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Palaeoenvironmental Investigations of Crannogs in south west Scotland and Co. Fermanagh, Northern Ireland

by

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ABSTRACT

FACULTY OF SOCIAL AND HUMAN SCIENCES

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PALAEOENVIRONMENTAL INVESTIGATIONS OF CRANNOGS IN SOUTH WEST SCOTLAND AND CO. FERMANAGH, NORTHERN IRELAND

Thierry Remi Fonville

Crannogs are widely distributed archaeological sites in Scotland and Ireland and can be described as artificially constructed islands, dated mainly to the Iron Age and Medieval periods. However, little is known about the function and chronology of these sites. This study aims to show how palaeoecological and palaeoenvironmental analyses can support the interpretation of these sites. Two regions were chosen, as national archaeological databases indicated that they had a high concentration of dated crannogs: south west Scotland and Co. Fermanagh, Northern Ireland. Five lakes in total were selected: Cults Loch, Barhapple Loch and Black Loch of Myrton from south west Scotland, and Derryhowlaght Lough and Ross Lough in Co. Fermanagh. By analysing the lake sediments near the crannogs using palaeoecological/environmental techniques, a more detailed concept of the timing and use of these sites can be formalized. The approach employed in this study explores multiple lines of evidence, where the lake cores were analysed for their geochemical proxies (loss-on-ignition, magnetic susceptibility and X-ray fluorescence) as well as their fossil diatom and pollen assemblages. By examining those sediments dating from around the time of the crannog, disturbances in the lake ecology as a result of the crannog can be identified and explored. The geochemical and diatom records show varying responses, indicating that crannogs had a wide range of impact upon the lake ecology. Some sites indicate eutrophication and acidification, while other sites indicate increased erosion rates. The most common crannog related disturbance is a minor deforestation event around the time of the crannog construction, indicating that the large wooden component of the crannog would have impacted nearby woodlands. In some sites a secondary occupation period showed a stronger palaeoecological response than the estimated depth of the crannog construction. By comparing the long term lake records within these regions, it was also possible to identify large scale regional disturbances. The Scottish crannogs appear to have been built between major deforestation phases in the catchment, while the sites in Co. Fermanagh indicate a major deforestation phase taking place after the main construction phase of the crannogs. In Co. Fermanagh this deforestation phase was synchronous with catchment erosion and increases in planktonic and periphytic diatoms. These disturbances all took place around the end of the Early Medieval Period. There are some limitations to the study, as all of the palaeoecological sequences would benefit from an improved age-depth model and an improved understanding of the interactions between diatom taxa in shallow lakes. Overall this thesis identified the potential of applying palaeoecological analyses to lake cores in these highly disturbed sediments and contributed to an understanding of this common occupation type and place in the landscapes of the North-West of the British Isles.

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DECLARATION OF AUTHORSHIP

I, Thierry Fonville, declare that this thesis and the work presented in it are my own and have been generated by me as the result of my own original research.

Palaeoenvironmental Investigations of Crannogs in South west Scotland and Co. Fermanagh

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. Parts of this work have been published as: [please list references below]:
   Fonville 2010, Cults Loch palaeoecology, in Cults Loch interim report, Cavers and Crone. AOC Archaeology
   Fonville 2015. Core stratigraphy. In Black Loch of Myrton interim report, Cavers and Crone. AOC Archaeology

Signed:...

Date: ....

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Definitions and Abbreviations

Crannog:	an artificial island built mainly in the Iron Age and the Early Medieval period
Diatom:	a type of mainly photosynthetic aquatic algae, see section 1.3.2
Epilithic:	diatom taxa growing on rocks
Epipelic:	diatom taxa growing on sediments
Epiphytic:	diatom taxa growing on plants
Episamnic:	diatom taxa growing on grains
Eutrophication:	the enrichment of the environment with nutrients, such as phosphates, nitrates and silica
Frustule:	the silica rich cell wall of diatoms which is very resistant to degradation, see section 1.3.2
Iron Age:	the period when iron artefacts became common, c. 800 BC – 300 AD, see also section 1.5.2
LOI:	loss-on-ignition, see section 1.4.2
MS:	magnetic susceptibility, see section 1.3.2
OM:	organic matter
Periphytic:	growing on and around plants
Pollen:	reproductive cells from plants and trees that can be identified to taxa, see section 1.3.3
Planktonic:	a taxon living in the water column
Ráth:	a circular ringfort, commonly dated to the Early Medieval period
Taxon:	the species or genus as identified from the fossil remains of the organism, plural taxa
Turbidity:	a measure of the cloudiness of fluids, mainly related to microscopic particles which are in suspension when sufficiently agitated
Tychoplanktonic:	a taxon that can exist both planktonic as well as attached to substrates
XRF:	X-Ray fluorescence, see section 1.3.1

Chapter 1: Introduction

1.1 An introduction to crannogs

Over the course of the 19th Century, the water level of many Scottish lakes was lowered to allow access to areas of arable land. During these drainage activities, wooden structures on elevated mounds were revealed in Scotland in several locations. Upon further inspection and archaeological analysis, it came to be believed that these were man-made islands (e.g. Stuart, 1865, Munro, 1882, Blundell, 1912-1913). The standard of these initial excavations was quite different from modern archaeological excavations and many of the sites were found by farmers trying to reclaim the land, as noted in one of the earliest extensive works on crannogs, the 19th century book “Ancient Scottish Lake Dwellings” by Robert Munro (Munro, 1882):

> “When subsequently engaged in reclaiming the bog, Mr. Hay states that as many as thirteen cart-loads of timber were removed from the "Knowe" and he distinctly remembers that, in consequence of the difficulty of detaching some of the beams mortised into others, his father then made the remark, *there maun hae been dwallers here at ae time*."

As the discovery of these sites was preceded by the discovery of pile dwellings in Switzerland (Keller, 1854), it was believed at that time that these were analogous. These discoveries fuelled many of the initial excavations, driven by the possibility of prehistoric bronze artefacts. Over the course of the 20th century, however, it became apparent that the Central European pile-dwellings were often from the Neolithic and Bronze Age. Furthermore they were more often built on the edges of lakes (e.g. Menotti, 2001, Vogt, 1955), rather than being dwellings that were surrounded by water.

Crannogs are artificial islands created in lakes in Ireland, Scotland and Wales. The Middle Irish word *crannóg* means 'small or young tree' (Fredengren, 2002), hinting at the wooden component that is usually found in crannog deposits. The Gaelic Scottish form is *crannag*, with a similar meaning as the Middle Irish form. They were also called 'knowe' in Scotland, meaning a small rounded hill, a hillock or a mound (Scottish Language Dictionaries).

Towards the end of the 19th Century it had already been noted that the Irish and Scottish crannogs more often had iron artefacts, compared to the lake dwellings of the Alps, which were more dominated by stone and bronze artefacts (Wilde, 1857-61). These dates were later verified with the establishment of modern dating techniques (Dixon, 1984a, Evans, 1966, Baillie, 1982b, Crone, 1988, Guido, 1974), indicating that the Scottish crannogs are general younger and belonging to the Iron Age.

Although a few hundred crannogs have been explored across the UK and Ireland and even fewer have been excavated in the last three decades, the majority of excavated crannogs are Scottish and most were excavated before 1920 (Morrison, 1985, Cavers, 2010, Fredengren, 2002). Thus, these excavations were not carried out using modern stratigraphic controls and recording methods, leading to some difficulties in synthesising the sites (e.g. Morrison, 1985, Cavers, 2010, Munro, 1882).

1.2 Project rationale and overview

The aim of this study was to apply a suite of palaeoecological proxies to selected lake cores associated with crannogs. Currently there is limited understanding of the impact that these archaeological sites can have on lake ecology, with studies mainly focussing on environmental reconstructions using the archaeological remains (e.g. Crone, 2000, Dixon, 2004, Cavers, 2010), apart from one study on lake sediments near crannogs in Ireland (O'Brien et al., 2005, Fredengren et al., 2010). This study in Ireland indicated that crannogs can be ideal in this respect given their proximity to the lake sediments and the direct impact upon the lake ecology. By analysing the lake sediments dating to the time of the crannog construction and use, it is possible to infer key disturbances related to the life of the crannog.

As this study relies on lake cores from different regions (Co. Fermanagh and south west Scotland), it is possible to infer the impact of crannogs on lakes within these regions. These regions are of particular interest as they contain large numbers of dated crannogs from the two main crannog construction phases, i.e. the Iron Age and the Early Medieval (Crone, 1993, O'Sullivan, 1998). By investigating the information from the lake sediments it is possible to gain a deeper understanding of the impact of the main crannog building communities upon the landscape and the ecology of the lake in which they were built.

A number of previous studies have employed both palaeoenvironmental and archaeological techniques to investigate crannog sites. Four sites in particular represent the most comprehensively excavated examples of crannog sites using these methods: the crannog of Llangorse Lake in Wales, Oakbank crannog in the Scottish Highlands, the Buiston crannog in the Scottish lowlands and finally Ballywillin crannog in Lough Kinale, in central Ireland. These examples will be discussed in greater detail in section 1.6.

One of the reasons why little research has been attempted on lake cores near archaeological sites, is that most palaeoecologists would avoid trying to collect sediments from heavily disturbed lakes, as they are more likely to have a disturbed stratigraphy. However, the approach taken at Lough Kinale (see section 1.6.5, O'Brien et al., 2005) can be regarded as the basis for further research studies. During this study, a lake core was taken adjacent to the crannog palisade. This methodology allows determination of the regional palaeoecology together with several indicators for crannog activities. By application of a wide range of palaeoecological techniques, a large amount of information can be combined to more robustly reconstruct the palaeoenvironments. Linking archaeology and palaeoecology has the potential to provide further insight on the influence of changing climates on prehistoric and Early Medieval cultures living in the British Isles.

By analysing the suite of proxies applied to the lake cores, it would be possible to develop a crannog detection 'toolkit', which would allow palaeoenvironmental analysis to identify crannog construction and occupation phases in the lake sediments. Furthermore, the lake sediments can provide a wealth of information on the crannog and the landscape surrounding it, which would have been far more expensive and time consuming to explore by standard archaeological means. By analysing the lake cores, it would be possible to select key sites that have indicated their potential, allowing archaeologists to focus on the most rewarding sites. To address the apparent gaps in the knowledge of crannogs, the palaeoecological approach is able to address a specific set of questions:

1) Are there disturbances in the palaeoenvironmental record that are related to the crannog?
    1.1) Which proxies are most suitable for detecting crannog-related palaeoecological disturbances?
    1.2) Are there differences between the proxies in their detection of crannog-related palaeoecological disturbances?
2) Are these disturbances comparable across crannogs from different archaeological periods and/or different geographical regions?
    2.1) How are the crannog-related disturbances from Early Medieval Northern Irish crannogs different from Iron Age south western Scottish crannogs?
    2.2) How do the crannogs from Co. Fermanagh and south west Scotland relate to the archaeological record from their catchment?

1.3 Palaeoecology

Palaeoecology is the study of past ecology and revolves around the reconstruction of historic environments using remains or indicators of these environments found in sediments (Berglund, 1987). By identifying and analysing how these remains change over time, it is possible to infer how the lake ecology and the surrounding landscape changed over time. The use of palaeoecology in this thesis is diverse and embraces the multi-proxy approach, meaning that rather than relying on the interpretation of a single proxy, it attempts to combine information derived from multiple proxies for a holistic understanding of changes in the lake sediments (Birks and Birks, 2006). In this thesis, sediments from the cores will be analysed for diatoms, pollen and geochemical sediment composition. This suite of analyses will provide information on disturbances from the lake (e.g. from diatom and geochemical analyses), as well as from the catchment (pollen and geochemical analyses) to determine some of the aspects of how crannogs have impacted upon the lake ecology including the surrounding landscape.

1.3.1 Geochemistry

Geochemistry encompasses many aspects of the analysis of the chemical components of sediments (Boyle, 2001). In lake sediments, these components reflect changes in organic and minerogenic matter. The most common technique used to estimate the organic matter content of core samples is loss-on-ignition (LOI, Dean, 1974, Heiri et al., 2001). The accumulation of organic matter in lake sediments represents the balance between the deposition and decomposition of organic matter, indicating that sediments with a high organic matter content are either derived from a very productive ecosystem or have a low decomposition. The carbonate components of sediments can also be inferred from the LOI, as this can make up a large component of lakes in a limestone-rich catchment or in certain lake ecosystems with a large amount of carbonate-producing plants (e.g. Charophytes).

Table 1.3.1 The main XRF derived elements and their interpretation from this thesis, adapted from Croudace et al. (2006) and Rothwell et al. (2006).

XRF elements	Interpretation
K	K is commonly associated with detrital clay and may be enhanced in turbidite muds
Rb	Rb is an element commonly associated with detrital clay and may be enhanced in turbidite muds
Zr or Ti	Zr and Ti are high in resistate minerals and may be enhanced in turbidite bases
	Useful as sediment-source/provenance indicators
Si	Important terrigenous or productivity indicator
	Normalisation using detrital divisor (e.g. Ti) can distinguish terrigenous or productivity origin
	May be useful as a sediment-source and provenance indicator
Fe	Commonly shows grain-size-related fractionation effects
	Fe mobilized during redox-related diagenesis and elevated Fe commonly seen in oxic, or formerly oxic, parts of sediment
Cu	Sharp Cu peaks are largely of diagenetic origin
Mn	Good indicator of redox-related diagenesis

Magnetic susceptibility (MS) revolves around the remnant magnetic activity of minerogenic particles (Dearing, 1999, Sandgren and Snowball, 2001). Increases in MS are related to increases in ferromagnetic or canted antiferromagnetic minerals, which usually identifies periods of increased erosion, while low levels of MS typically relate to high amounts of diamagnetic or paramagnetic minerals, which derive from organic matter.

A recent advance in geochemical analyses of sediment cores is the development of the ITRAX core scanner (Croudace et al., 2006, Rothwell et al., 2006), which allows a semi-quantitative assessment of the elemental components of the sediments by X-Ray Fluorescence (XRF). This technique allows the rapid, non-destructive analysis of a large range of chemical elements at a high resolution. Examples of the properties measured and the interpretation can be seen in table 1.3.1. There is a distinct lack of XRF analysis of shallow lake and wetland ecosystems, as these often contain sediments low in minerogenic matter, which is a primary component for the XRF analyses. Furthermore, the high water content of the cores can be a complication that will influence the counts.

