# shoredate: An R package for shoreline dating coastal Stone Age sites in south-eastern Norway


## Summary

As a result of glacio-isostatic rebound, large regions of Fennoscandia have undergone a process of relative sea-level fall following the retreat of the Fennoscandian Ice Sheet. Furthermore, coastal Stone Age sites in the region appear to have been predominantly located on or close to the shoreline when they were in use. This can be combined with a reconstruction of past relative sea-level change to assign an approximate date to when the sites were in use, based on their altitude relative to the present-day sea-level. This method, called shoreline dating, has been used in the region since the early 1900s (e.g. Brøgger 1905) and is still widely applied today (e.g. Solheim and Persson 2018; Manninen et al. 2021).


## Statement of need

`shoredate` is an R package for shoreline dating Stone Age sites on the coast of south-eastern Norway, based on local geological reconstructions of past relative sea-level change. Drawing on an empirically derived estimate of the likely elevation of the sites above sea-level when they were in use, the method for shoreline dating implemented in the package was recently published in Roalkvam (2023). No open-source software with which to perform shoreline dating exists. The only closed-source software available is `sealev` from the University of Tromsø, Tromsø Geophysical Observatory (https://www.tgo.uit.no/sealev/, see Møller 2003), which provides non-probabilistic point estimates of shoreline dates based on data last updated in 2002.

`shoredate` is aimed at providing researchers and students dealing with the coastal Stone Age of south-eastern Norway with tools for performing and handling shoreline dates. This complements software for handling radiocarbon dates and other sources of temporal data, such as the R packages `rcarbon` (Crema and Bevan 2021), `bchron` (Haslett and Parnell 2008), `oxcAAR` (Hinz et al. 2021), `kairos` (Frerebeau 2022) and `ArchaeoPhases` (Philippe and Vibet 2020), as well as proprietary software such as `OxCal` (Bronk Ramsey 2009).

Shoreline dating is frequently applied in the research and cultural resource management sectors in Norway, both to plan archaeological investigations and for establishing temporal frameworks with which to analyse the archaeological material. Case-studies employing `shoredate` are currently being undertaken. Furthermore, future archaeological material can be drawn on to further test the method as it is implemented here, and potentially lead to adjustments in how it could be applied in a given setting.

## Spatial and temporal coverage

As the method of shoreline dating is dependent on reliable reconstructions of relative sea-level change, the package is at present limited to being applicable in the coastal region between Horten in the north east to Arendal in the south west (Figure 1). Geologically derived displacement curves from this region have recently been compiled for Skoppum in Horten (Romundset 2021), Gunnarsrød in Porsgrunn (Sørensen et al. 2023), Hanto in Tvedestrand (Romundset, Lakeman, and Høgaas 2018) and Bjørnebu in Arendal (Romundset 2018). The spatial coverage of `shoredate` will be extended to surrounding regions as forthcoming data on shoreline displacement becomes available.

Following from the latest start date among the displacement curves, 9469 BCE marks the lower temporal limit of the package. The oldest verified anthropogenic activity in Norway currently dates to around 9300 BCE (Glørstad 2016). In Roalkvam (2023) it was found that sites tend to be located at more variable distances from the shoreline after c. 2500 BCE. This therefore marks the upper temporal limit of the package.

# Example of base functionality

To shoreline date a site, this has to provided as a spatial object of class `sf` from the `sf` package (Pebesma 2018), and be set to the coordinate reference system WGS 84 / UTM zone 32N (EPSG:32632). The elevation of the site above present sea-level must be provided when running `shoreline_date()`. This can be done by either manually specifying the site elevation, or by providing an elevation raster of class `SpatRaster` from the `terra` package (Hijmans et al. 2022), from where this is derived. When calling `shoreline_date()`, the trajectory of shoreline displacement at the location of the site is interpolated under the hood with the function `interpolate_curve()`, using inverse distance weighting. This is based on the distance between the site and the isobases of the displacement curves.

Figure 2 shows the location of an example site, plotted by passing it to `target_plot()`. Figure 3 displays the result of running the command `interpolate_curve()` on the example site, and plotting the resulting interpolated displacement curve with `displacement_plot()`. Finally, Figure 4 shows the result of dating the example site with `shoreline_date()` when manually specifying that the site is situated at 58.8m above present sea-level. The resulting date is plotted with the function `shoredate_plot()`.


# Acknowledgements

I owe great thanks to David Wright, Anders Romundset, Ingrid Fuglestvedt, Per Persson, Steinar Solheim and Hallvard Bruvoll for valuable feedback during work with this project.


