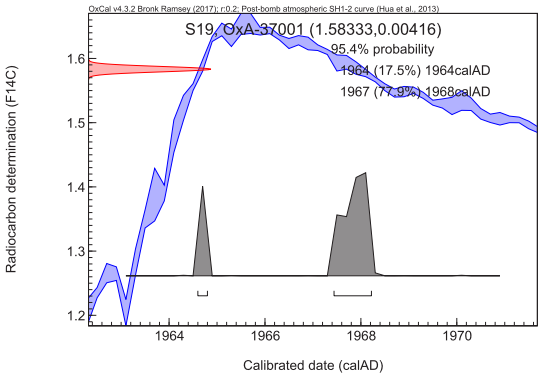

OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
S14, OxA-36984 (1.16689,0.00302)
95.4% probability
1959 (8.9%) 1960calAD
1988 (86.5%) 1992calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
S15, OxA-36976 (1.2781,0.00319)
95.4% probability
1962 (15.1%) 1963calAD
1980 (76.0%) 1981calAD
1982 (4.3%) 1982calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
S17, OxA-36978 (1.30601,0.00323)
95.4% probability
1963 (3.4%) 1963calAD
1978 (92.0%) 1980calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
S18a, OxA-37002 (1.10358,0.00341)
95.4% probability
1958 (4.6%) 1959calAD
1997 (90.8%) 2001calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
S18b, OxA-37039 (1.0963,0.00352)
95.4% probability
1998 (93.8%) 2002calAD
2003 (1.6%) 2003calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
S19, OxA-37001 (1.58333,0.00416)
95.4% probability
1964 (17.5%) 1964calAD
1967 (77.9%) 1968calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

3.10 United Kingdom

One of the five worked ivory specimens purchased in the UK has a radiocarbon determination which is not consistent with it being formed prior to 1947.

Table 10. Radiocarbon determinations, stable carbon and nitrogen isotope compositions and 95.4% confidence intervals of the calibrated ages for worked ivory specimens purchased in the United Kingdom.

Specimen	Laboratory code	$F^{14}C$	$\delta^{13}C$ / ‰	$\delta^{15}N$ / ‰	Calibrated age, 95.4% confidence interval / cal AD
UK0002 Glove stretcher	OxA-36445	0.98449 ± 0.00273	-22.6	+7.5	1697–1949
UK0004 Knife	OxA-36318	0.99914 ± 0.00306	-9.2	+12.0	1954–1956
UK0005 Small elephant	OxA-36319	0.97195 ± 0.00290	-18.9	+9.9	1650–1804
UK0012 Bracelet	OxA-36452	0.98609 ± 0.00277	-23.9	+8.8	1697–1955
UK0013 Knife	OxA-36453	0.97765 ± 0.00290	-25.0	+12.9	1668–1955