1.3.2 Diatoms

Diatoms are small (2-200 µm) photosynthetic algae which can live as planktonic algae in the epilimnion, attached to various substrates (e.g. plants, sediments), or a combination of both (Jones, 2007, Round et al., 2007, Barber and Haworth, 1981). They are important members of the planktonic food chain and play a key role in the global carbon cycle. They share biogeochemical features of both plants and animals and have a well-documented fossil record from the middle Cretaceous (Jones, 2007). As the cell wall of diatoms is heavily impregnated with silica ($SiO_2 \cdot nH_2$), they preserve well and can be identified up to a subspecies level under a light microscope. The frustule is boxlike in structure, composed of two halves, called valves, which can viewed under the light microscope at high magnification (x1000). These valves have elaborate structures, such as spines, areolae, raphes and septae, which allows determination of species and occasionally sub-species. As many as 200,000 species have been identified to date, with many of the genera recently being re-evaluated as scanning electron microscopes have allowed a more detailed taxonomy of many species. However, this has led to many nomenclatural changes since the initial description of diatoms almost 160 years ago (Jones, 2007).

Diatoms can be grouped into three main types: centrales, which are round, and pennates, which are elongated species and can be split into raphid and araphid pennates (see figure 1.3.1). The main centric genera in shallow freshwater lakes are *Cyclotella*, *Stephanodiscus*, *Cyclostephanos* and *Aulacoseira*. Of these, *Cyclotella* and *Stephanodiscus* are euplanktonic, indicating that they are probably adapted to specific light and nutrient concentrations and prefer more stratified waters (Happey, 1970). *Aulacoseira* and *Cyclostephanos dubius* are slightly more complicated, as they have been found attached to substrates (Gibson et al., 2003), indicating that they might be classified as tychoplanktonic genera. The genus *Stephanodiscus* is a good indicator of mesotrophic to eutrophic lakes, while *Cyclotella*, *Cyclostephanos* and *Aulacoseira* have a large range across oligotrophic to mesotrophic lakes (Van Dam et al., 1994, Bennion et al., 2004a), for example *Aulacoseira granulata* and *Cyclotella ocellata* are considered mesotrophic, while *Aulacoseira alpigena* and *Cyclotella distinguenda* are considered oligotrophic (Van Dam et al., 1994).

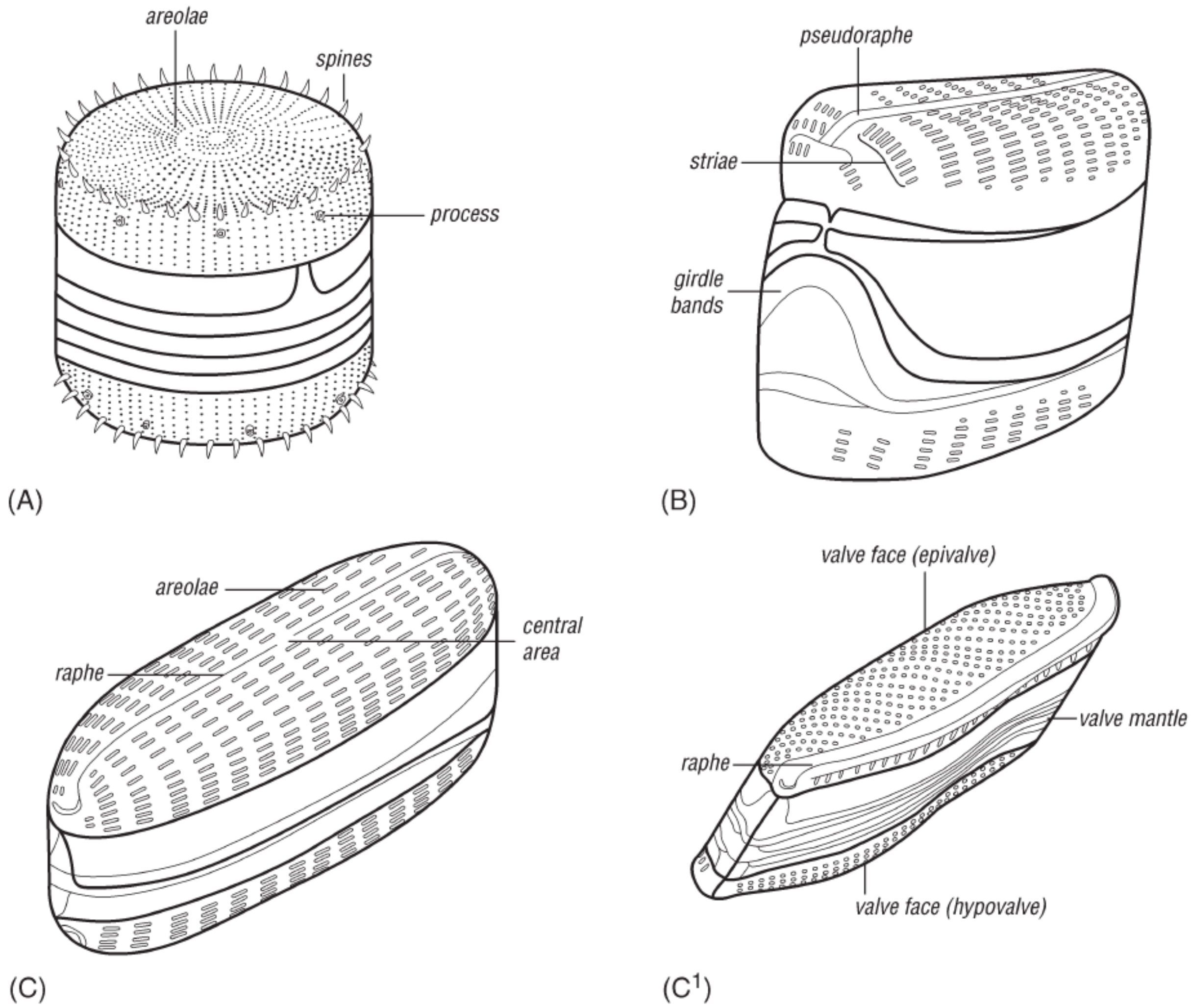


Figure 1.3.1 Frustule morphology of the main diatom types: (A) Centric diatom, (B) araphid pennate, (C) raphid pennate, symmetrical, (C^1) raphid pennate, asymmetrical. From Jones (2007).

Araphid pennates are almost all tychoplanktonic taxa, which are mainly fragilarioids, from genera that used to be called *Fragilaria*, for example *Staurosira, Staurosirella, Pseudostaurosira, Stauroforma* and *Ulnaria*, as well as *Tabellaria*. These taxa are facultative planktonic and are normally loosely attached to substrates (plant, rocks or sediment), but when they get agitated they become planktonic while they sink to the bottom or attach to substrates again. These taxa are very common in shallow lakes, where the near-constant circulation provides good access to nutrients in the water column and the lack of stratification has a negative impact on taxa less adapted to circulation, such as euplanktonic taxa. However, araphid pennate encompass a wide range of habitats, with some taxa predominantly euplanktonic, such as *Fragilaria crotonensis*, while others are predominantly attached to substrates, such as *Fragilaria capucina*.

In this thesis the taxon *Staurosira* cf. *elliptica* is separated from the other small fragilarioid taxa on the basis of striae length (reaching the middle of the valve), striae thickness (15-25 str./10µm) and outline (elliptic). Recent SEM studies have been able to identify several taxa which appear similar under the LM (Morales et al., 2010). For purpose of the palaeoenvironmental interpretation, these valves will be grouped under *Staurosira* cf. *elliptica*.

Raphid pennates are more or less all periphytic, i.e. diatoms that grow on or near plants. Periphytic diatoms have the highest species diversity, but often only make up a small amount of the total count (Round et al., 2007). To assist in the interpretation of the periphytic environment, these taxa were split into groups based on their attachment type (see also figure 1.3.2). These groups can provide more information on the diatom community structure (Hoagland et al., 1982, Wang et al., 2014, Passy, 2007, Hudon and Legendre, 1987). Stalked taxa are attached with one of their apices to a substrate (i.e. upright), commonly macrophytes or other algae; prostrate diatoms are attached with their valve face to a substrate with a mucilage pad (i.e. flat). Increases in stalked taxa can indicate a low energy environment, as well as increases in nutrient levels, while prostrate taxa are more common in high energy and coarser grain size environments, where stalked taxa would be prone to abrasion and grazing. Finally, motile diatoms have moderate to high mobility and are mainly epipelic. Increases in motile taxa have also been linked to higher benthic nutrient levels (Passy, 2007).

Species can also be classified into categories based on their ecological preferences, for example trophic status, pH and saprobity. These categories were based on initial work by Husted (Hustedt, 1927-1964) and more recently Van Dam (1994). As non-planktonic taxa were not common in the lakes analysed and araphid diatoms were dominant, it was chosen not to pursue transfer functions, as the taxonomy and therefore ecological categories for fragilarioids are poorly understood (Sayer, 2001, Morales et al., 2010).

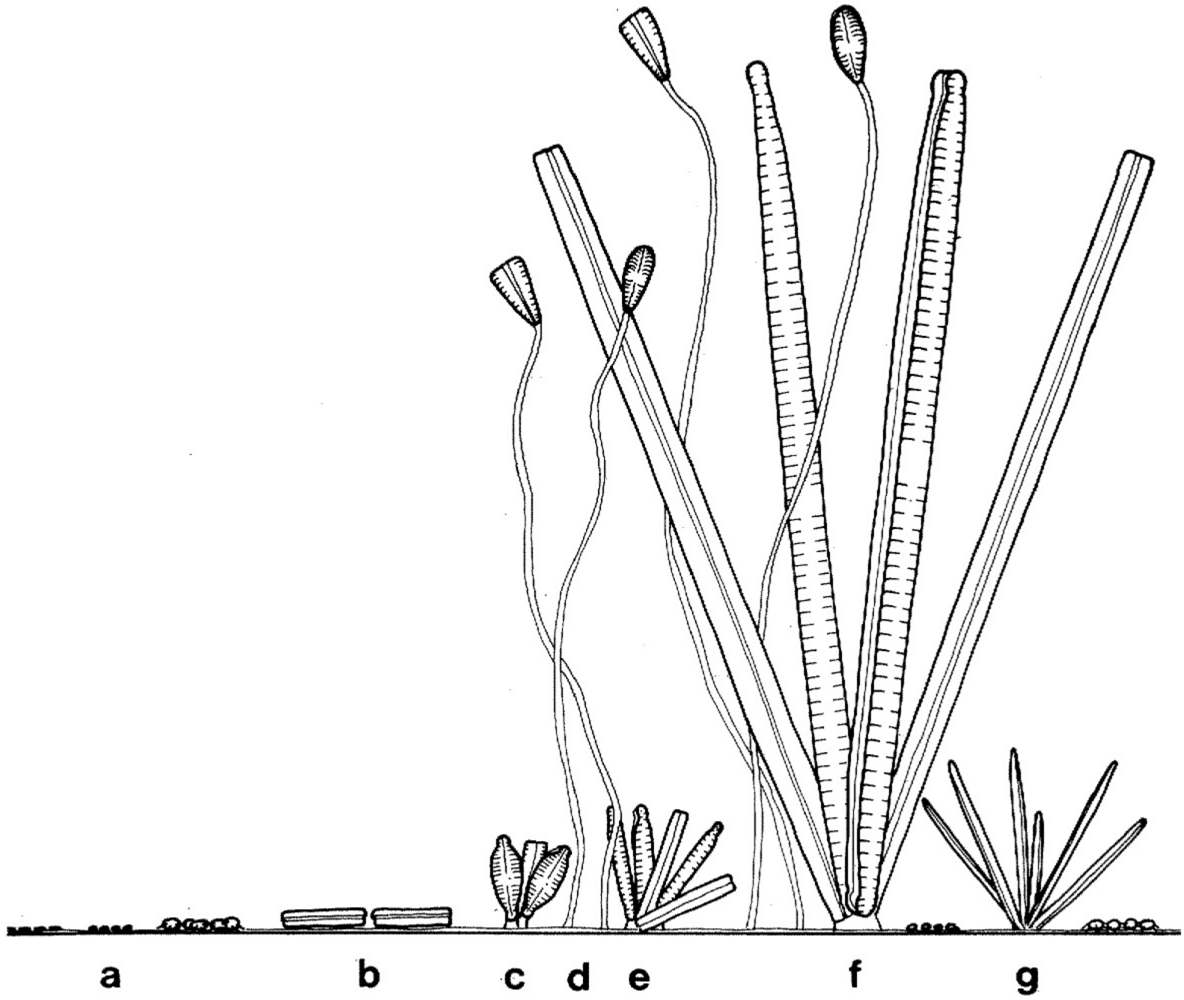


Figure 1.3.2 Sample vegetation structure of diatoms: (a) attached bacteria, (b) *Navicula menisculus*, prostrate attachment, (c) *Gomphonema parvulum*, short stalks, (d) *Gomphonema parvulum*, long stalks, (e) *Fragilaria vaucheriae*, rosette, mucilage pads, (f) *Synedra acus*, large rosette, mucilage pads, (g) *Nitzschia* sp., rosette, mucilage pads. Adapted from Hoagland et al (1982).

1.3.3 Pollen

Pollen grains contain the reproductive cells (male gametes) of seed plants. Pollen grains are commonly used in palaeoenvironmental studies, as the cell walls contain sporopollenin, which is very resistant to degradation and preserves well in soils and sediments. Together with spores (reproductive cells of mosses and ferns) the identification of these cells are the basis of pollen analysis. The pollen and spores are usually identified to the genus level, but can frequently be identified to species level as the pollen grains have a unique morphology for each species based on the number of furrows, pores and the surface pattern (Moore et al., 1991, Beug, 2004).

Pollen can accumulate in lake sediments via a few modes of transport. Some pollen grains are dispersed via wind (anemophilous), while others are dispersed via animals (zoophilous). The morphology affects the distance that a pollen grain might travel. For example, pine tree pollen are composed of air sacs (sacci) and lightweight pollen grains that allow them to travel hundreds of miles from where they were produced, while zoophilous pollen travel much shorter distances. Furthermore, many of the wind-pollinated plants produce copious amounts of pollen (e.g. 350 million from one 10-yr old pine branch), while most animal pollinated plants produce a magnitude less. This is not the case for all zoophilous plants, as for instance lime, willows and heather produce comparable amounts of pollen as anemophilous plant (Broström et al., 2008).

