

University of Groningen

Are Medieval *Mya arenaria* (Mollusca; Bivalvia) in the Netherlands also clams before Columbus?

Essink, K.; Oost, A. P.; Streurman, H. J.; Van der Plicht, J.

Published in:
 Netherlands journal of geosciences-Geologie en mijnbouw

DOI:
[10.1017/njg.2016.17](https://doi.org/10.1017/njg.2016.17)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
 Publisher's PDF, also known as Version of record

Publication date:
 2017

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Essink, K., Oost, A. P., Streurman, H. J., & Van der Plicht, J. (2017). Are Medieval *Mya arenaria* (Mollusca; Bivalvia) in the Netherlands also clams before Columbus? *Netherlands journal of geosciences-Geologie en mijnbouw*, 96(1), 9-16. <https://doi.org/10.1017/njg.2016.17>

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Are Medieval *Mya arenaria* (Mollusca; Bivalvia) in the Netherlands also clams before Columbus?

K. Essink^{1,*}, A.P. Oost^{2,3}, H.J. Streurman⁴ & J. Van der Plicht^{4,5}

¹ Sunken History Foundation, Vosbergerlaan 14, NL-9761 AK Eelde, the Netherlands

² Deltares, P.O. Box 85467, NL-3508 AL Utrecht, the Netherlands

³ Utrecht University, Department of Physical Geography, P.O. Box 80021, NL-3508 TA Utrecht, the Netherlands

⁴ Centre for Isotope Research, Groningen University, Nijenborgh 4, NL-9747 AG Groningen, the Netherlands

⁵ Faculty of Archaeology, Leiden University, Einsteinweg 2, NL-2333 CC Leiden, the Netherlands

* Corresponding author. Email: karelessink@hetnet.nl

Manuscript received: 11 May 2015, accepted: 15 April 2016

Abstract

During the Pleistocene, the coastal marine bivalve mollusc *Mya arenaria* became extinct in northwest Europe. The species remained present in North America. Datings of *Mya* shells found in northern Denmark and the southern Baltic Sea suggest that repopulation of northwest European coasts already occurred before Columbus' discovery of America (1492), possibly facilitated by Viking (Norse) settlers at Greenland and northeast North America. In this paper we report on findings of *M. arenaria* at five locations in the coastal landscape of the Netherlands: polders reclaimed from the Wadden Sea and the former estuaries of Oer-IJ and Old Rhine. The shells from four of these locations also date before 1492 AD.

Keywords: North America, North Sea, ¹⁴C dating, pre-Columbus, Wadden Sea

Introduction

The coastal marine bivalve mollusc *Mya arenaria* is considered to have become extinct in northwest Europe during the (late) Pleistocene (Strasser, 1999; Lasota et al., 2004). The species remained present along the Atlantic coasts of North America. Van Benthem Jutting (1942), however, states that *M. arenaria* was present during several Holocene periods in the Netherlands. A re-introduction to European coasts did not occur for a long time. The species was not found in Stone Age kitchen middens ('køkkenmøddinger') around the North Sea and the Atlantic coast of France (Hessland, 1946; Petersen et al., 1992; Dupont et al., 2007, 2009), nor in a Bronze Age shell midden in Normandy (France) (Mougue et al., 2014). It didn't show up either in Roman and post-Roman middens (Dubois, 1924, in Bernard, 1979). In Rondeletius (1554) no description is given of a *Mya*-resembling bivalve among his listing of over 70 species from Gallia and Germania superior. The first record in Western Europe of a living specimen was reported in Belgium in 1583 (Raeymaekers, 1898, in Bernard, 1979). The oldest record of living *M. arenaria* in the Netherlands is from a creek in the

southwest Netherlands (Baster, 1765). These records were considered the result of transport of the species by early (16th century) French colonisers of the North American Atlantic shores (Petersen et al., 1992). There are, however, finds of older *M. arenaria* shells at the Kattegat coast, northern Denmark (dated 1245–1295 AD by Petersen et al., 1992) and in the Greifswalder Bodden, southern Baltic Sea (dated 1310 ± 70 AD by Behrends et al., 2005). These finds, clearly predating Columbus' discovery of America in 1492, support the hypothesis by Petersen et al. (1992) of Viking-mediated transport of this species c. 200 years earlier. In this paper we report on the ages of shells of *M. arenaria* found in old coastal deposits in the Netherlands and answer the question of whether these are pre-Columbian or not.

Materials and methods

Sampling

Samples of *M. arenaria* were collected at five locations in the Netherlands (Fig. 1). Further sample information is given in