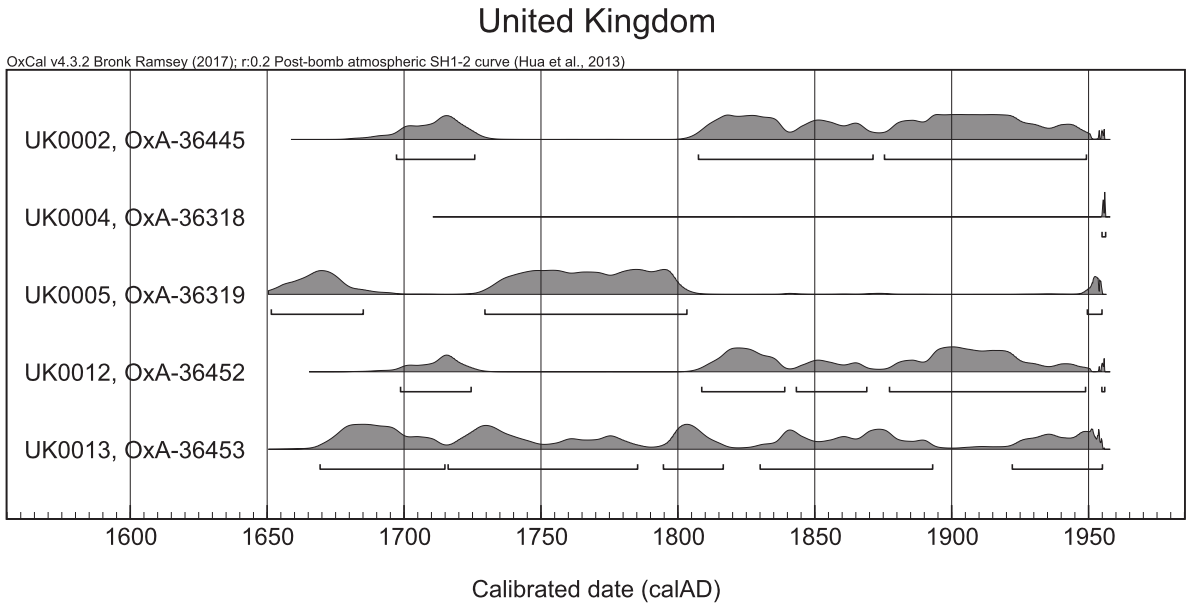
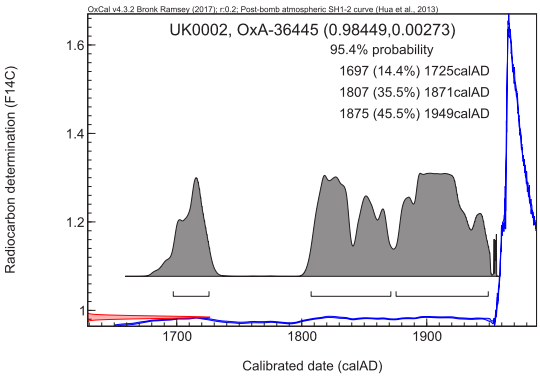
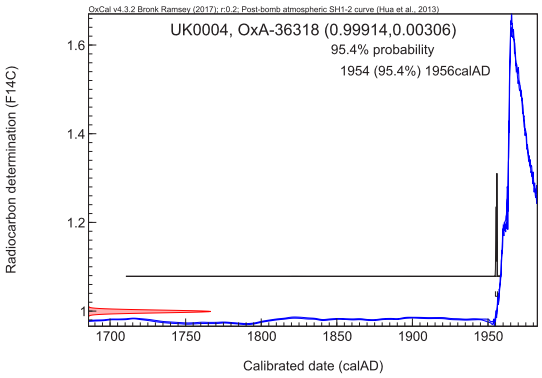
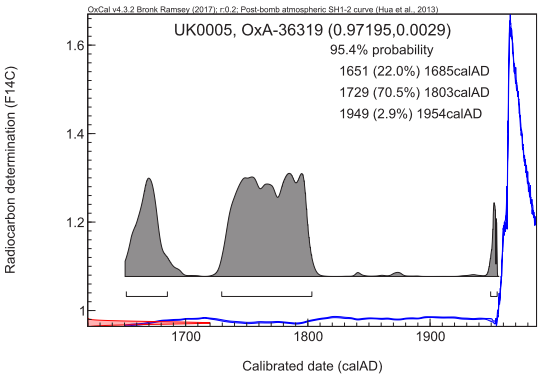


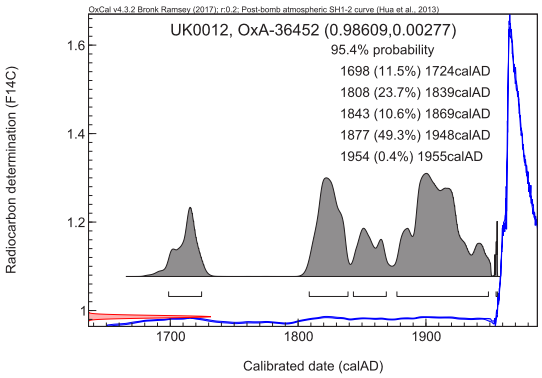
Figure 19. Probability distributions for the calibrated calendar ages of worked ivory specimens purchased in the United Kingdom. The brackets under each distribution show 95.4% confidence intervals.

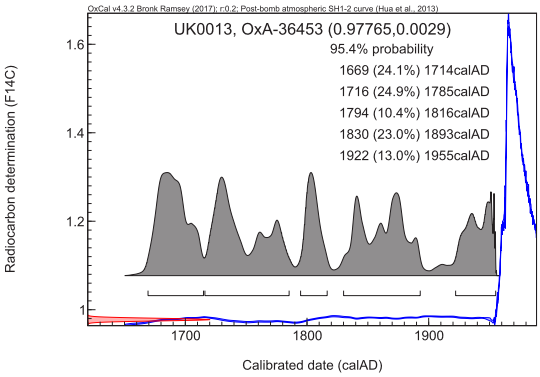
Following page: Figure 20. Calibration plots for radiocarbon determinations of worked ivory specimens purchased in the United Kingdom.