Pollen analysis is commonly used to reconstruct the landscape vegetation structure of the catchment. A high amount of tree pollen is usually indicative of extensive woodlands, while increases in herbs and grasses are indicative of meadows and pastures. Specific herb taxa are often used to indicate human disturbances to the natural vegetation and the main anthropogenic indicators (Behre, 1981) identified in this thesis are: cereal-type, *Matricaria*-type, Cichorioideae, Chenopodiaceae, *Humulus*/*Cannabis*-type, *Plantago lanceolata*, *Polygonum*, Ranunculaceae, Rubiaceae, *Rumex acetosa*/*acetosella*-type and Urticaceae. Currently, the landscape in Scotland and Northern Ireland is dominated by extensive pastures, as well as frequent pine plantations. It was not until the Bronze Age that large areas of oak and hazel woodlands were deforested in south west Scotland (Edwards and Whittington, 2003, Tipping, 1997). In Northern Ireland, similar large-scale woodland clearance may have taken place much later, with evidence of extensive deforestation during the Early Medieval period (Mitchell, 1956), although locally disturbances might have taken place during prehistoric times.

1.3.4 Limnology of shallow lakes in the British Isles

To tie together the information from the above proxies, it is important to consider the ecology of shallow lakes, which are ideal lakes for crannog construction, as well as a common lake type on the British Isles. These lakes are comprised of a relatively small body of water compared to their surface area and are continuously influenced by wind shear, which mixes the water. Macrophytes can be abundant and can be a relatively large part of the primary productivity, while planktonic algae have to be adapted to the constant circulation. Shallow lakes appear to be subject to bifurcation, with either clear water with abundant macrophytes or turbid without macrophytes (Scheffer, 2004). The interaction between turbidity and macrophytes is considered to be at the centre of shallow lake ecosystems, as both states are self-reinforcing (figure 1.3.3).

Palaeoecological studies and particularly diatoms have been successfully applied to investigate shallow lakes and their nutrient status. For instance Groby Pool (Leicestershire, England) was investigated using this approach to determine when and how the lake switched from a clear water to a turbid lake ecosystem (Sayer et al., 2010). Another study exploring the eutrophication of shallow lakes was the study of diatom assemblages in Lough Augher (Co. Tyrone, Northern Ireland) by Jon Anderson (Anderson, 1990a, Anderson, 1989). Furthermore, diatoms from shallow lakes have been investigated during studies on acid rain (Battarbee et al., 1984), which have been more recently applied to construct pH transfer functions for south west Scotland (Bennion, 1994). However, it has been noted that shallow lakes are particularly difficult for estimating nutrient status, due to high abundance of araphid diatoms, which have poorly understood nutrient optima (e.g. Sayer, 2001).

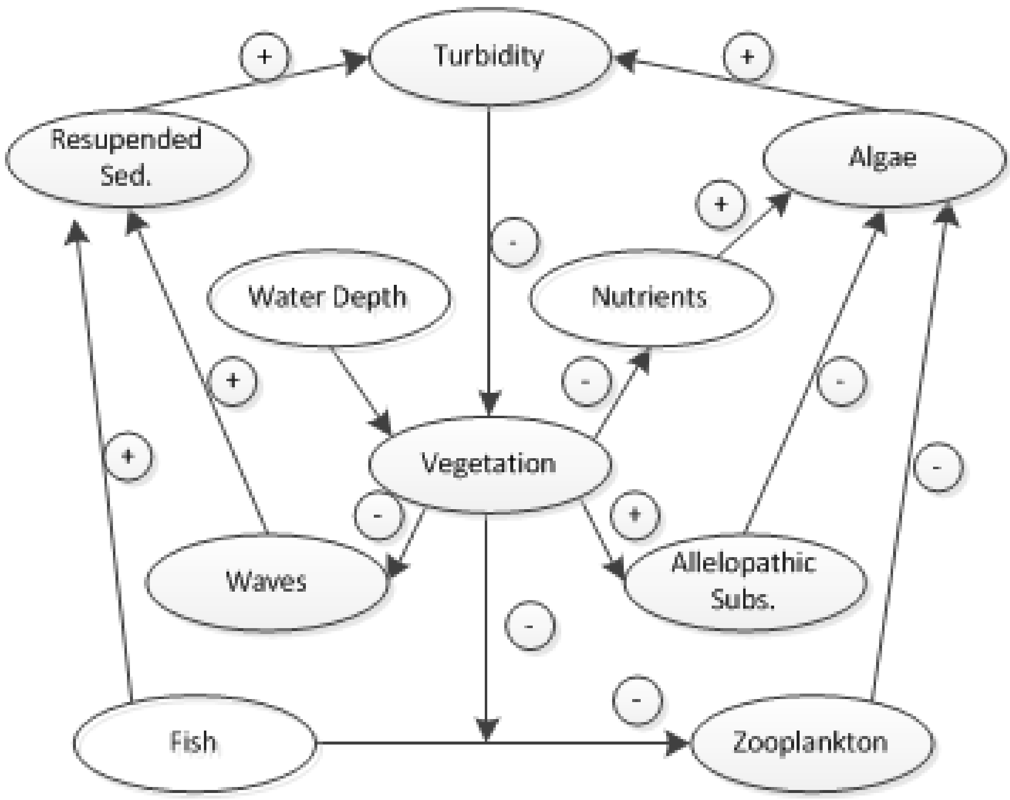


Figure 1.3.3 A diagram of whole system feedbacks in shallow lakes. Note the central position of vegetation in the diagram and how both vegetation and turbidity are self-reinforcing. Redrawn from Scheffer et al (1993)

1.3.5 Late Holocene climate

In order to understand whether disturbances in lake sediments are related to human impact or natural variation in the environment, it is important to reflect on the long-term climate of the British Isles, for example evidence from continental pollen assemblages (figure 1.3.4).

These last c. 11,600 years can be divided into three phases (e.g. Nesje and Dahl, 1993, Wanner et al., 2008). The first phase lasted from approximately 11,600 to 9000 years BP, while the second phase lasted from approx. 9000 to 5000-6000 years BP. During this phase, warmer conditions were experienced in northern latitudes. The final phase lasted from approx. 5000-6000 BP until pre-industrial times. This phase was significantly cooler and is sometimes referred to as the “Neoglacial”. These three phases were driven primarily by orbital forcing, in combination with the collapse of the North American icesheet during the second phase under continuous high summer insolation in the northern hemisphere.

The latter half of this third phase will be discussed further in this section, as it overlaps with some of the crannog occupation phases. As the crannog sites analysed in this thesis are younger than 3000 cal. BP (see chapter 4), this final phase is good point to start describing climate change in detail.

Palaeoecology offers excellent opportunities for reconstructing past climate and much work has been done on understanding Late Holocene climate, in particular using peat stratigraphy (Barber, 2007) and pollen analysis (Birks, 1989). There is good evidence of distinct wet and dry phases in the peat bogs in Ireland and Northern Britain (figure 1.3.5), however, they are not always in phase between sites (e.g. Barber et al., 2003, Langdon and Barber, 2005). Between c. 6000 and 4400 cal. BP, there appears to have been a dry period in Northern England and Central Ireland (Barber et al., 2003), while between 4400 and 1500 cal. BP it was distinctly wetter. These observations agree with northern Scottish peat records (Anderson et al., 1998) and English palaeochannel studies (Brown, 2008). However, when Scottish peat bogs were analysed with high dating precision across a large geographical range, it appeared that short-term fluctuations were not always in phase and might be considered regional on short time scales (Langdon and Barber, 2005). From about 1000 cal. BP onward, historical records become available and allow comparisons with the palaeoecological data (Lamb, 1965, Lamb, 1977, Lamb, 1995). Around that time a warm phase has been described (Lamb, 1965), while from around 650 BP cooler conditions appear to indicate higher bog wetness (Barber et al., 1994).

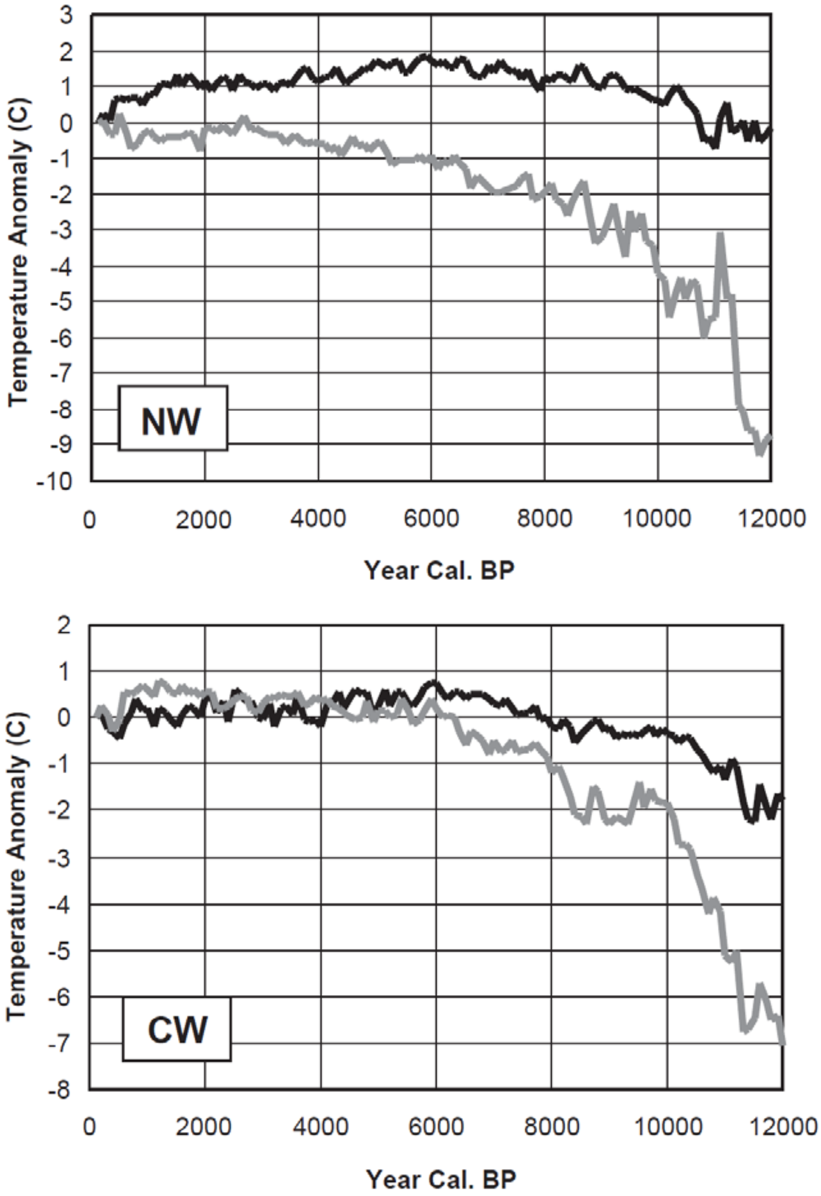


Figure 1.3.4 Pollen mean temperature reconstruction for North Western (NW) and Central Western (CW) continental Europe from Davis et al (2003) over the last 12,000 years. The light grey lines indicate the coldest month temperature anomaly, while the black lines reflect the warmest month temperature anomaly

When looking at lake accumulation rates in Scotland (Edwards and Whittington, 2001), catchment processes appear to be a driving force for lake disturbances. From the Neolithic period onwards (c. 5100 BP) accelerations in lake sedimentation take place, driven by catchment disturbances. These changes in sedimentation rates are a synthesis of soil availability, woodland density, peat growth and human population pressure in the catchment. This highlights the likelihood of human impact on lake sediments during the time period of the crannogs and highlights lakes as indicators of human disturbances. As this study is not an attempt to understand climate change during the late Prehistoric and Early Medieval periods, no additional cores were analysed from the sites, nor were nearby cores collected from, for example, peat bogs. The multi-proxy approach employed here is an attempt to understand catchment and crannog disturbances, rather than climatic influences. Where possible, the sites will be compared to regional climatic records from more undisturbed sites if neither catchment nor crannog can be a satisfactory explanation for palaeoenvironmental disturbances.

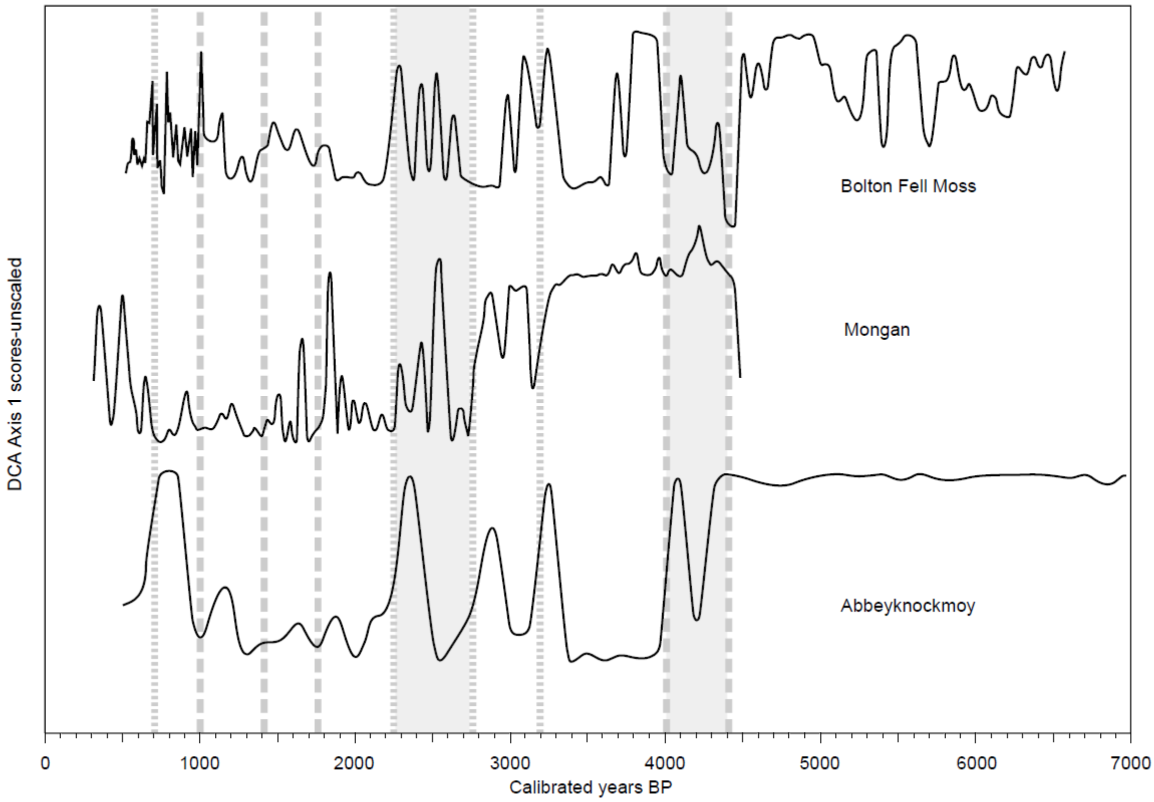


Figure 1.3.5 DCA axis 1 scores for bogs in Northern England and Western Ireland, from Barber et al (2003). Peaks indicate dry conditions, while troughs reflect wetter conditions. The shaded zones are major phases of change while the dashed lines are minor changes that are evident in at least two of the sites

1.4 Archaeological and palaeoecological dating techniques

Several techniques are available to estimate the age of an archaeological site. The most common technique which has been used to date archaeological sites is the identification of the cultural period to which the artefacts belong. Currently there is a good amount of knowledge about for instance the types of pottery belonging to for example the Iron Age, Roman Period or Medieval periods. A recurring type of pottery found regularly on Irish crannogs is crannog ware pottery (e.g. Ivens, 2001). Similarly, when metal, stone or wooden objects are discovered, it will often be possible to determine roughly to which period this object will belong, by comparing it to objects found at similar sites. This will give an estimation of when the crannog was occupied. Occasionally there are a few surviving references dating from before the Early Medieval Period, found in either historical record or oral traditions. Examples of crannogs in historical literature are: Island MacHugh (Hennessy, 1887, O'Donovan, 1856), Loughbrickland (Lett, 1905), Llangorse Lake (Redknap and Lane, 1994), Loch of Forfar (Stuart, 1872-74) and Loch Tearnait (Blundell, 1912-1913).