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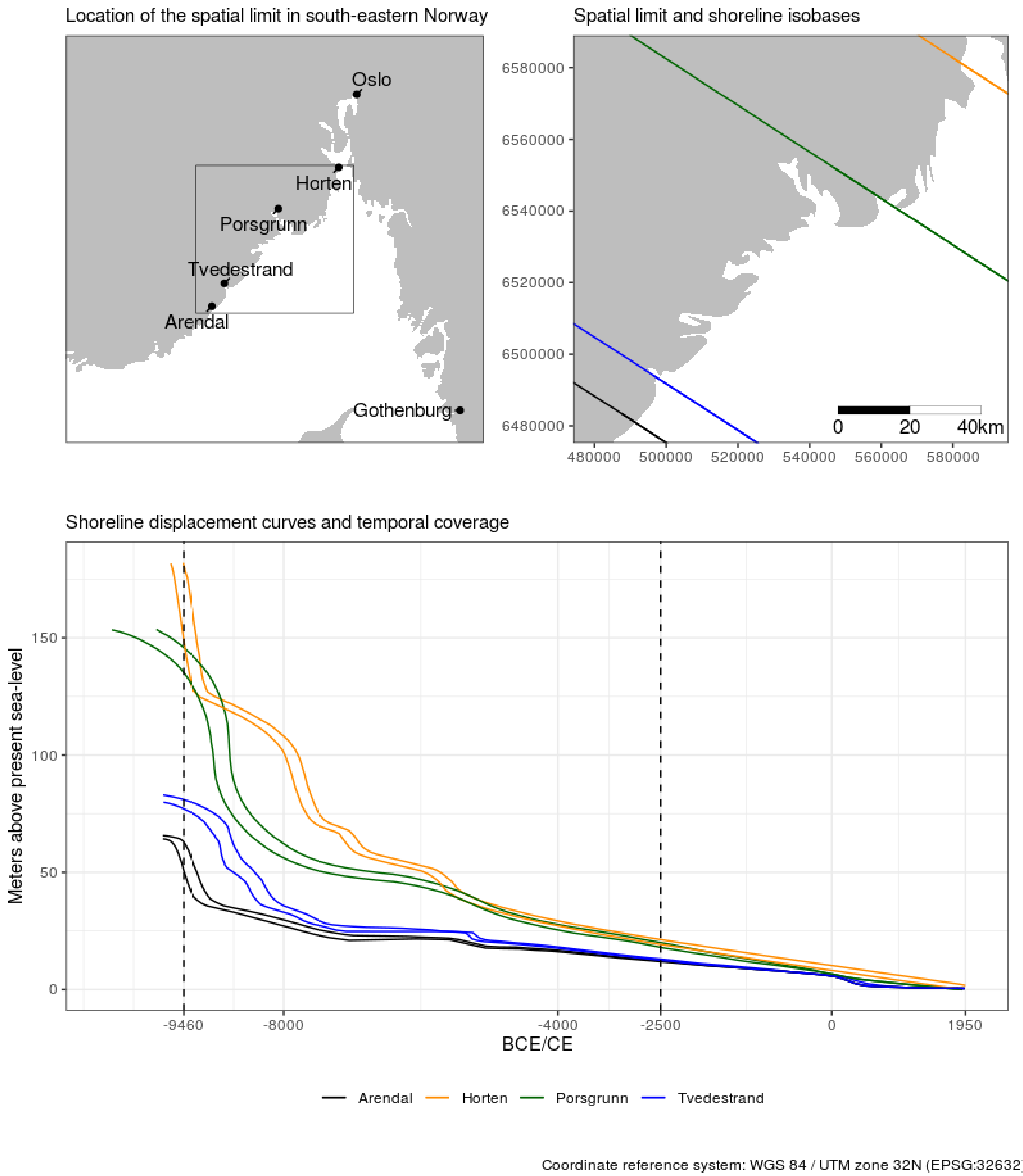


Figure 1: The spatial and temporal coverage of the package. The first figure displays the location of the spatial extent in south-eastern Norway. The second figure displays the location of the isobases, representing contours along which the shoreline displacement has followed the same trajectory. The isobases correspond to the displacement curves in the third figure, where the temporal limits are marked with dashed lines.