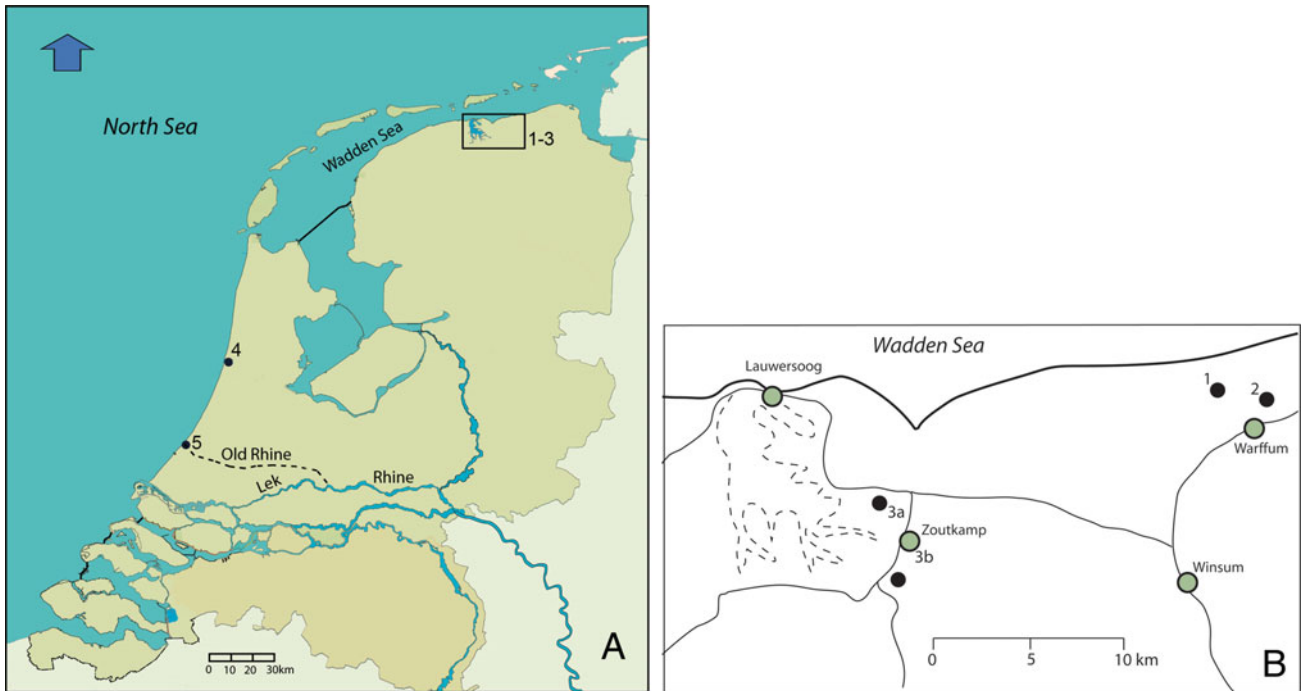


Fig. 1. A. Locations in the Netherlands where shells of *Mya arenaria* were found. 1–3, Province of Groningen; 4, Wijker Tunnel; 5, Katwijk aan de Rijn; B. Details of the Groningen area: solid black line indicates the sea dike; thin black line shows roads; dashed line indicates Lake Lauwersmeer. See text for further description of locations and inferred paleo-environment.

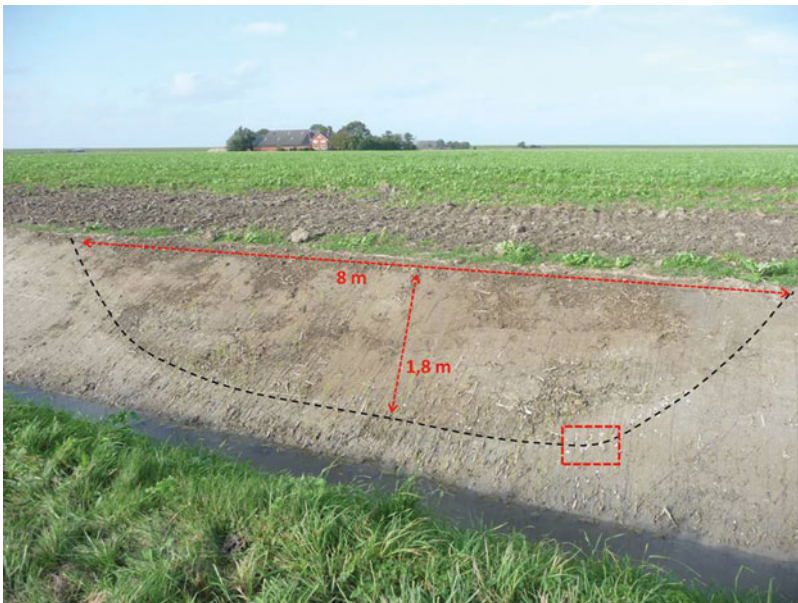


Fig. 2. Cross-section and dimensions of the filled former tidal creek at location 1, Noordpolder, province of Groningen. Rectangle shows the position of shell valves of *Mya arenaria*. (Photo: Dr K. Essink.)

Table 1. Location 1 is in the Noordpolder in the northern part of the province of Groningen, where shells were collected by the third author from newly dug polder ditches where the bottom of a filled former tidal creek became visible (Fig. 2). Location 2 is also in the Noordpolder; here, *Mya* shells were collected by the third author from a dredged polder canal. Location 3 consists of two sites northwest and southwest, respectively, of the fishing village of Zoutkamp. At location 3a (Vierhuizen), a *Mya* shell

was collected by geologist Peter C. Vos during the construction of a natural gas pipeline (Bakker et al., 2009) just seaward of the old dike of the Lauwerszee. At location 3b (Zoutkamp-SW) a *Mya* shell was collected by the third author from a newly dug ditch.