1.4.1 Radiocarbon dating

A more accurate technique to date crannogs is by means of radiocarbon analysis, which is often employed on modern crannog excavations (Cook et al., 2010, Dixon et al., 2007). Organic carbon incorporates small amounts of the carbon isotope ^{14}C, the heavier isotope of stable carbon isotopes ^{12}C and ^{13}C during their life. However, upon death, this fixation stops and the unstable ^{14}C starts to decay into the stable ^{14}N. By determining the ratio of ^{14}C and ^{14}N it is possible to determine how long ago the organism died, as the isotope has a known half-life of 5730 ± 40 years, allowing organic remains to be dated to a range of 300-50,000 years ago (Reimer et al., 2013). A complication was discovered when radiocarbon dates were compared to continuous tree ring records, as the radiocarbon dates proved increasingly inaccurate in older records, which is why calibration curves have been developed (e.g. Stuiver, 1970, Reimer et al., 2002, Reimer et al., 2013), which allows a more accurate determination of when the organism died. There are a few other complications associated with radiocarbon dating, for instance, between 800 and 400 BC the ^{14}C concentration appears more or less stable. This period is called the Hallstatt plateau and is often cited as a particular problematic interval, as it occurs around the end of the Bronze Age and the start of the Iron Age. This interval is especially problematic for Scottish crannogs as many of these are dated to around this time interval (Crone, 1993). As an example, the radiocarbon date on the Cults

Loch promontory site (GU-12138, 2340 ± 50 BP) has been calibrated, indicating that it might date to between 737 BC and 211 BC (95.4%, see figure 1.4.1). This led to the development of the dating of individual tree rings for the Oakbank crannog in Loch Tay, to more accurately date the construction period using radiocarbon dating techniques (Cook et al., 2010).

Care has to be taken to submit the correct sample for dating the construction of the crannog, as difficulties often arise with determining a structural layer. As crannogs are inherently unstable and new piles might be introduced to the mound to reinforce or expand the crannog during reoccupation phases, as was the case in the Buiston crannog (Crone, 2000). This might lead to too young a date of the crannog if the pile selected was of a later occupation phase.

Radiocarbon dating is the main tool in the dating of lake sediments in this thesis, as the sediments are usually rich in organic matter. More importantly, the sediments often contain some relatively large plant remains, such as roundwood or timber fragments. As these contain a relatively large amount of organic carbon, they are ideal for dating. However, dating can be complicated by inwash of old carbon, for instance from catchment erosion or the dissolution of limestone. Furthermore, erosion events might cause slumping on lake slopes, where fragments of the slope erode downward. The most straightforward way to avoid slumps is by not coring near the edge of the lake, which is why it is important to do initial explorative coring and depth ranging of the lakes (Glew et al., 2001).

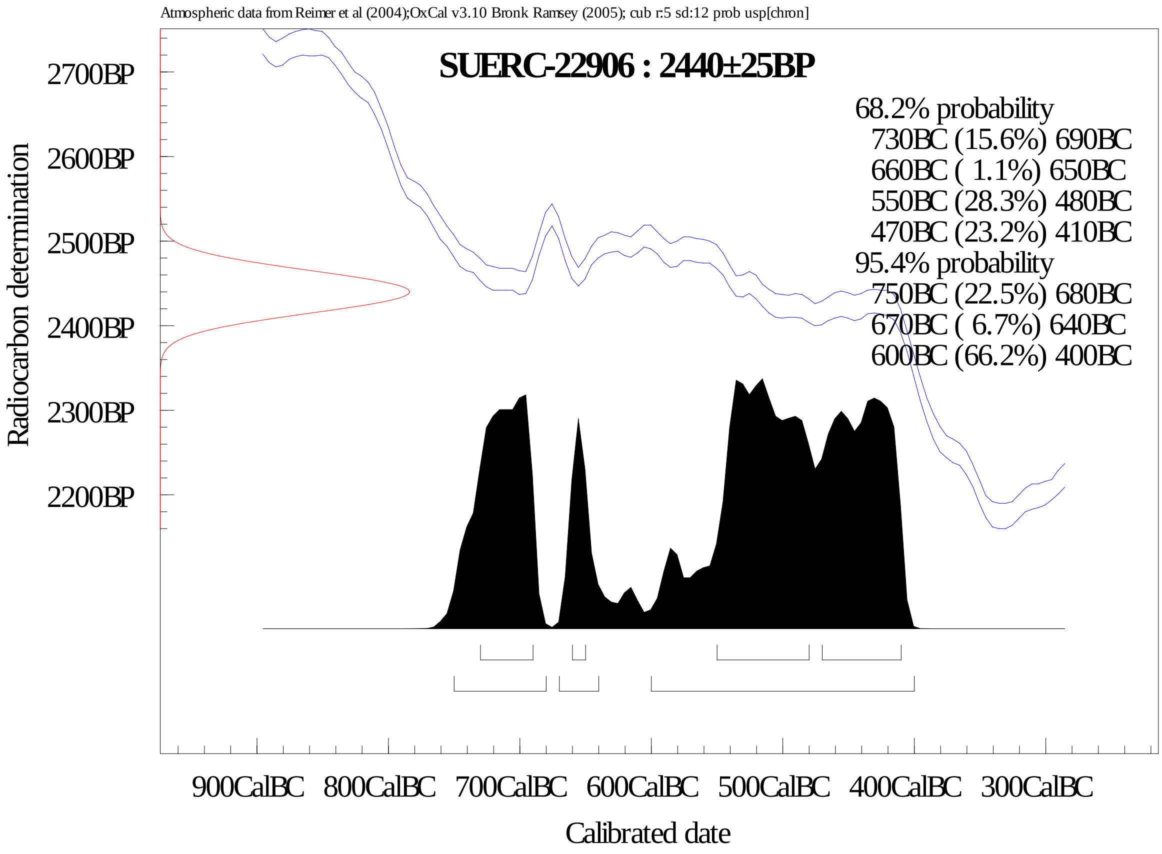


Figure 1.4.1 Calibration curve for the radiocarbon date from a pallisade pile from Cults Loch. The red curve along the vertical axis identifies the Gaussian probability distribution of the radiocarbon date, while the horizontal axis indicates the calibrated calendar age probability distribution. This specific radiocarbon range has a calibrated age range of 750-400 BC (95.4%). Produced using OxCal 4.2 (Bronk Ramsey, 2009a) based on the IntCal13 calibration curve (Reimer et al., 2013)

1.4.2 Dendrochronology

Another dating technique which is especially applicable with regards to crannogs is dendrochronology. Every year rings are added to the stems of trees and by synchronising with sequences from recent times to further back, and it is now possible to use this dating technique very reliably up to 10,000 years ago. The most often used species in Europe is oak (*Quercus* sp.). The tree rings vary in thickness depending on the environmental conditions in which the tree is growing. This can be used as both an indicator of climate, or for the development of a local or regional dendrochronological record (Baillie, 1982b). Due to the high number of well-preserved timbers and piles, tree rings have been used on several sites to determine, in very great detail, the chronology of the crannog (Crone, 1988, Crone and Cavers, 2015). By matching ring width sequences from individual pieces of wood of the same species with each other, it is possible to determine which piece was older and thus uncover the relative dates of the occupations layers. This has been done for Moynagh Lough and

Oakbank crannog (Crone, 1988) as well as the Buiston crannog (Crone, 2000). Furthermore, it might be possible to link some of these tree ring sequences with existing dendrochronological records to try and determine the age of these occupation layers. Work in Ireland and continental Europe has led to a well-established and continuous dendrochronological record spanning the last 11,000 years (Becker, 1993), compared to the shorter English and Scottish records. As there can be environmental and climatic differences between the countries, it is important to establish separate long and continuous records for each region to help with dating structures. Work is currently underway to improve the pine and oak chronologies for Scotland (Crone and Mills, 2002, Mills, 2008). Relative alder chronologies have been developed for several crannog sites (Cavers and Crone, forthcoming, Crone, 1988, Crone, 2000), as this tree has been used extensively in the construction of crannogs. However, there are several problems associated with the use of this species related to sequence length, tree structure and growing conditions (Crone, 2014).

1.5 Crannog archaeology

1.5.1 Crannog morphology, taphonomy and definition

Although excavations were not part of this thesis, it is important to assess some of the aspects of crannog archaeology. Taking into account large morphological and functional differences, crannogs are distinguishable from other wetland sites by a few particular features. They are usually artificial islands (either in lakes or bogs) which have wooden features with stone and/or clay elevating them from the surrounding water level. This includes depositing on or building-up the lake bed into islands (e.g. Morrison, 1985, Cavers, 2010). An extensive study by Cavers (Cavers, 2010) considers two types of crannogs: packwerk crannogs and free standing pile structures. The packwerk crannog consists of a built up mound of the organic deposits (e.g. brushwood, peat and turf) secured together and held in place by vertical piles and weighed down by stones. On top of this mound the occupation superstructure would have been built. Examples of this include Buiston (Crone, 2000), Ederline Boathouse (Cavers and Henderson, 2005) in Scotland and Lagore in Co. Meath (Lynn, 1986). Furthermore, these sites all indicate extensive post-depositional processes, with evidence of pile erosion and collapse associated with abandonment phases. The decay of organic matter from the mounds might also be the reason why some crannogs appear to be stone mounds rather than organic mounds, exemplified by the so called Island Duns on the Inner Hebrides (Holley, 2000, Cavers, 2010). The occupation, abandonment, reoccupation and final abandonment might lead to very complex excavation deposits, with adjacent piles potentially from different occupation periods (see figure 1.5.1).

Since the 19th century more crannogs have been found through the implementation of modern excavation techniques and as a result of radiocarbon dating it has become apparent that they were constructed at different times and were intermittently occupied and constructed for over 2600 years, from the late Bronze Age until as late as the 17th century (e.g. Fredengren, 2002). Difficulties lie with disentangling the several occupation layers, which are often found on a single crannog (e.g. Barber and Crone, 1993, Fredengren, 2002). Furthermore it has been revealed that many sites are threatened due to drainage and erosion.

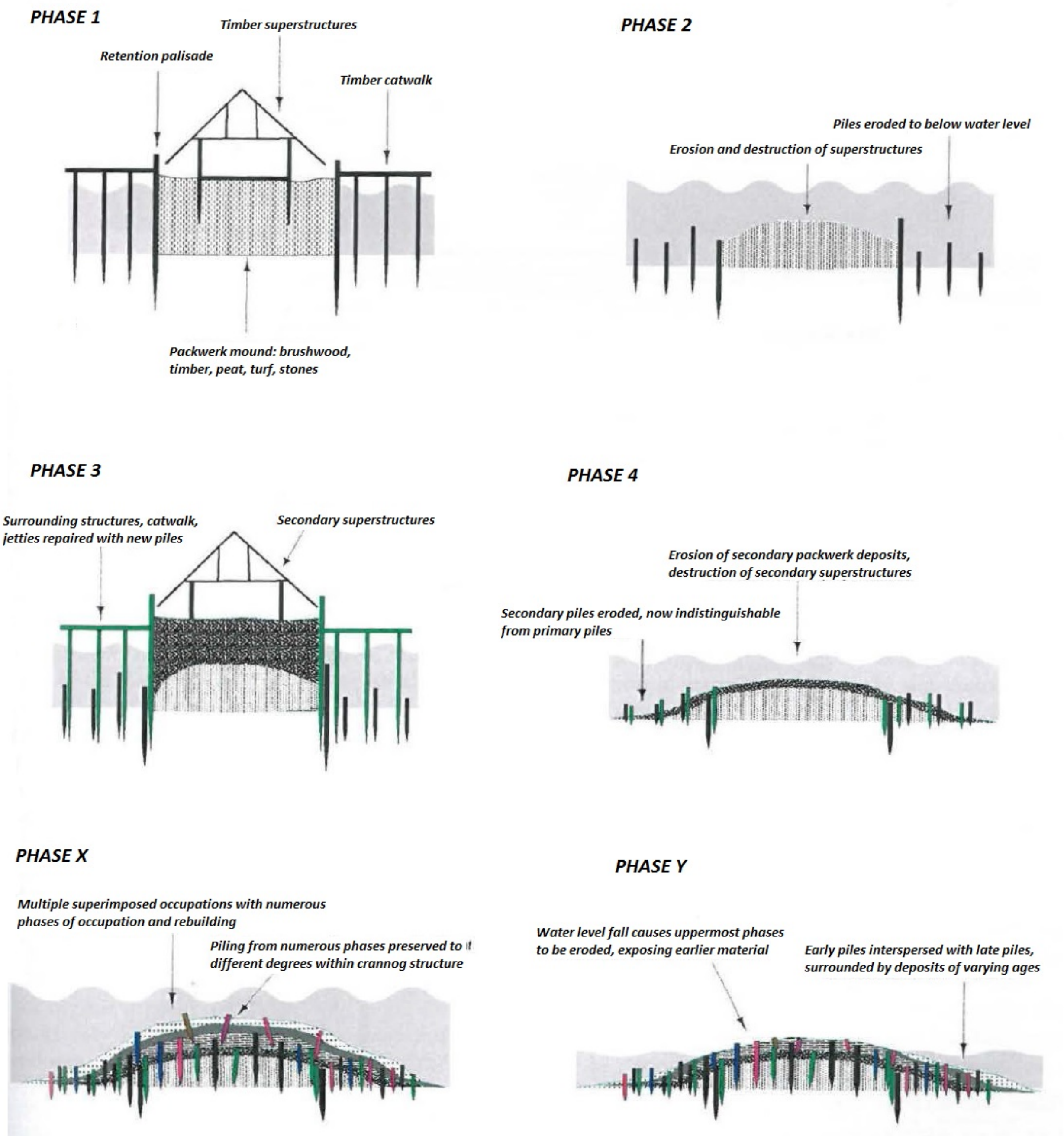


Figure 1.5.1 Packwerk crannog taphonomy, from Cavers (2010)

The sites in the South west Scottish crannog survey were evaluated for their preservation state and in a large number of cases it was revealed that the drainage facilitated increased afforestation of the sites and as a result were at risk of being turned into dry-land sites with a concomitant loss of archaeological information (Barber and Crone, 1993).