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
UK0002, OxA-36445 (0.98449,0.00273)
95.4% probability
1697 (14.4%) 1725calAD
1807 (35.5%) 1871calAD
1875 (45.5%) 1949calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
UK0004, OxA-36318 (0.99914,0.00306)
95.4% probability
1954 (95.4%) 1956calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
UK0005, OxA-36319 (0.97195,0.0029)
95.4% probability
1651 (22.0%) 1685calAD
1729 (70.5%) 1803calAD
1949 (2.9%) 1954calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
UK0012, OxA-36452 (0.98609,0.00277)
95.4% probability
1698 (11.5%) 1724calAD
1808 (23.7%) 1839calAD
1843 (10.6%) 1869calAD
1877 (49.3%) 1948calAD
1954 (0.4%) 1955calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


OxCal v4.3.2 Bronk Ramsey (2017); r:0.2; Post-bomb atmospheric SH1-2 curve (Hua et al., 2013)
UK0013, OxA-36453 (0.97765,0.0029)
95.4% probability
1669 (24.1%) 1714calAD
1716 (24.9%) 1785calAD
1794 (10.4%) 1816calAD
1830 (23.0%) 1893calAD
1922 (13.0%) 1955calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)

4 Methods

Sampling of the worked ivory specimens was performed to limit visual impact and, where it was possible to determine, to sample as close as possible the proximal end of the tusk. On each specimen, the sampling location was surface cleaned using air abrasion with alumina powder. ~150 mg of ivory powder was then sampled using a modelling drill.

The ivory powder was washed with sequential washes of organic solvents (acetone, 50°C, 1 hour; methanol, 50°C, 1 hour; chloroform, room temperature, 1 hour) to remove any wax or polish. Collagen was extracted by demineralising the ivory in 0.5 M hydrochloric acid for ~18 hours, before washing in 0.1 M sodium hydroxide and followed by a further rinse of 0.5 M hydrochloric acid. After each acid or base wash the samples were rinsed three times with ultrapure water. The extracted collagen was then gelatinised in a pH 3 aqueous solution of hydrochloric acid at 75°C for 20 hours before being filtered through a ~90 µm HDPE membrane and then freeze-dried. (ORAU pretreatment code AG*; Brock et al., 2010).

After chemical pretreatment the extracted collagen was converted to carbon dioxide and dinitrogen using an elemental analyser. A portion of this gas was diverted to an isotope ratio mass spectrometer to determine the carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope composition while the remainder of the carbon dioxide was collected and graphitized at 560°C in the presence of hydrogen gas and an iron catalyst (Dee and Bronk Ramsey, 2000). The radiocarbon content of the graphite was determined using the Oxford accelerator mass spectrometer (Bronk Ramsey et al., 2004). Radiocarbon measurements were calibrated against the post bomb atmospheric SH1-2 curve (Hua et al., 2013) using OxCal v4.3.2 (Bronk Ramsey, 2009).

5 References

Dee M. and Bronk Ramsey C. (2000) Refinement of graphite target production at ORAU. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 172, 449–453.

Brock F., Higham T., Ditchfield P. and Ramsey C. B. (2010) Current Pretreatment Methods for AMS Radiocarbon Dating at the Oxford Radiocarbon Accelerator Unit (ORAU). Radiocarbon 52, 103–112.

Bronk Ramsey C. (2009) Bayesian Analysis of Radiocarbon Dates. Radiocarbon 51, 337–360.

Hua Q., Barbetti M. and Rakowski A. Z. (2013) Atmospheric Radiocarbon for the Period 1950–2010. Radiocarbon 55, 2059–2072.

Ramsey C. B., Gigham T. and Leach P. (2004) Towards high-precision AMS; progress and limitations. Radiocarbon 46, 17–24.

Van der Merwe N. J., Lee-Thorp J. A., Thackeray J. F., Hall-Martin A., Kruger F. J., Coetzee H., Bell R. H. V. and Lindeque M. (1990) Source-area determination of elephant ivory by isotopic analysis. Nature 346, 744.