Location 4 is in the western part of the Netherlands, east of IJmuiden. Here, small articulated shells of *M. arenaria* were collected by Dr T. Meijer (RGD – Geological Survey of the

Table 1. Information on the *Mya arenaria* shells and the results of age determination, calibration and abundance ratios for stable C and O isotopes. For locations see Fig. 1. X and Y: RD (Amersfoort) co-ordinates. The ¹⁴C age (1-sigma) and calibrated ages are rounded to the nearest 5. Further explanation in the text.

Location	X co-ordinate	Y co-ordinate	Sampling date	Size (mm)	Laboratory code	Measured ¹⁴ a (%)	¹⁴ C age (BP)	δ ¹³ C (‰)	δ ¹⁸ O (‰)	Final age (yr)	Calibrated age (AD; 1σ)	Calibrated age (AD; 2σ)
1a: Noordpolder I	231900	603800	08-08-1990	113	GrN 26651	91.88 ± 0.20	1000 ± 20	-4.98	+0.78	600	1310-1360, 1385-1395	1300-1405
1b: Noordpolder II	231900	603800	08-08-1990	113	GrN 18009	91.73 ± 0.75	1015 ± 65	-5.22	+0.87	615	1295-1400	1275-1425
1c: Noordpolder III	231900	603800	08-08-1990	105	GrN 32873	91.90 ± 0.55	1000 ± 50	-5.21	+0.88	600	1305-1400	1290-1415
2: Warffum-Middendijk	233700	603300	19-02-1997	85	GrN 32849	93.19 ± 0.58	885 ± 50	-5.47	+0.76	485	1400-1455	1310-1495, 1600-1615
3a: Vierhuizen MZ 10	214300	597500	05-02-2008	?	GrN 31434	93.42 ± 0.25	910 ± 20	-2.46	+0.33	510	1415-1430	1405-1440
3b: Zoutkamp-SW	214800	593700	01-08-1996	83	GrN 32940	93.72 ± 0.54	900 ± 45	-1.56	+0.23	500	1405-1445	1315-1465
4: Wijker Tunnel	c. 106000	c. 497000	Nov. 1993	c. 25	GrA 738	92.52 ± 0.50	955 ± 50	-5.28	-0.40	555	1315-1425	1300-1440
5: Katwijk aan de Rijn	c. 88900	c. 469000	c. 1950	54	GrA 61270	91.11 ± 0.46	1110 ± 40	-3.11	-2.78	270	1525-1795	1485-1800

Netherlands) in 1993 in the building pit for the Wijker Tunnel, which provides an A9 motorway crossing underneath the North Sea Canal between IJmuiden and Amsterdam (Beets et al., 2003).

Also in the western part of the Netherlands, shells of *M. arenaria* were collected in the 1950s near Katwijk aan de Rijn (location 5) by the late Dr E.H.J. Warns, a non-professional resident malacologist. Part of his shell collection came into the possession of the second author in 2013. Unfortunately, the documentation regarding the find location of *Mya* shells in the historic estuary of the River Rhine ('Old Rhine') had been lost. Shells were partially covered with traces of clay, suggesting fairly sheltered sedimentary conditions. Among this shell material was one doublet, indicating that the specimen was found in a living position (*in situ*). Of this doublet one valve was used for radiocarbon age determination.

Age determination and stable isotopes

All shells were dated at the Centre for Isotope Research (CIO), Groningen. Samples received the standard chemical treatment (Mook & Streurman, 1983). Age determination of the samples from locations 1-3 was done using the conventional ¹⁴C method (GrN-code; Mook & Streurman, 1983). The samples from locations 4 and 5 were dated using accelerator mass spectrometry (AMS; GrA-code; Van der Plicht et al., 2000). The dates are reported in conventional radiocarbon years (BP), i.e. measured relative to the oxalic acid reference, using the conventional half-life value and including normalisation for isotope fractionation using the ¹³C isotope (Mook & Van der Plicht, 1999). Shell samples are subject to reservoir effects; these need to be subtracted from the conventional age before transformation to calendar years can be done (see Discussion).

In addition to ¹⁴C, the content of the stable isotopes ¹³C and ¹⁸O of the shell carbonates was also measured by isotope ratio mass spectrometry (IRMS) using the international standard VPDB as reference material (Mook, 2006). The results are expressed as delta values, i.e. deviations (in ‰) of the rare/abundant isotope ratio from reference materials:

$$\delta^{13}\text{C} = \frac{[^{13}\text{C}/^{12}\text{C}]_{\text{sample}}}{[^{13}\text{C}/^{12}\text{C}]_{\text{reference}}} - 1 (\times 1000\text{‰}) \quad \text{and}$$

$$\delta^{18}\text{O} = \frac{[^{18}\text{O}/^{16}\text{O}]_{\text{sample}}}{[^{18}\text{O}/^{16}\text{O}]_{\text{reference}}} - 1 (\times 1000\text{‰})$$

Results

All relevant data and results are presented in Table 1. This table contains administrative data such as sampling locations, location co-ordinates, dates of sampling and laboratory codes. For the *Mya* shells analysed the length is given in millimetres when known. The shells from location 3a (Vierhuizen) were fragments, not an entire valve. Table 1 also shows the stable

isotope ratios $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ (in ‰), and the measured (not-normalised) ^{14}C activity ratio ^{14}a (in ‰). The latter is defined as $^{14}\text{a} = ^{14}\text{A}_{\text{sample}}/^{14}\text{A}_{\text{reference}}$, with ^{14}A being the ^{14}C radioactivity in becquerels per gram of carbon (Mook & Van der Plicht, 1999).