Due to changing lake levels and compaction or erosion of the crannogs, many sites are currently under water. Thus an important scientific advance in the analysis of crannogs came when modern technology and diving techniques were applied to the underwater excavation of crannogs. These modern techniques have been extensively implemented in two large

Highland lakes, Loch Awe and Loch Tay, where in total 38 crannog sites have been identified (McArdle et al., 1973, Dixon, 1984b). All of these sites have been dated to the Early or Roman Iron Age. Other examples of underwater crannog excavations can be found in the large scale surveys in Scotland and the Western Isles (Henderson et al., 2003, Holley, 2000, Hale, 2004).

1.5.2 Prehistoric and Medieval crannog communities

In order to allow some understanding of the activities that took place on and around the crannog, some knowledge of prehistoric and proto-historic communities is required. The Iron Age constitutes the latest period in prehistory and is marked by the common presence of iron artefacts in the archaeological sites (Cunliffe, 2009). In Britain, the tradition of using artefacts commonly used by older cultures, such as Bronze artefacts or Neolithic quern stones, complicates the Iron Age as a period (Cavers, 2010). For example, quern stones are very common on crannogs from the Bronze Age until the Medieval periods and were used to grind down cereal grains (O'Sullivan, 1998, Cavers, 2010). The current consensus appears to be that there are diffuse transitions between the Bronze Age (c. 2000 BC – 700 BC), the Iron Age (c. 800 BC – AD 300) and the Early Medieval Period (c. AD 300 – AD 900). The Bronze Age probably saw a rapid expansion in population across Europe (Batini et al., 2015). Conflict in the Iron Age was probably widespread, which led to increased pressure for claims of the land and the construction of for instance promontory forts, brochs and crannogs. These sites were defensive strongholds, where communities could retreat too during times of conflict. There is a distinct lack of archaeological finds related to the Iron Age from Ireland, although pollen records from bogs appear to indicate that around between 200 BC and AD 300 human impact upon vegetation declined (Mitchell, 1976). Most of the archaeological records from Ireland were either dated to the Bronze Age or the Early Medieval periods.

Scotland experienced the Iron Age slightly differently, as Scotland was hit by some of the Roman invasion, most notably with the construct of Hadrian's Wall and the Antonine Wall. In Roman history there are several descriptions of campaigns against the Picts of northern Britain. However, the Galloway region was largely unaffected by the Roman forces for most of the period, although Roman trade goods were discovered on several sites. A few trade good have been discovered in some of the main trade ports of Ireland, but there is no evidence that the Romans ever tried to conquer Ireland.

During the Early Medieval period, the population of Ireland underwent the conversion from pagan beliefs to Christianity, led by Palladius and St. Patrick. From the 4th Century AD, this led to the construction of initially small churches, but later large monasteries and other secular sites were built. These sites were important parts of the community and some sustained very large populations (Manning, 1997), which might have led locally to extensive deforestation in (Hall, 2005). It is important to note that Christianity travelled to other parts of the British Isles soon after. For example, a well-known missionaries who travelled from Ireland is St. Ninian, a saint associated with the church of Whithorn in Galloway, who is attributed with the conversion to Christianity of the southern Picts (Barrow, 1983). As crannogs are functional islands, the book shrine that was recovered from near the Tonymore crannog in Lough Kinale might indicate that crannog had another function from the Early Christian period in Ireland (Fredengren et al., 2010), as hermitages. Indeed, two larger natural islands near Enniskillen, Inishmacsaint and Devenish, were notable monastic sites during the Early Christian period (Waterman, 1979).

The Early Medieval period was a period of major social and political disturbances in Ireland, but specifically Co. Fermanagh, which was overlapped by at least three different kingdoms (Charles-Edwards, 2000a). The kingdom of Ireland was divided into multiple sub-kingdoms, each ruled by their king (see figure 1.5.1). Towards the north of Co. Fermanagh, the Northern Uí Néill sub-kingdoms Cenél nÉogain and Cenél Conail controlled most of current Co. Donegal and parts of Co. Tyrone. Towards the south west, the dominant forces were the sub-kingdoms affiliated with the Connachta, who were in alliance with the Northern Uí Néill. Towards the east of Co. Fermanagh the lands were under the control of the Aírgíalla, although their kingdom was relatively recently established during the early 4th Century AD, as the Collas made a “swordland” of half Ulster in seven days of hard fighting. After the Battle of Magh Rath in AD 637, in which the High King Domhnall II of Cenél Conail defeated the combined forces of Congal of Ulster and Domnall of Dál Riata, the Uí Néill became the dominant force in Ireland (Hennessy, 1887). The political instability of Ireland impacted western Scotland as well, as the Dál Riata kingdom spanned the Irish sea and is believed to have had their capital in Dunadd, in Argyll and Bute (Campbell and Lane, 2000), while the southern clans of Uí Liatháin and Laigin are known to have settled in Dyfed, Wales in the 4th Century AD (Coplestone-Crow, 1981).

The Early Medieval period ends with the Viking invasions and the raiding of monasteries from 793 AD, most famously Lindisfarne. The Viking invasions impacted both Ireland and Scotland, as the Viking raiders became the dominant force in the Scottish Hebrides, as well as the Shetland and Orkney Islands (Woolf, 2009). Between the 8th and 13th centuries AD the

Hebrides and the Isle of Man were largely under Scandinavian control and are considered a part of the Kingdom of the Isles (Woolf, 2007, McDonald, 2007).

Soon after the Norman conquest of England in AD 1066, south west Scotland followed towards the end of the 12th Century (Oram, 2001). In Ireland the conquest was led by Richard "Strongbow" de Clare, who led several Anglo-Norman landings from AD 1169, at the request of Diarmait Mac Murchada, who had recently be ousted as king of Leinster. Some of the key features of the Norman period are the impressive castles and tower houses, remnants of which are still standing today. It is not until the plantation of Ireland that crannogs appear in historical literature, with several descriptions of Irish rebels retreating to a crannog in an attempt to escape the English (e.g. Lett, 1905).

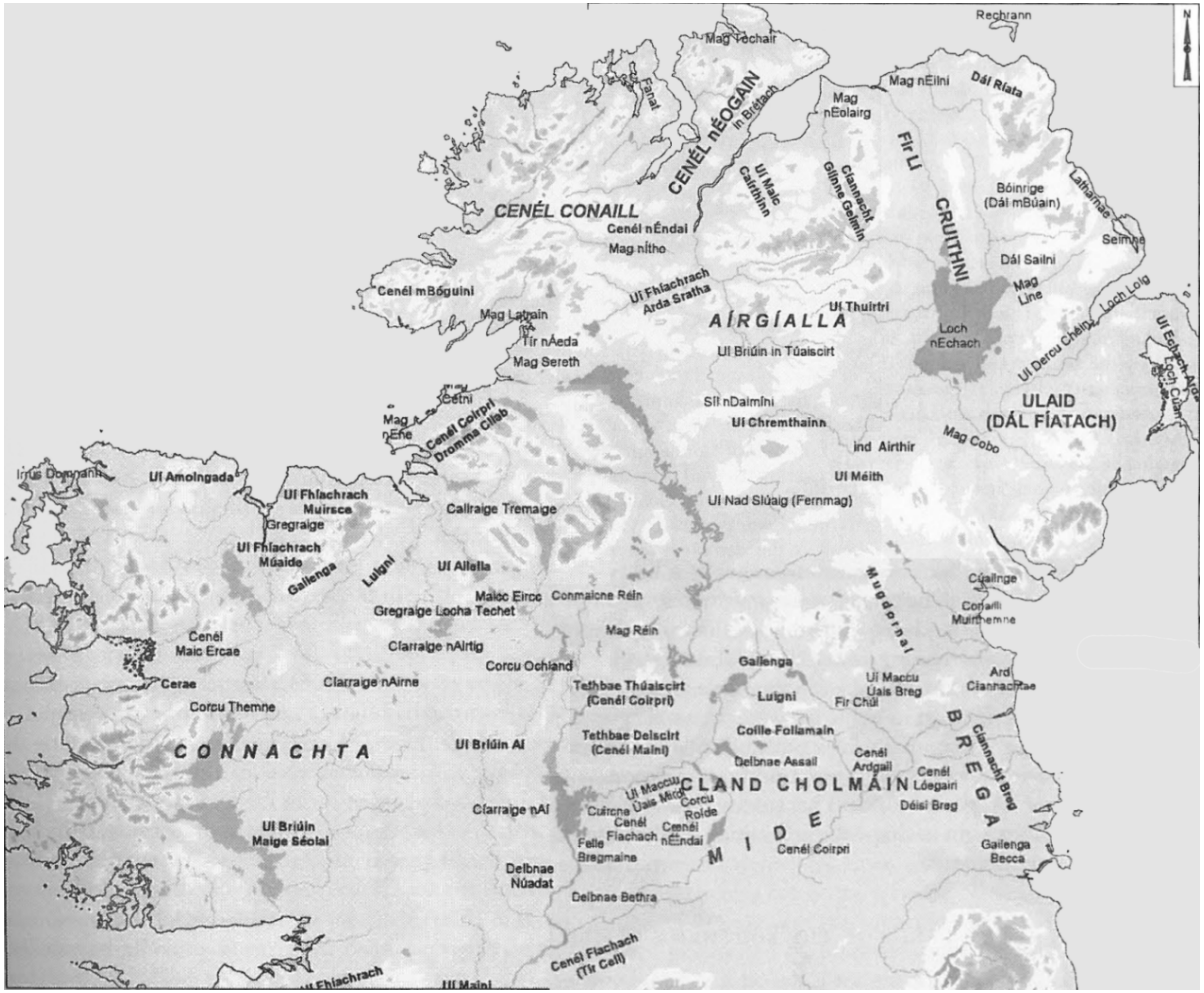


Figure 1.5.2 Map of the northern part of Ireland, indicating the distributions of the kingdoms (in bold capitals) and the people around 700 A.D. Adapted from Charles-Edwards (2000)

1.6 Case Studies

1.6.1 Introduction

At present there are a few examples of palaeoecological studies taking place at crannog sites, the most important of which summarised below. This usually involves the environmental analysis of sediments collected on site, involving animal bone, bulk sediment analysis and occasionally pollen and or insect remains. The sites discussed below are at present the most thoroughly excavated or analysed examples of crannogs, which have had both an archaeological and palaeoenvironmental analysis. By exploring these studies some inferences might be made regarding the disturbances picked up in the lake sediments relating to crannogs and it will assist in the interpretation of the lake cores from the sites analysed in this thesis.

1.6.2 Llangorse Lake crannog (Powys, Wales)

Although this is the sole crannog not in Ireland or Scotland, the crannog in Llangorse Lake has been excavated (Redknap and Lane, 1994) and the palaeoenvironmental history of Llangorse Lake is also well studied (Chambers, 1999). This makes this site a good candidate to explore further in connection with this thesis, as very few crannogs have an understanding of their lake palaeoecology.

The crannog in Llangorse lake (Figure 1.6.1) was first discovered during the late 19th century (Dumbleton, 1870). Llangorse Lake is located between the rivers Usk and Wye at 150m above sea level (Campbell and Lane, 1989). The crannog was revisited during the 20th century leading to the discovery of a logboat (Fox, 1926) and finally it was re-evaluated again from 1988 until 1993 (Redknap and Lane, 1994, Redknap and Lane, 1999). The crannog lies on the northern edge of the lake and the mound, consisting of angular and rounded boulders has an approximate diameter of 40 m. Boulders were used as one construction material, though a large amount of Mesolithic and Neolithic waste flakes were found within the mound that must have come from the surrounding dry land and which indicates the manufacturing of prehistoric tools in the proximity of the crannog. Roman artefacts have been found, though it is uncertain at what time these were deposited (Redknap and Lane, 1994). Surrounding the mound, two lines of oak plank palisades have been found. Dendrochronological dating indicates that construction of these palisades took place in the late 9th century or early 10th

century AD. The authors interpret the crannog as a royal residence of the kings of Brycheiniog, based on several historical references (Anglo-Saxon Chronicle B, Taylor, 1983). Furthermore several features led to authors linking the Llangorse crannog to Irish crannogs instead of Scottish crannogs (Campbell and Lane, 1989, Redknap and Lane, 1994).