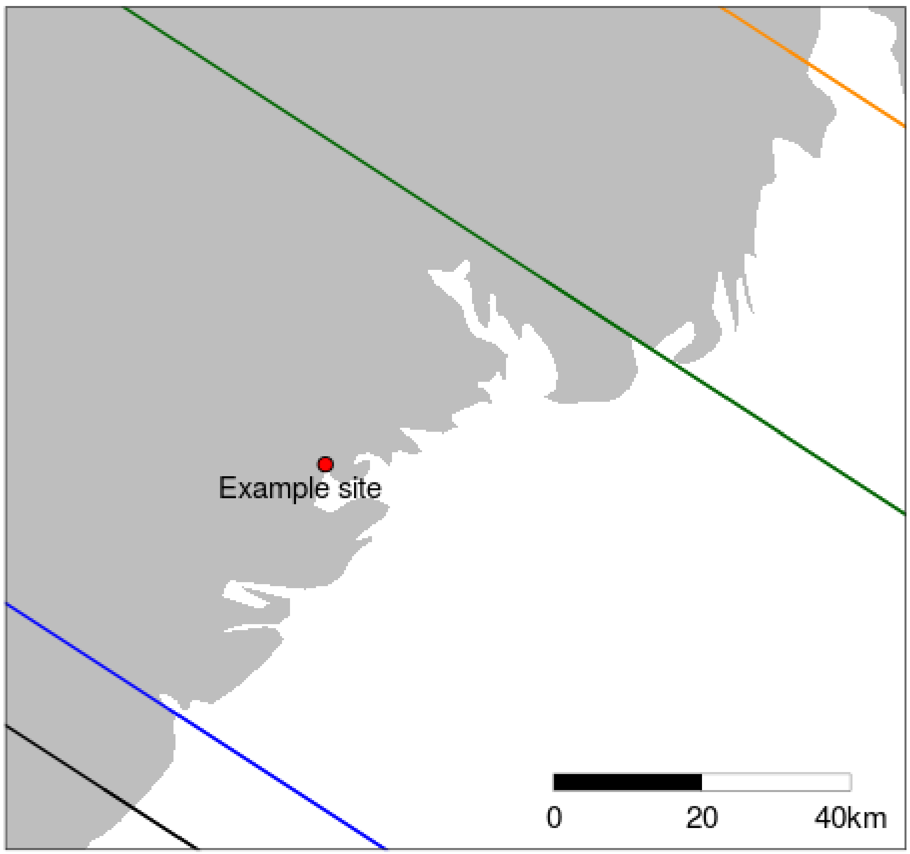


Figure 2: The location of the example site relative to the isobases of the displacement curves. The base map is a simplified and lightweight map of the region.