After normalisation for isotope fractionation, the ^{14}a value provides the conventional ^{14}C age (BP) with 1σ confidence levels. This approach is valid for terrestrial samples that are in equilibrium with the atmosphere. The ocean and rivers, however, contain less ^{14}C than the atmosphere, hence shells show apparent ages: the so-called reservoir effect. This has to be subtracted from the conventional age.

For the North Sea, the reservoir effect is 400 years (e.g. Reimer et al., 2013), certainly for the time range discussed here. For rivers, the reservoir effect is significantly larger, typically 1300 years for the Rhine (Lanting & Van der Plicht, 1998). Estuaries, where sea water and river water are mixed, obviously show intermediate values (e.g. Philippsen et al., 2013; Reimer, 2014). To obtain absolute dates for shells from the coastal area of the Netherlands, it is therefore necessary to assess the environment these bivalves were living in. This determines the recent activity of the shells during their lifetime. This is lower than the activity for contemporaneous terrestrial organisms, which translates in apparent ages: the reservoir effect.

The samples from locations 1–4 are fully marine, hence the reservoir effect can be taken as 400 years. For the *Mya* shell from Katwijk, a reservoir effect of 840 years applies (see Discussion). The calibrated ages (1σ and 2σ) of the *Mya* shells from locations 1–4 are all older than 1492 AD. The possible age of 1600–1615 AD (2σ) for the shell from location 2 should be disregarded because at that time the find location was agricultural land that had been endiked some centuries before. This second date range is caused by a fluctuation in the calibration curve; it has a low probability (c. 1%) and can also mathematically be neglected. The calibrated age of the *Mya* shell from location 5 is much younger (1485–1800 AD; 2σ).

Paleogeographic setting

The Noordpolder (sampling locations 1 and 2) is a former salt marsh area in the Wadden Sea; it was endiked in 1811. The older subsoil of the Noordpolder consists of marine sediments in which the following bivalve species were found: cockle (*Cerastoderma edule*), blue mussel (*Mytilus edulis*), Baltic tellin (*Macoma balthica*), peppery furrow shell (*Scrobicularia plana*) and soft-shell clam (*M. arenaria*). Judging from the age determinations on this material (Streurman & Van der Plicht, 2014) the subsoil of the Noordpolder and adjacent polders was an intertidal flat biotope at least between c. 700 and 1500 AD.

The find location 3a (near Vierhuizen) is on the seaward side of the dike of the former Lauwerszee, an embayment of the Wadden Sea, which was endiked in 1969 (see Fig. 1). The Lauwerszee was initially formed by a series of sea intrusions

in the coastal peat landscape between 600 and 800 AD, and reached its largest extension between 1000 and 1200 AD. The salt marsh area north of the find location 3a was endiked as late as 1875–1877 (Westpolder) and the area south of it was endiked in 1927 (Kerkvoogdijpolder).

The find location 3b (Zoutkamp-SW) is in the Nieuwe Ruigezandsterpolder on the landward side of the dike that closed the Reitdiep estuary in 1877, after which this polder was embanked (Roeleveld, 1974; Hacquebord & Hempenius, 1990). At both these locations intertidal flats were present for centuries, as is shown on the much detailed Beckering Chart of the Province of Groningen from 1781. Paleogeographic reconstruction maps for c. 800 AD and c. 1150 AD by P.C. Vos and S. de Vries also indicate intertidal flats present at the find locations 3a and 3b (see Van Beek & Vos, 2008).

Find location 4 (Wijker Tunnel) is in the historic Oer-IJ estuary that provided outflow of the small river Vecht (a Rhine tributary) to the North Sea. When the river Vecht connected to Lake Flevo in Roman times, the mouth of the estuary silted up; a small opening may have remained until c. 1100 AD (Roep et al., 1991; Beets et al., 2003). Articulated valves of juvenile *M. arenaria* and *Cerastoderma glaucum* were found in a layer of lacustrine (Zuiderzee) clays less than 1 m thick (unit 7). These shells and clay are considered to indicate new brackish conditions that resulted from the north-oriented progressive opening up of the Flevo Lakes to the North Sea, first creating the tidal Almere lagoon (c. 850 AD) and then the brackish tidal embayment of the Zuiderzee that reached its maximum size around 1200 AD (Zagwijn, 1971; Lenselink & Koopstra, 1994; Vos et al., 2015).