By comparison of pollen records from several cores taken from Llangorse Lake, the Holocene vegetation history of the lake has been analysed in detail (Chambers, 1999). The earliest signs of human impact date to roughly 3800 BC. This is described as a decline in *Ulmus* (elm) pollen, together with a decrease in *Quercus* pollen. A large increase in non-arboreal pollen (NAP), specifically *Plantago lanceolata* (ribwort plantain) and *Poaceae* (grasses), has been found during the Bronze and Iron Ages (1900 BC – 100 AD), indicating substantial human impact in the region. Following this interval, there is a transition from organic mud (nekron) to red-brown silty clay, during which there is a clear reduction in arboreal taxa and increases in meadow and cultivated pollen (e.g. *Rumex* (sorrel), *Plantago lanceolata*, Cerealia). Around Iron Ages/Roman times (approx. 400 BC – 100 AD) there are major indications of human impact, with high Cerealia and *Secale* (rye) pollen. Together this might imply the clearing of woodland for arable agriculture, which elevated the sediment influx. After this period the cereal pollen decreased and arboreal pollen increased, indicating woodland regeneration. During macrofossil analysis of crannog sediments a few charred cereal remains were identified (Dowse, 1991), mostly *Tricitum* (wheat) and some *Hordeum* (hulled barley).

There is little evidence of crannog construction or occupation phases in the lake cores analysed so far. In other studies lake sediments have been analysed that were closer to the crannog, however it became apparent that the crannog is surrounded by an Early Holocene marl layer underlying half a metre of black nekron mud, which has a minimum date of about AD 220 (Walker et al., 1993, Palmer et al., 2008) - this means that no information regarding ecological disturbance caused by the crannog can be added to the macrofossil study. In a short core taken in the lake (Jones et al., 1978), a distinct colour transition at c. 200 AD was noted, from black nekron to reddish/brown clay.

This stratigraphic transition was attributed to increased catchment erosion and shallowing of the western part of the basin, due to forest clearing and increased arable cultivation by Roman occupiers between AD 74 and AD 78 (Jones et al., 1978). Previous analysis of this (pre-)historic brown-reddish clay indicated a distinct shift from more periphytic diatom taxa, i.e. *Cocconeis placentula*, *Eunotia denticulata*, *Staurosira construens* and *Martyana martyi,* towards planktonic taxa, i.e. *Aulacoseira granulata*, *Stephanodiscus astraea* and *S. minutulus* (Jones et al., 1978).

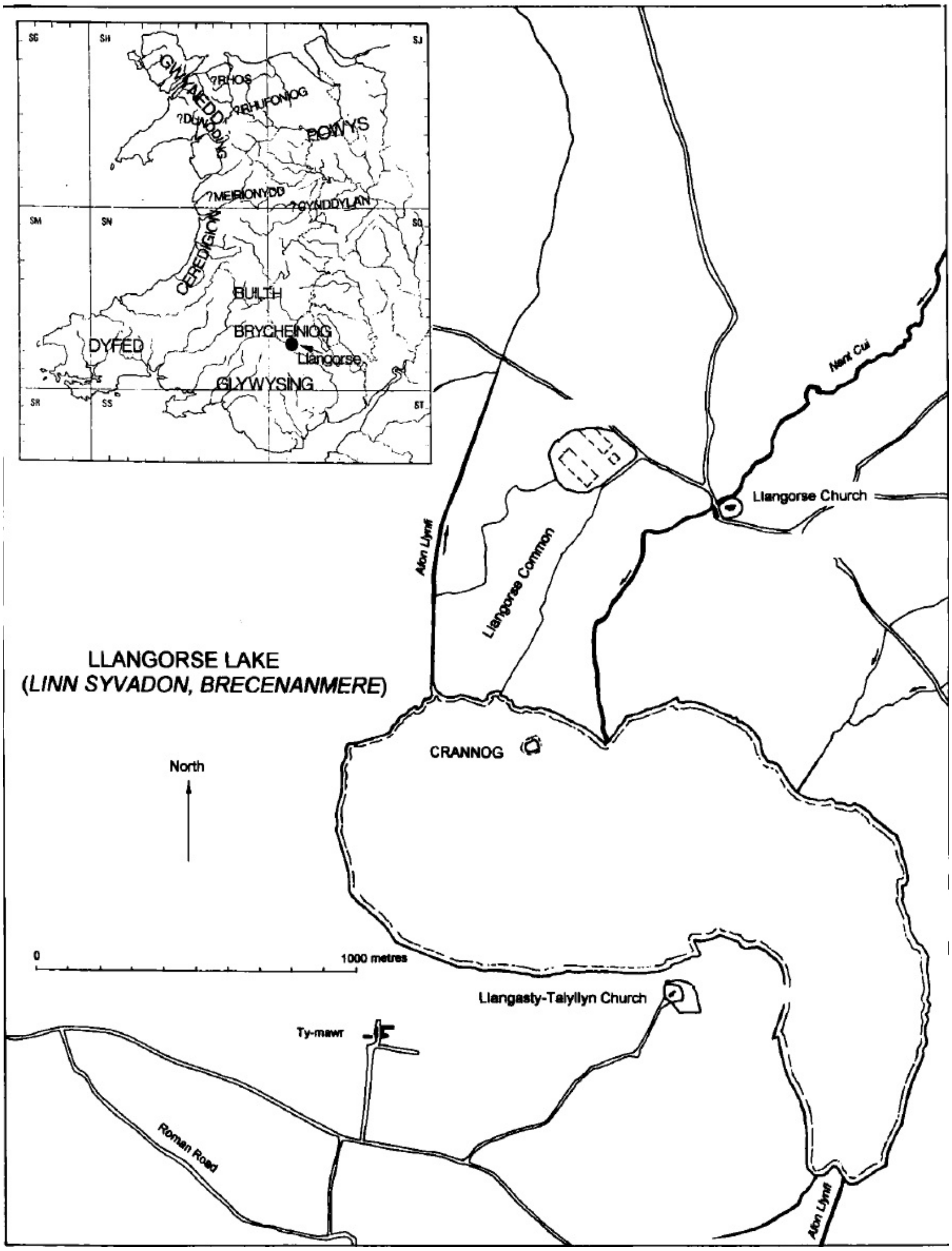


Figure 1.6.1 Map of the area surrounding Llangorse Lake, the location of the crannog and several points of archaeological interest (adapted from Redknap and Lane 1994). In the top-left there is a map of known kingdoms of Early Medieval Wales (Davies 1982)

It is assumed that the Llangorse crannog was a royal residence, based on historical references (e.g. Anglo Saxon Chronicle B inTaylor, 1983). It was likely constructed and occupied in the 9th – 10th century AD. Its mound consists mainly of lithic, wooden and other organic components.

The environmental record indicates significant human disturbance in the catchment, however, this started well before the crannog construction and as yet this appears a more regional signal. Currently there is no evidence for crannog establishment in the lake sediment studies. This can be attributed to the great distance between the crannog and the cores. In the instance that lake sediment near to the crannog was analysed, no indication of crannog construction or occupation was noted.

1.6.3 Oakbank, Loch Tay (Perthshire, Scotland)

Loch Tay is one of the largest Scottish freshwater lakes (24 km long), located in the Highlands. From the south near Killin, Loch Tay is fed by the rivers Dochart and Lochay, whereas the northern end outflows via the river Tay. The lake contains many crannogs (figure 1.6.2), which were surveyed in detail about 30 years ago (e.g. Dixon, 1982a, Dixon, 1984b). The principle method of research for this lake has been underwater archaeology, as only a portion of the lake sites are normally above water. Upon detailed analysis of the loch, it was found that it contained 18 crannogs (1984b, Dixon, 1982b). A few sites were analysed by means of radiocarbon dating, indicating that the Oakbank and Fearnan crannogs were of Early Iron Age origin (c. 800-400 BC), while Firbrush crannog dates from the Late Iron Age. Several islands were noted in a 17th century edition of Mercator's Atlas. Further evidence of historic knowledge of the crannog islands in Loch Tay is that Sybilla, wife of Alexander I the first king of Scotland, supposedly died on Priory Island around 1122 AD. The king then gave the island to the monks of Scone Abbey to construct a church in Sybilla's memory. When Priory Island was examined in the early 20th century, however, no traces of such a building could be found (Gillies, 1938).

A more detailed exploration of crannog sites described in atlases over the past c. 450 years can be found in the appendices of the PhD thesis of Matthew Shelley (Shelley, 2009). In recent years the chronology of the crannogs of Loch Tay were re-evaluated, using AMS radiocarbon dating techniques (Dixon et al., 2007, table 1.6.1). Although this allowed dating of the majority of sites, five crannogs had no datable materials. Of the many crannogs in Loch Tay, Oakbank crannog has been analysed in the greatest detail. This crannog has been extensively excavated and analysed with respect to the plant macrofossils and pollen in the near-crannog sediment.

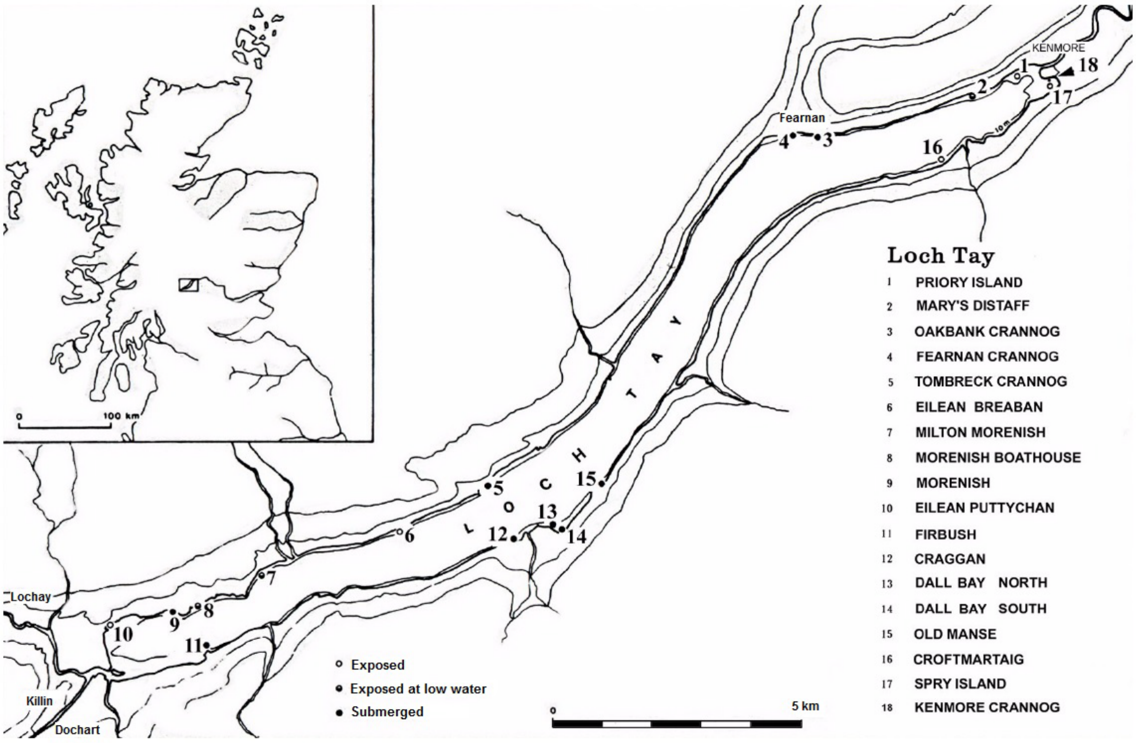


Figure 1.6.2 Distribution of crannogs in Loch Tay (adapted from Dixon et al. 2007)

The Oakbank crannog consists of a principal mound approximately 15m in diameter and now roughly 1.3 m below loch level (Dixon, 1984b). Next to this principal mound a younger, smaller mound was found. This protruded less from the loch bed, indicating that it was less probable that the small mound was used as a living platform (though it may have been used as a jetty). This mound was formed by initial layers of organic material, held together and secured by timbers. The organic matrix consisted of bracken and fern stems, twigs, straw and leaves. On top of these organic remains there are layers of stones. Based on initial radiocarbon dating the crannog was constructed between the 7th and 5th centuries BC. The large uncertainty in dating is mainly caused by the Early Iron Age plateau in the radiocarbon calibration curve (Hallstatt Plateau).

A recent study was able to more accurately date a structural timber of Oakbank crannog (Cook et al., 2010). Although just a single timber was analysed in this way, this timber pile sat in the occupation deposit and was probably important in more than one occupation phase. The high resolution dating was accomplished by wiggle-matching subsamples taken from the oak timber at decadal or subdecadal increments. The oak timber that was chosen to be analysed contained just over 70 rings, allowing 14 subsamples to be wiggle-matched. It provided an age of c. 500 BC (max range 520-465 BC), placing the crannog construction towards the end of the previously assumed age range of 7th to 5th century BC.

Table 1.6.1 Radiocarbon dates of tree rings from an Oakbank crannog structural timber

Lab no.	Ring no.	Age (yr. BP)	1-σ error
15702	0–5	2405	28
15703	6–10	2457	13
15704	11-15	2460	12
15705	16-20	2429	8
15706	21-25	2449	8
15707	26-30	2442	7
15708	31-35	2462	11
15709	36-40	2447	20
15710	41-45	2443	8
15711	46-50	2470	8
15712	51-55	2456	18
15713	56-60	2452	11
15714	61-65	2444	13
15715	66-70	2436	11

On the site several wooden and stone artefacts were found, including a whistle, an ard, a plate, net weights, beads and pottery fragments (Dixon, 1984b). Furthermore pieces of slag were found, containing high amounts of iron, suggesting metalworking on the site. Several small pieces of burnt bone and teeth were found, mainly of cattle and other animals. The organic material was found to be rich in cereal, seeds, nuts and insect remains. Hazelnuts and cherry stones were abundant, probably indicating a foraged food source. When a test sample for macrofossil work was analysed, all plant taxa identified were found to be either indicative of human activity or plants with a food value. Examples are *Linum usitatissimum* (flax), several arable cultivation indicator taxa and cereal grains. A variety of insect remains could also be identified. Dendrochronological dating helped constrain the chronology of the site and identified the variety of tree taxa used in its construction.

The organic remains of Oakbank Crannog have been further analysed in more recent studies (Miller, 1997, Miller et al., 1998). When the macrofossil assemblages were analysed in great detail, several species were identified not usually found in archaeological deposits. Although *Hordeum vulgare* (barley) was the main crop, *Triticum dicoccum* (emmer) and *T. spelta* (spelt) were also found. As this is the earliest find of spelt in Scotland, it indicates earlier usage of this crop and perhaps even trade links with England. Another unusual find is the identification of *Papaver somniferum* (opium poppy), which again has only been found in England. Finally *Rubus chamaemorus* (cloudberry) has been identified, which is a semi-rare species found only at specific locations (i.e. blanket bogs). The foragers would have to travel several kilometres to collect them, or they may have been brought home during hunting. These finds reinforce the view that some crannogs could be high-status sites, as several similar unusual herbs were found at the Buiston crannog (Holden, 1996).