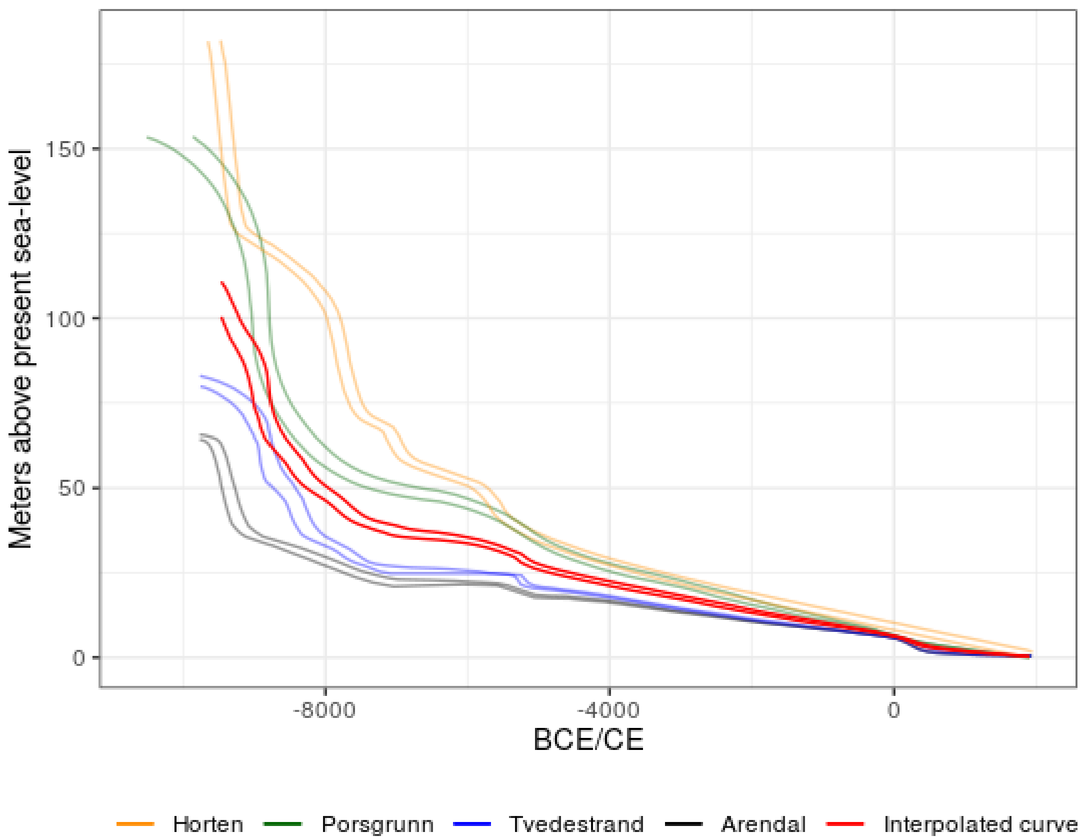


Figure 3: The curve interpolated to the example site by means of inverse distance weighting. This is based on the distance between the site and the isobases of the geological displacement curves.

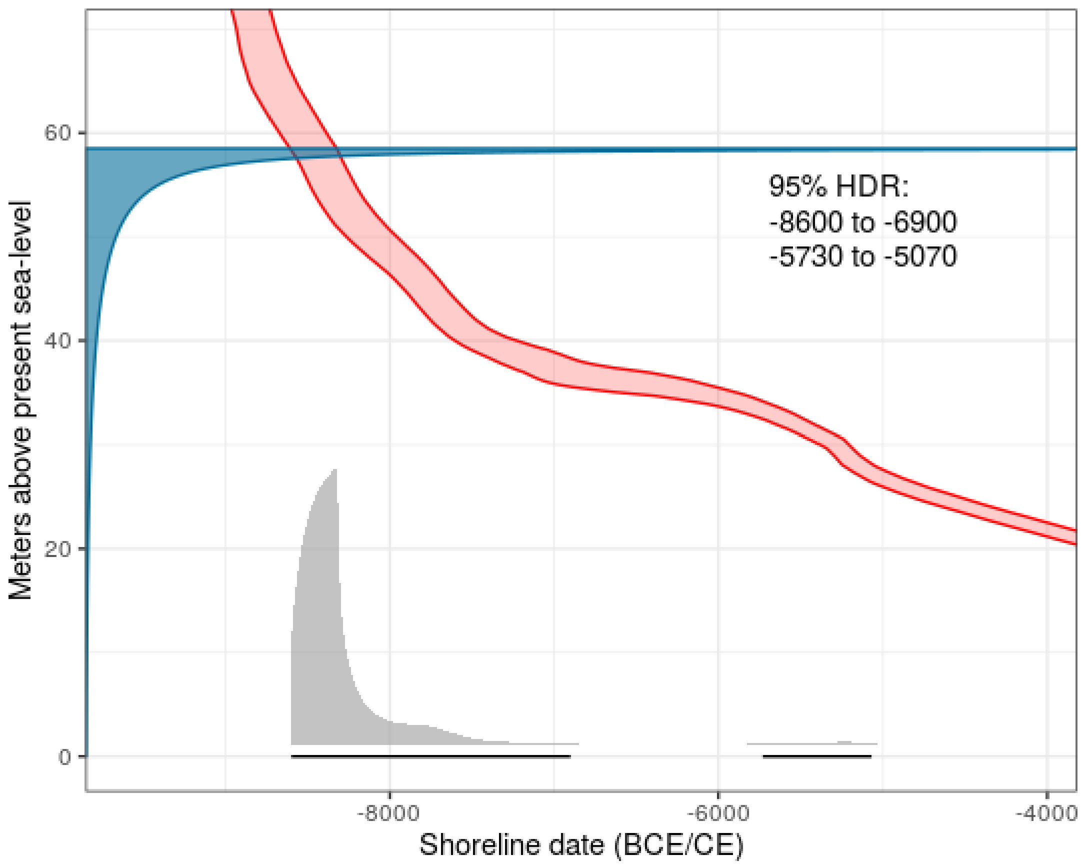


Figure 4: The resulting shoreline date for the example site. The blue gamma distribution on the y-axis indicates the likely elevation of the site above sea-level when it was occupied. The red envelope is the interpolated shoreline displacement curve for the site location. The resulting shoreline date in grey is the result of transferring the probability from the gamma distribution to the calendar scale by coupling it with the displacement curve. The date is underlined with the 95% highest density region (HDR) in black.

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