Location 5 (Katwijk aan de Rijn) is in the estuary of the historic Rhine river, which once formed the northern border (limes) of the Roman Empire (Van Dinter, 2013). From around 250 AD onwards the river branch Lek became increasingly important for discharging via Rotterdam into the North Sea. As a consequence, the discharge through the Old Rhine towards Katwijk decreased, causing silting up of the river mouth (Henderikx, 1987; Bazelmans et al., 2011). It is assumed that this river mouth was finally closed off from the North Sea after reduction of river discharge and the building of a dam (Zwammerdam) far upstream and the effect of a storm surge in 1163 (Buisman, 1995; Van Dam, 1999; Parlevliet, 2001; Van de Ven, 2004). The closure of the river mouth was certainly not much later than 1200 AD (Van Heeringen & Van der Valk, 1989; Van de Ven, 2004).

Discussion

Marine or estuarine lifetime conditions

In our samples we used the stable isotopes ^{13}C and ^{18}O as tracers for their lifetime environment. For the North Sea, shells

typically show $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values of c. 1.5‰ and c. 1.0‰, respectively (Mook, 1970). For the river Rhine, the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values are typically -10.5‰ and -9.0‰ , respectively. For the Rhine/North Sea estuary, these values represent the end values of the mixing line for these water bodies (Mook, 1971).

The *M. arenaria* shells from locations 1–4 show $\delta^{18}\text{O}$ values that are considered as marine. The $\delta^{13}\text{C}$ values are lower than the marine value, but the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values combined do not plot on the Rhine/North Sea mixing line; there is no apparent riverine component. These negative $\delta^{13}\text{C}$ values are caused by complex fractionation processes, which are included in the calculation of the conventional ^{14}C age. Based on $\delta^{18}\text{O}$, we consider these shells to be 100% marine. It is therefore justified to assume for the shells from locations 1–4 a reservoir effect of 400 years, resulting in the final ages shown in Table 1.

The *M. arenaria* shell from location 5 (Katwijk) must have lived under different conditions. The $\delta^{18}\text{O}$ value clearly shows riverine influence. In fact, the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values together are exactly on the mixing line of the Rhine/North Sea estuary. For the Rhine, the recent activity $^{14}\text{a}_{\text{recent}} = 85\%$, corresponding to the 1300 years reservoir effect mentioned before. Taking this value and the parameters from the mixing line, the recent activity for the Katwijk shell can be calculated (see Mook, 2006). The result is $^{14}\text{a}_{\text{recent}} = 94.24\%$; from this the final age can be calculated as 270 years. Comparing this with the conventional ^{14}C age (BP), we see that the reservoir effect for this *Mya* shell is 840 years.

For our *Mya* shells, we know what their living conditions were: marine or estuarine. This has a significant influence on the reservoir effect that has to be taken into account. Petersen et al. (1992) only published the calibrated date; neither the ^{14}C date in BP, nor the $\delta^{13}\text{C}$ values were reported. It is also very unlikely that they measured $\delta^{18}\text{O}$. In the *Mya* shells dated by Behrends et al. (2005) no stable isotope levels were assessed either. At Greifswalder Bodden the ambient salinity was about 7.3 (Behrends et al., 2005). The shells analysed by Petersen et al. (1992) originate from the coast of the Kattegat. This is also an area of reduced salinities between the North Sea/Skagerrak and Baltic Sea, although to a lesser extent than in Greifswalder Bodden. Therefore, for these *Mya* shells vital information is missing in relation to the extent of the reservoir effect to be taken into account.

Calibration procedure

The ages shown as final ^{14}C ages in Table 1 include the necessary reservoir effect corrections to allow for comparison with terrestrial samples. To determine the absolute age of the *Mya* shells, these ages need to be calibrated to calendar ages. This is done using the presently recommended calibration curve IntCal13 (Reimer et al., 2013). The calibrated age ranges are presented in calendar years AD, at both 1-sigma and 2-sigma confidence levels (Table 1). All ages are rounded to the nearest 5.

As an example, the calibration of sample GrN-26651 (from location 1a) is shown in Fig. 3. The blue curve is the relevant part of the (terrestrial) calibration curve, established by paired dating of wood by ^{14}C and dendrochronology. The ^{14}C date (600 ± 20) is plotted along the vertical ^{14}C axis. It shows a Gaussian probability distribution. The probability distribution of the calibrated date is shown in black along the horizontal axis. This distribution is obviously no longer Gaussian, as this is caused by the fluctuation ('wobble') in the calibration curve. In fact it shows that a ^{14}C date may yield multiple solutions on the calendar. We rounded the numbers to the nearest 5, and ignored the gaps between calibrated ranges when these were not significant compared with the measurement error (see Table 1). In Table 1, the 1-sigma results are presented as 1310–1360 and 1385–1395 calAD, the 2-sigma results as 1300–1405 calAD. For more mathematical details we refer to the literature (Van der Plicht & Mook, 1989). The calibrated ^{14}C dates are by convention reported in calAD (Mook, 1986).

Paleo-environmental setting

For the *Mya* shells found in the province of Groningen (locations 1–3) the datings comply with the inferred paleogeographic setting of coastal intertidal sediments. The same holds for the shell from the Wijker Tunnel (location 4), where an estuarine environment was anticipated.

All shells from locations 1–4 clearly date as pre-Columbian. Whether these datings are really younger than those reported from Denmark is hard to say because Petersen et al. (1992) did not report on stable isotopes (see before).