A single pollen core was taken through the organic layers and into the loch bed (Clapham and Scaife, 1988). The loch bed sands contained pollen and spores, though in lower numbers than the organic matrix (as can be expected). Dominant arboreal taxa were *Alnus* and *Corylus* (hazel). *Alnus* is probably overrepresented in the pollen record, indicating a mixed woodland of *Quercus*, *Ulmus* and *Corylus*. The herbs were dominated by *Poaceae*. The sandy layers at the bottom of the core were, however, generally dominated by *Dryopteris* (wood fern) and *Pteridium aquilinum* (bracken). This can be interpreted as that either pteridophyte material was either deposited as bonding material, or that the sand originated from the shore, possibly being dumped on the site. The generally low pollen frequencies indicate it is not probable that periods of increased fluvial discharge would have elevated the spore frequencies. On top of the sandy layer was a layer of small boulders, containing low frequencies of arboreal taxa and high amounts of diverse herbaceous taxa (i.e. *Ranunculus* type (buttercup), *Plantago lanceolata*, *Artemisia* (sagebrush/wormwood), *Taraxacum* type (dandelion), *Poaceae* and cereals). This shift in pollen frequencies (except for the dominance of *Taraxacum* type) is typical for the subsequent floor layers as well. It is, however, probably not caused by forest clearance, but by higher pollen influx from the herbaceous taxa. Three important potential processes for the influx of high cereal pollen frequencies in anthropogenic environments are: on-site pollen processing, incorporation in human or animal faeces and utilisation of straw for floorcoverings or animal feeding. Overall the pollen frequencies throughout the layers indicate arable and pastoral agriculture with mixed woodlands. There is weak evidence for heathland.

To summarize, Oakbank crannog was likely built in the early Iron Age (c. 500 BC). In at least one of its initial occupation phases the crannog was probably a pile-dwelling, containing a wooden platform raised above the loch bed. As discussed by the excavator, there is evidence of several construction and reinforcement phases: 1) A free-standing timber framework is constructed, dated to c. 595 ± 55 BC (GU-1323), 2) Piles are inserted into the mound of occupation debris, following the rotting away of the joints of the platform structure. Environmental archaeology indicates that a variety of wheat was processed or stored on the site, while it also indicates that large amounts of pteridophyte material was used in the base layers of the crannog. Pollen evidence indicates agriculture and some forest clearing in the catchment. Finally the macrofossil analysis indicates several valuable plants (i.e. opium poppy, spelt wheat and cloudberry) were collected or imported from long distances. Access to these more valuable resources, indicate that Oakbank crannog was probably a high-status dwelling. As none of the other crannogs in Loch Tay have been analysed to this level of detail, it is unclear if all of these sites had a similar status and function.

1.6.4 Buiston (Ayrshire, Scotland)

This site (figure 1.6.3) was first described and discovered by the schoolteacher Mr McNaught during the late 19th century (McNaught, 1912). Already in the early 19th century the loch had been drained and the small mound that was apparent at that time had been removed by the farmer. The crannog was excavated and documented for the first time by Munro (1882, figure 1.6.4). Although these initial excavations were crude by modern standard, they were recorded and planned in some detail. This became apparent during the late 20th century, when the site was revisited as part of a crannog preservation survey (Barber and Crone, 1993). Furthermore the site was deemed more accessible for the analysis of its substructure at that time, as the occupation deposits were presumably removed. However as the site was being excavated, it became apparent that there was still a wealth of information to be found (Barber and Crone, 1993, Crone, 2000). Due to anaerobic conditions below the water-table, the structural remains of two dwellings were found at the Buiston site, together with a large amount of organic material in “pristine condition” (Crone, 2000).

The primary mound on which most of the crannog is built, is at least 28 m in diameter (Barber and Crone, 1993, Crone, 2000). This mound consists of alternating layers of turves and brushwood, with overlying boulders and oak beams. The earliest occupation is indicated by three superimposed floors and hearths. Radiocarbon dating of the first timber indicated an initial construction age during the second half of the 1st Century AD (radiocarbon date:

1950±50 BP), while the uppermost timber gave a comparable date (radiocarbon: 1920±50 BP). Thus a Late Iron Age for this initial mound can be postulated. Squared stakes had been inserted into the primary mound and indicate a double stockade around the settlement. Following a slumping event, the primary mound was extended and a roundhouse of at least 7 m in diameter was constructed. The flooring of this structure was replaced at least four times. A collapsed part of a complex stockade indicates that the settlement was enclosed by horizontal planks, pinned in place by stakes. This collapse was probably accompanied by slumping of a large part of the flooring and the house was rebuilt. However the early 19th Century excavation probably removed a large amount of material from the site.

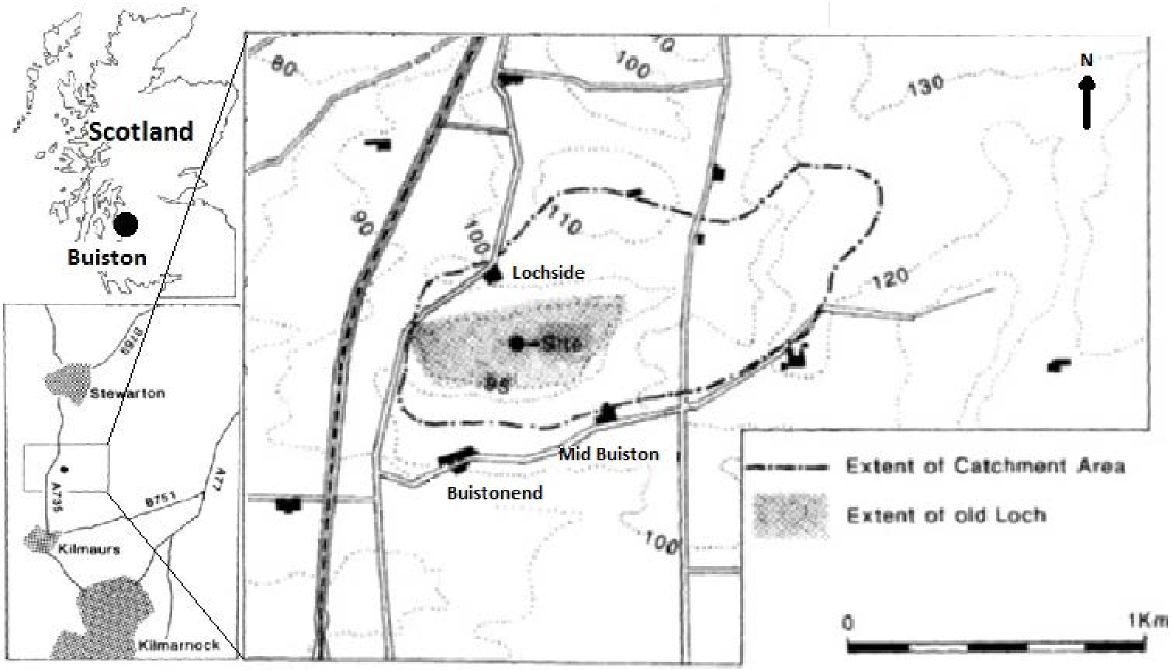


Figure 1.6.3 Maps showing the location of Buiston crannog (adapted from Holden, 1996)

The chronology of the site was determined in detail by both radiocarbon and dendrochronological dating techniques. This allowed a very precise detection of the construction and occupation phases. The initial mound was constructed in the Late Iron Age (around the 1st or 2nd Century AD). Only a few artefacts and occupation remains were found, indicating that the primary mound had probably remained above water for an extended period of time. Both radiocarbon and dendrochronological dating techniques indicate a c. 400 year deposition hiatus in the crannog occupation deposits. Only a limited amount of organic mud was deposited during this hiatus, indicating a period of submergence, which is substantiated by soil micro-morphological analysis. As there is no evidence of initiation or duration of this submergence, it is assumed that the site was abandoned between the 2nd and the late 6th century AD, as indicated by dendrochronological dating of structural timbers. In the late 6th century a dwelling was constructed in the centre. This was however replaced by the end of the 6th century with a roundhouse further to the north-west from the initial mound. This was possible due to expansion of the mound. Further evidence of crannog reconstruction phases comes from several distinct hearths found in separate stratigraphic layers. There is a large hiatus in sediment deposition during the period between the mound construction and the structural layers (Tipping, 2000). Previously analysed sub-regional pollen data (Turner, 1970, Turner, 1975) provide some palaeoenvironmental information for this period. The vegetation history indicates that prior to c. 600 BC there were minor clearances taking place in the area. It was not until c. 310 BC that a clearance phase was sustained, lasting until c. 600 BC. This clearance phase can be divided in two stages:

1) Pasture creation is indicated by *Plantago lanceolata*, *Ranunculus* (buttercup) and *Rumex acetosa*. This lasted until c. c. 305 BC.

2) It was then followed up by *Calluna* (heath) and *Poaceae*, but ultimately the woodland regenerated (indicated by significant increases in tree taxa pollen).

Between c. 1196 and 1354 AD several intense clearances occurred. Further late Iron Age clearance is indicated by pollen evidence from Walls Hill Bog (Ramsay, 1995), occurring between c. 320 BC and 34 BC.

During this occupation phase there are episodic increases in grasses and herbs (pastoral and arable). This is followed by fluctuating increases in *Betula* (birch), *Alnus* and *Corylus*, indicating partial abandonment of farmed land. After c.940 AD (1100 radiocarbon BP) there is a limited increase in grasses and pastoral herbs. Farming activity increased significantly by c. 1354 AD (600 radiocarbon BP). The regional woodland clearance and pasture creation phases cannot be linked with crannog occupation phases, indicating that either the peat cores are too far from the crannog or that other human activities are more dominant in the region.

Both aquatic and terrestrial plant macrofossils were identified during the analysis of the Buiston crannog deposits (Holden, 2000). Aquatic seed assemblages from before the 6th century AD contained *Chara* sp. (stonewort), *Elatine hydropiper* (waterwort), *Potamogeton* (pondweed) and *Nymphaea alba* (white water-lily). This confirms that during this period the mound was inundated. However *Chara* sp. and *Elatine hydropiper* disappear from the deposits after the late 6th century AD, at roughly the same time as the re-occupation of the crannog. This is probably linked to changes in water quality, as the Charophyte flora shows ecological inhibition by phosphate (Moore, 1986). This might for instance be phosphate from organic effluent from the crannog. Competitors such as aquatic angiosperm flora would have experienced heightened productivity, which together with heightened algal growth would enhance shading of the hypolimnion, thus reducing Charophyte productivity.

From all of the Buiston crannog deposits heather has been identified. This means that acid heath would have been accessible to the builders of the crannog, even though it is absent from the modern flora. *Betula pubescens*, together with *Quercus* sp. and *Alnus glutinosa* indicates trees growing on the water edge in more or less waterlogged conditions. Mixed woodlands nearby are indicated by *Sorbus* (e.g. rowan or bird cherry). Several other species indicate mesotrophic and eutrophic mires, most comparable with the *Juncus acutiflorus - Acrocladium cospidatum* mire (Ratcliffe, 1964). This would indicate high, but fluctuating water levels, slightly acidic waters and a more mesotrophic nutrient status. Another facet of the nearby ecosystem is indicated by grassy, water edge communities (*Glyceria fluitans* (floating sweet-grass) and *Lycopus europaeus* (gypsywort)). Disturbed areas are indicated by *Polygonum lapathifolium* (pale pesicaria) and *Urtica dioica* (nettle). Nitrogen rich muds, such as river banks and cattle drinking areas, are indicated by *Polygonum hydropiper* (waterpepper) and *Polygonum mite* (tasteless waterpepper).

A high fraction of aquatic insects in the Coleoptera assemblages of Phase I (mound construction) and parts of Phase III (re-occupation) indicates that some deposits of the site could have originated from the lake bottom, probably being dug or dredged up for crannog heightening (Kenward et al., 2000). Lower fractions could have been derived from being trampled in to the deposits by the occupants. The aquatic assemblages were also be used to indicate water quality. The assemblages can be divided in four groups: eurytopic (*Colymbetes fuscus*, *Gerris*, *Heloborus* and *Gyrinus* species), nutrient rich waters with emergent vegetation (*Microvelia reticulate*, *Sigara distincta*, *Donacia* spp. and *Hydronomus alismatis*), muddy/vegetated water edges (*Anacaena globulus*, *Chaetarthria seminulum*, *Coelostoma orbiculare* and *Ochtebius minimus*) and flowing water/active lake edges (*Deronectes latus*, *Oulimnius* sp., *Elmis aenea* and *Stictotarsus duodecimpuntatus*). These species groups probably originated from aquatic habitats such as the crannog fringes and the loch shores.