The *Mya* shells found in the Old Rhine estuary near Katwijk (location 5) are not pre-Columbian, but younger: between 1525 and 1795 AD (1-sigma). The stable isotope values of these shells clearly indicate that estuarine living conditions have been present. This can be explained as follows. After the closure of the mouth of the Old Rhine around 1200 AD serious drainage problems developed in the low-lying areas behind the dune ridges north and south of the Old Rhine. Local communities began the construction of canals discharging in a northerly direction (Parlevliet, 2001; Van de Ven, 2004), but no solution to the flooding problems was achieved. In 1404, plans to re-open the river mouth were considered, but not carried out. Between 26-3-1571 and 30-11-1571, a new plan (Het Malle Gat) was realised, re-connecting the North Sea and the river Rhine via two sluice-gates. This canal, however, could not be maintained due to enduring war conditions (the Eighty Years' War against the Spanish king) (Boomgaard, 1984). Later on, a new channel was dug and opened in 1807, but locks closed the inland area off from the sea. We hypothesise that the *Mya* shells dated 1525–1795 AD (1-sigma) were living in the Malle Gat area around 1571 AD under short-term estuarine conditions that may have occurred due to intrusion of saline water through the sluice-gate system.

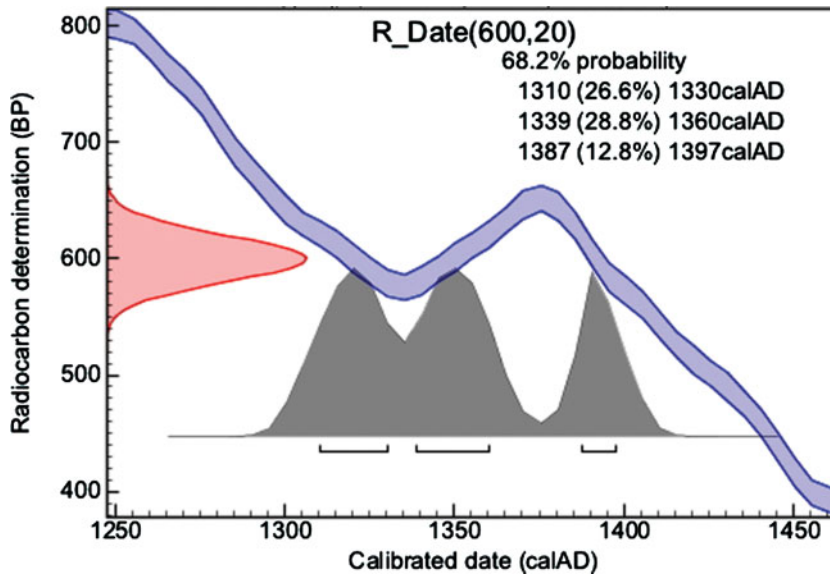


Fig. 3. Illustration of the calibration procedure applied for the *Mya arenaria* shell from location 1a. The IntCal13 calibration curve is shown in blue. See text for further explanation.

Dispersal mechanism

Our datings of shells of *M. arenaria* in the northern and western parts of the Netherlands are in line with the hypothesis of Viking-mediated dispersal of this species across the northern Atlantic Ocean. This hypothesis was first put forward by Petersen et al. (1992) and repeated by Behrends et al. (2005) as an explanation for their finds of pre-Columbian *Mya* shells in northern Denmark and the Greifswalder Bodden. The calibrated ages (with 2σ range) of the shells found in Denmark seem to predate to some extent the ages of shells found in the Netherlands. This, however, cannot be used as a definite clue for a first arrival of North-American clams in Danish coastal waters. It has to be realised that from any site of first introduction of this species, dispersal along the shores of the North Sea would have taken place easily by means of pelagic larvae, as was illustrated for the later Northern American bivalve immigrant *Ensis directus* (Essink, 1985, 1986).

Conclusions

The finds of *M. arenaria* shells at four locations along the North Sea coast of the Netherlands dating to the 13th to 15th centuries AD provide further evidence of the re-introduction of this species from its native range in northeast America into European waters well before the discovery of America by Columbus. As a consequence, it supports the hypothesis of Viking-mediated transfer of this species from northeast America to northwest European waters as put forward by Petersen et al. (1992). The *M. arenaria* shell found at Katwijk (location 4) was dated 1485–1800 AD (2-sigma), with stable isotopes indicating estuarine living conditions. This indicates the existence of es-

tuarine conditions long after the closing of the mouth of the Old Rhine around 1200 AD. Such conditions may have occurred for some time due the digging of a temporary connection (Malle Gat) between the Old Rhine and the North Sea around 1571 AD. For a reliable dating of mollusc shells from (former) coastal and estuarine environments it is essential to also assess the stable isotopes ^{13}C and ^{18}O because this determines the reservoir effect that has to be taken into account.

Acknowledgements

Thanks are due to Dr R. Daan for donating to the second author the *Mya* shells from Katwijk aan de Rijn, collected by the late Dr E.H.J. Warns. Dating of one of these shells was made possible by the Deltares' Research Program Coastal and Estuarine Morphodynamics. Information on the historic situation at Katwijk around 1571 AD was kindly provided by Mr D. Parlevliet, Dr B. Voormolen and Dr A.W.E. Wilbers. Fig. 1 was prepared by Mr. Rob Jungcurt.

Dedication

This paper is dedicated to the memory of Prof. Dr W.G. (Wim) Mook, who passed away at the age of 83 on 24 January 2016. Wim Mook was for a long time leader of the Centre for Isotope Research (CIO) in Groningen and played a significant role in the development of radiocarbon dating.

References

Bakker, A.M., la Fèber, D.J. & Vos, P.C., 2009. Inventariserend veldonderzoek door middel van een proefsleuf en een archeologische begeleiding op het

- gasleidingstracé Vierhuizen-Munnekezijl, gemeente De Marne. Archeologisch Rapport Oranjewoud 2008/17.
- Baster, J.**, 1765. Natuurkundige uitspanningen, behelzende eenige waarnemingen, over sommige zeeplanten en zee-insecten, benevens derzelver zaadhuisjes en eijernesten. Tweede deel, vijfde stukje. J. Bosch (Haarlem): 53–110.
- Bazelmans, J., Weerts, H. & Van der Meulen, M.** (eds), 2011. Atlas van Nederland in het Holoceen. Bert Bakker (Amsterdam): 94 pp.
- Beets, D.J., De Groot, T.A.M. & Davies, H.A.**, 2003. Holocene tidal back-barrier development at decelerating sea-level rise: a 5 millennia record, exposed in the western Netherlands. *Sedimentary Geology* 158: 117–144.
- Behrends, B., Hertweck, G., Liebezeit, G. & Goodfriend, G.**, 2005. Earliest Holocene occurrence of the soft-shell clam, *Mya arenaria*, in the Greifswalder Bodden, Southern Baltic. *Marine Geology* 216: 79–82.
- Bernard, F.R.**, 1979. Identification of the living *Mya* (Bivalvia: Myoida). *Venus* 38: 185–204.
- Boomgaard, J.E.A.**, 1984. De eerste doorgraving van de duinen bij Katwijk. De aanleg van duikers en plannen voor een uitwateringssluis in de periode 1404–1629. In: De uitwateringssluizen van Katwijk 1404–1984. Hoogheemraadschap van Rijnland (Leiden): 9–17.
- Buisman, J.**, 1995. Duizend jaar weer, wind en water in de lage landen. Deel 1. Tot 1300. Van Wijnen (Franeker): 656 pp.
- Dupont, C., Schulting, R. & Tresset, A.**, 2007. Prehistoric shell middens along the French Atlantic façade: the use of marine and terrestrial resources in the diets of coastal human populations. In: *Milner, N., Craig, O. & Bailey, G.* (eds): Shell middens in Atlantic Europe. Oxbow Books (Oxford): 123–135.
- Dupont, C., Tresset, A., Desse-Berset, N., Gruet, Y., Marchand, G. & Schulting, R.**, 2009. Harvesting the seashores in the Late Mesolithic of Northwestern Europe: A View From Brittany. *Journal of World Prehistory* 22: 93–111.
- Essink, K.**, 1985. On the occurrence of the American jack-knife clam *Ensis directus* (Conrad, 1843) (Bivalvia, Cultellidae) in the Dutch Wadden Sea. *Basteria* 49: 73–80.
- Essink, K.**, 1986. Note on the distribution of the American jack-knife clam *Ensis directus* (Conrad, 1843) in N.W. Europe (Bivalvia, Cultellidae). *Basteria* 50: 33–34.
- Hacquebord, L. & Hempenius, A.L.**, 1990. Groninger dijken op deltagoogte. Wolters-Noordhoff/Egbert Forsten (Groningen): 103 pp.
- Henderikx, P.A.**, 1987. De beneden-delta van Rijn en Maas. Landschap en bewoning van de Romeinse tijd tot ca. 1000. Verloren (Hilversum): 174 pp.
- Hessland, I.**, 1946. On the quaternary *Mya* period in Europe. *Arkiv för Zoologi* 37A: 1–51.
- Lanting, J.N. & Van der Plicht, J.**, 1998. Reservoir effects and apparent ^{14}C ages. *Journal of Irish Archaeology* 9: 151–165.
- Lasota, R., Hummel, H. & Wolowicz, M.**, 2004. Genetic diversity of European populations of the invasive soft-shell clam *Mya arenaria* (Bivalvia). *Journal of the Marine Biological Association of the UK* 84: 1051–1056.
- Lenseink, C. & Koopstra, R.**, 1994. Ontwikkelingen in het Zuiderzeegebied: van Meer Flevo, via Almere lagune, tot Zuiderzee. In: *Rappol, M. & Soonius, C.M.* (eds): In de bodem van Noord-Holland, geologie en archeologie. Lingua Terrae Books (Amsterdam): 129–140.
- Mook, W.G.**, 1970. Stabiele isotopen van koolstof en zuurstof in water en kalk. *Geologie en Mijnbouw* 49: 397–404.
- Mook, W.G.**, 1971. Paleotemperatures and chlorinities from stable carbon and oxygen isotopes in shell carbonate. *Palaeogeography, Palaeoclimatology, Palaeoecology* 9: 245–263.
- Mook, W.G.**, 1986. Business meeting, 12th International Radiocarbon Conference. *Radiocarbon* 28: 799.
- Mook, W.G.**, 2006. Introduction to isotope hydrology. Stable and radioactive isotopes of hydrogen, oxygen and carbon. Taylor & Francis (London): 226 pp.
- Mook, W.G. & Streurman, H.J.**, 1983. Physical and chemical aspects of radiocarbon dating. In: *Mook, W.G. & Waterbolk H.T.J.* (eds): Proceedings of the Groningen Symposium 14C and Archaeology. PACT Publication 8: 31–55.
- Mook, W.G. & Van der Plicht, J.**, 1999. Reporting ^{14}C activities and concentrations. *Radiocarbon* 41: 227–239.
- Mougue, C., Dupont, C., Giazzon, D. & Quesnel, L.**, 2014. Shellfish from the Bronze Age Site of Clos des Châtaigniers (Mathieu, Normandy, France). *Internet Archaeology*. doi:10.11141/ia.37.5.
- Parlevliet, D.**, 2001. De Rijnmond verstopt. *Holland, Historisch Tijdschrift* 33: 3–16.
- Petersen, K.S., Rasmussen, K.L., Heinemeier, J. & Rudd, N.**, 1992. Clams before Columbus? *Nature* 359: 679.
- Philippens, B., Olsen, J., Lewis, J.P., Rasmussen, P., Ryves, D.B. & Knudsen, K.L.**, 2013. Mid- to late-Holocene reservoir age variability and isotope based palaeoenvironmental reconstruction in the Limfjord, Denmark. *The Holocene* 23: 1017–1027.
- Reimer, P.J.**, 2014. Marine or estuarine radiocarbon reservoir corrections for mollusks? A case study from a medieval site in the south of England. *Journal of Archaeological Science* 49: 142–146.
- Reimer, P.J., Bard, B., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk Ramsey, C., Buck, C.E., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hafliðason, H., Hajdas, I., Hatté, C., Heaton, T.J., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, C.S.M. & Van der Plicht, J.**, 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon* 55: 1869–1887.
- Roeleveld, W.**, 1974. The Groningen coastal area: a study in Holocene geology and low-land physical geography. PhD thesis, Vrije Universiteit Amsterdam: 252 pp.
- Roep, Th. B., Van der Valk, L. & Beets, D.J.**, 1991. Strandwallen en zeegaten langs de Hollandse kust. *Grondboor & Hamer* 45 (5/6): 115–124.
- Rondeletius, G.**, 1554. *Libri de Piscibus marinis, in quibus verae Piscium effigies expressae sunt: quae in tota Piscium historia contineantur, indicat Elenchus pagina nona & decima.* Matthiam Bonhomme (Lyon).
- Strasser, M.**, 1999. *Mya arenaria* – an ancient invader of the North Sea coast. *Helgoländer Meeresuntersuchungen* 52: 309–324.
- Streurman, H.J. & Van der Plicht, J.**, 2014. Het insula ten Noorden van Warffum. Een bijdrage van de koolstofisotopen. *Historisch Jaarboek Groningen 2014*. Koninklijke Van Gorkum (Assen): 6–15.
- Van Beek, J.L. & Vos, P.C.**, 2008. Regio Groningen. Gemeenten De Marne, Winsum, Bedum, Ten Boer, Loppersum, Eemmond, Appingedam en Delfzijl. Archeologische verwachtingskaart en beleidsadvieskaart. RAAP-Rapport 1732, kaart-bijlagen 7 & 8.
- Van Benthem Jutting, W.S.S.**, 1942. On the fossil occurrence of *Mya arenaria* L. in the Netherlands. *Basteria* 7: 1–40.

- Van Dam, P.**, 1999. Stuivend zand en stormende golven De vorming van de Hollandse kust in de Middeleeuwen. *Madoc* 13: 224–234.
- Van de Ven, G.P.** (ed.), 2004. Man made lowlands. History of water management and land reclamation in the Netherlands, 4th revised edn. Matrijs (Utrecht): 432 pp.
- Van der Plicht, J. & Mook, W.G.**, 1989. Calibration of Radiocarbon ages by computer. *Radiocarbon* 31, 805–816.
- Van der Plicht, J., Wijma, S., Aerts, A.T., Pertuisot, M.H. & Meijer, H.A.J.**, 2000. The Groningen AMS facility: status report. *Nuclear Instruments and Methods B172*: 58–65.
- Van Dinter, M.**, 2013. The Roman Limes in the Netherlands: how a delta landscape determined the location of the military structures. *Netherlands Journal of Geosciences – Geologie en Mijnbouw* 92: 11–32.
- Van Heeringen, R.M. & Van der Valk, L.**, 1989. De mond van de Oude Rijn komt in beweging. IJzertijdvondsten uit het Katwijkse duingebied. *Westerheem* 38: 198–203.
- Vos, P.C., De Koning, J. & Van Eerden, R.**, 2015. Landscape history of the Oer-IJ tidal system, Noord-Holland (the Netherlands). *Netherlands Journal of Geosciences* 94: 295–332.
- Zagwijn, W.H.**, 1971. De ontwikkeling van het 'Oer-IJ' estuarium en zijn omgeving. *Westerheem* 20: 11–18.