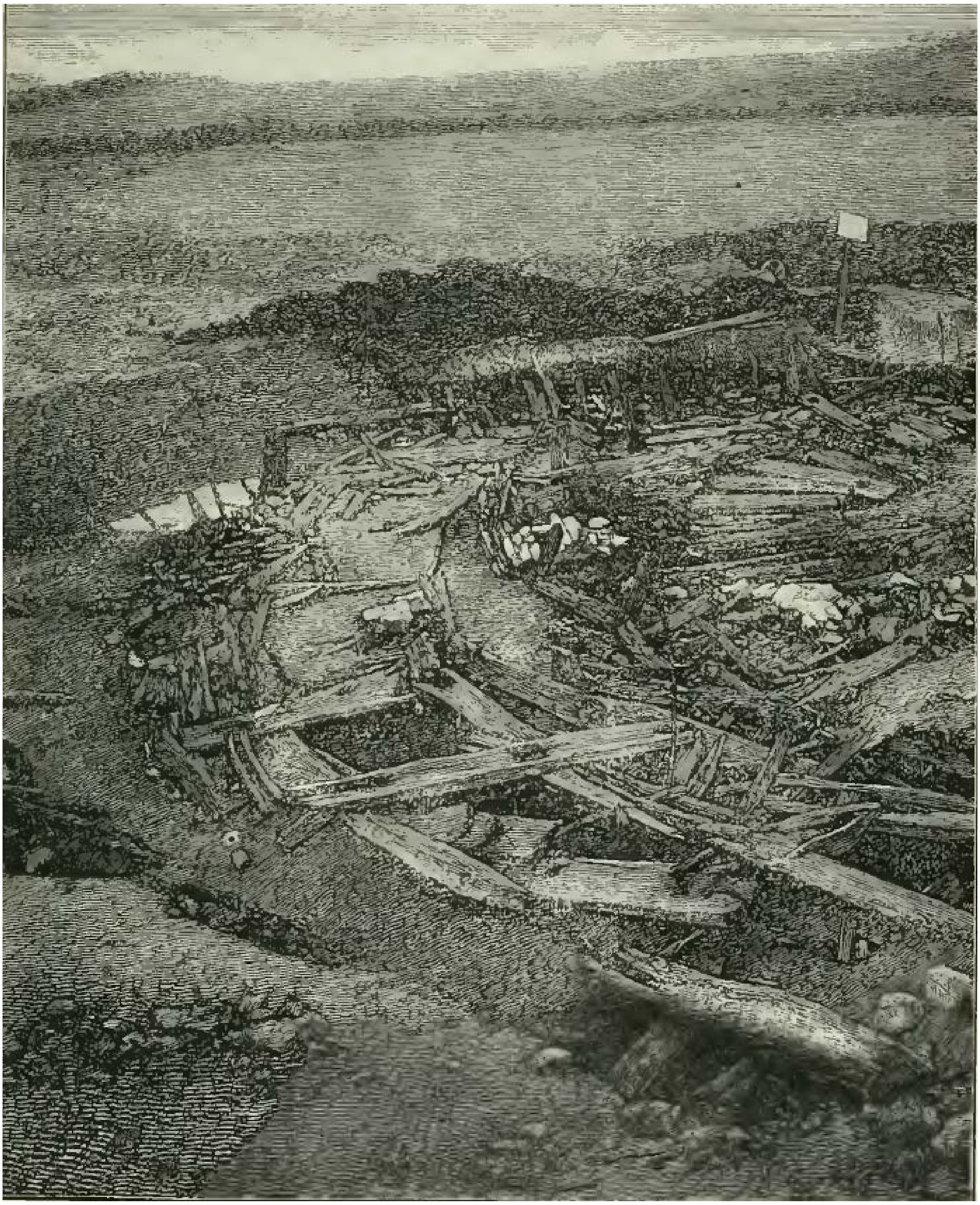


Figure 1.6.4 Image of the 19th century Buiston excavation (Munro, 1882). Visible are the stockades and the log pavement

Only a few examples of dead wood insects were found. A higher number of beetle taxa associated with living trees were identified e.g. *Elasmuch grisea* (shieldbug) which is associated with *Betula. Chionaspis salicis* is associated with various trees and shrubs (especially willow), and can be abundant on occupation sites. Hazel and oak are indicated by *Strophosomus melanogrammus* (a weevil), while *Anoplus roboris* is indicative of alder and oak. Many species indicate herbaceous vegetation and a substantial portion can be linked to waterside plants, e.g. *Donacia marginata* is associated with *Sparganium* species (bur-reed) and *Hydronomus alismatis* is associated with *Alisma* species (water-plantains). Species associated with general waterside or damp soil vegetation that were identified are *Conomelus anceps* and *Livia juncorum*. Several species indicate nearby meadows containing amongst others typical plants such as Brassicaceae, *Plantago* sp. and clovers. Grazing land is hinted at by low numbers of dung beetles. Heath-/moor-land is indicated by low numbers of *Scolopostethus decorates*, *Ulopa reticulate*, *Bradycellus ruficollis* and *Mecrelus ericae*, though these species have associations with some of the previous habitats as well. Beetle remains associated with peat or turf have also been found, but these were probably are recent invaders due to the lowering of the water level in the past 150 years rather than imported in peat or turf to the site or.

The detailed analysis of this site reveals that flooding and structural collapse was a serious problem for the inhabitants of this crannog. The mound was initially constructed in the 1st century AD and it was occupied for less than a century. Following a 400 year submergence period, it was re-occupied in the mid-6th Century AD. The disappearance of charophytes in the macrofossil record around this time probably indicates eutrophication during this final period of occupation. The processing of various materials and evidence of valuable goods indicate that this site was actually a high-status palisaded enclosure. However, structural collapse appears to have taken place several times, which is probably the reason why the site was ultimately abandoned in the early 7th Century AD. This site highlights the question why people would invest so heavily in a structure with uncertain stability and a high risk of flooding.

1.6.5 Ballywillin, Lough Kinale (Central Ireland)

In central Ireland lies the Lough Kinale – Derragh Lough lake system, which can be divided into three distinct hydrological cells (Selby and Brown, 2007, figure 1.6.5). Lough Kinale (64.3 m OD) can be divided into an upper and lower section and is connected in the south to

Derragh Lough (64.6 m OD). As most of its catchment bedrock consists of limestone and shale, the lake system is well buffered and weakly alkaline (pH 8). The regional archaeology ranges from the Mesolithic to the post medieval period (Fredengren et al., 2010). Lowering of the water level led to the discovery of artefacts on the shores of the lakes (Raftery, 1972). As part of the Irish Discovery program the lakes and their surroundings have been analysed, identifying many megalithic sites. This led to several crannog sites undergoing further exploration (Farrell, 1989). Apart from the crannogs, there has been a large number of Mesolithic finds on the shores and around Lough Kinale, indicating substantial activity around the lake during this time. For the Neolithic period fewer artefacts have been found in the direct vicinity of the shore, although several megalithic monuments can be found within a larger radius (~10 km) around the lake. Three crannogs have been identified within the lake system: Ballywillin and Tonymore in Lough Kinale and another in Derragh Lough (figure 1.6.5). As the Ballywillin crannog underwent the most complete environmental analyses (table 1.6.2), that site will be discussed in detail, while the other two crannogs will be summarized.

Table 1.6.2 Palaeoenvironmental analyses of the crannog cores of around Lough Kinale

Crannog \ Analysis	Loss-on-ignition	Pollen	Macrofossil	Diatom	Chironomid
Ballywillin	X	X	X	X	X
Tonymore	-	-	-	X	-
Derragh Lough	-	X	X	-	-

The Ballywillin crannog is defined by the excavators as a high-cairn site currently overgrown with grass, nettles and mature trees at the crannog edge (Fredengren et al., 2010). The site is approximately 41m in diameter excluding the reed beds. The site itself displays several structural features. The outer berm of the crannog contained stony material, mainly shattered and fire-cracked stones and some animal bones. The berm is delineated by a discontinuous line of about 60 vertical timbers at the mainland (west) side of the site. These timbers are mainly oak, with alder and ash represented in small numbers. On the inside of this line of vertical timbers, on top of the berm, is a flat plateau, currently overgrown by grass. The plateau consisted of brushwood, soil and grass, with a limited number of horizontal timbers. On top of the plateau is the mid-mound, consisting of material similar to that found in the plateau.

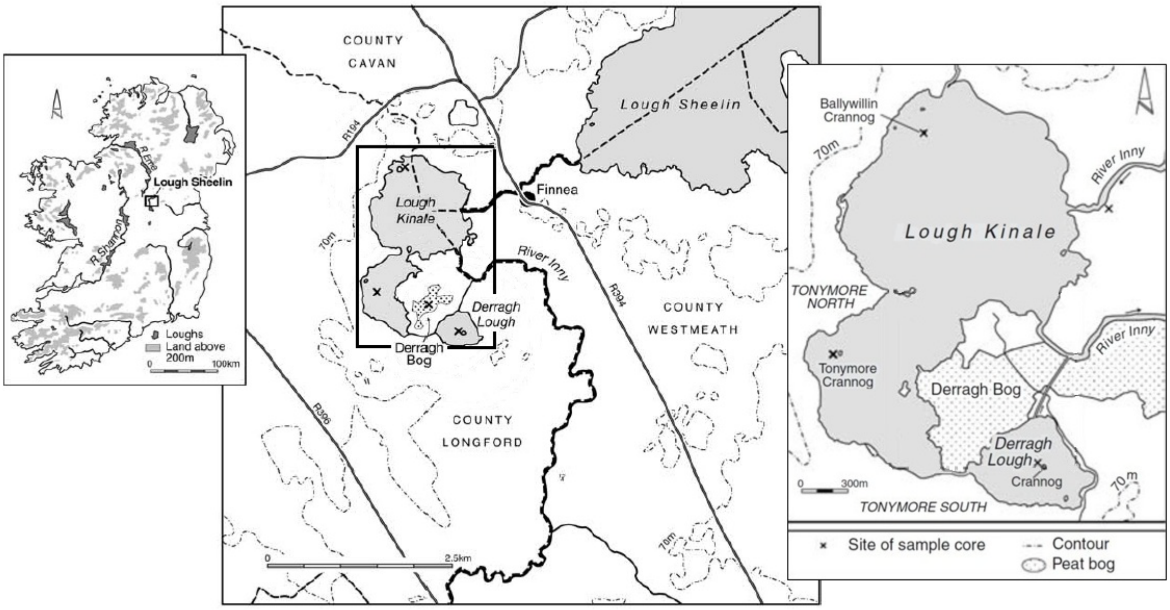


Figure 1.6.5 Locational map of Lough Kinale, indicating the crannogs (rightmost image), crannog edge cores (marked with an ‘x’) and geography of the site (adapted from Selby and Brown, 2007, Brown et al., 2005)

The palaeoenvironmental ecology of the Ballywillin crannog has been analysed in significant detail by means of chironomids, diatoms, pollen and plant macrofossils collected from a core adjacent to the crannog (Selby et al., 2005, O'Brien et al., 2005, Selby and Brown, 2007, Fredengren et al., 2010). This multiproxy analysis allowed a thorough examination of the effect of the crannog construction and prehistoric human impact on the lake sediment and ecology.

The core taken adjacent to Ballywillin crannog (figure 1.6.5) was analysed for its carbon content by means of loss on ignition (LOI). Up to 30 cm core depth, both the organic and carbonate content is low (<6%), with carbonate content slightly higher. The highest values of carbonate content are in the marl sections of the core. From 30 cm the values increase, however, as there is no stratigraphic change, this is most likely caused by disturbance in the catchment. When examining the vegetation history prior to 620 AD (figure 1.6.6), the sediment indicates an open woodland dominated by *Quercus*, with *Fraxinus* (ash), *Ulmus* and *Betula* also present. *Corylus* and *Alnus* were growing near the water edge. Low abundances of herbs, specifically *Plantago lanceolata*, might indicate local openings. After AD 620, there is a gradual decrease in tree and shrub abundance, accompanied by an increase in herbs, specifically Poaceae. Several meadow and disturbance indicator taxa, such as Cyperaceae (sedges), *P. lanceolata* and *Taraxacum*-type (e.g. dandelion), indicate woodland clearance and increased human activity. This is further substantiated by increases in Poaceae and *Hordeum*-type (e.g. barley) pollen, microscopic charcoal and *Gelasinospora* sp. spores (the latter associated with charcoal, van Hoeve and Hendrikse, 1998). From around the 10th century AD until the 11th century AD, higher percentages of tree taxa (*Quercus, Alnus, Corylus*) and a reduction of herb taxa were found, suggesting woodland recovery and a significant reduction in human impact. Following this interval the woodland taxa decreased again and herb taxa became dominant. High values (up to 50%) of *Hordeum*-type pollen were found in the sediment. This may partly reflect construction, that is flooring and vegetable refuse. However, human activities such as grain storage and/or processing might have elevated the cereal pollen accumulation further.

Prior to AD 620 the plant macrofossil assemblage is dominated by submerged aquatic plants (figure 1.6.7), such as several species of charophytes (e.g. *Chara* sp(p.), *Najas flexilis* and *Nitella* sp(p.)). This indicates a mesotrophic, clear, deep lake (> 6m) with a pH of 6-9 and abundant submerged aquatic vegetation. After AD 620, the abundance of the charophytes decreases and terrestrial plants become abundant. An increase in the total number of taxa reflects a greater diversity of available habitats.

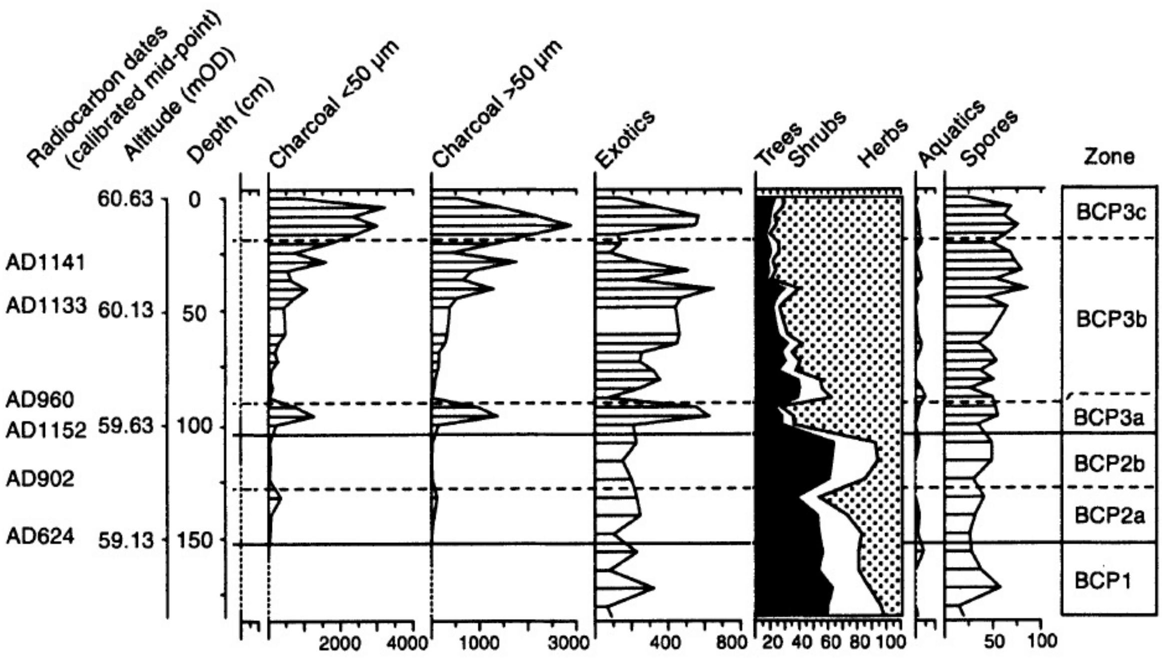


Figure 1.6.6 Summary pollen and charcoal diagram of the Ballywillin core, modified from O'Brien et al (2005)

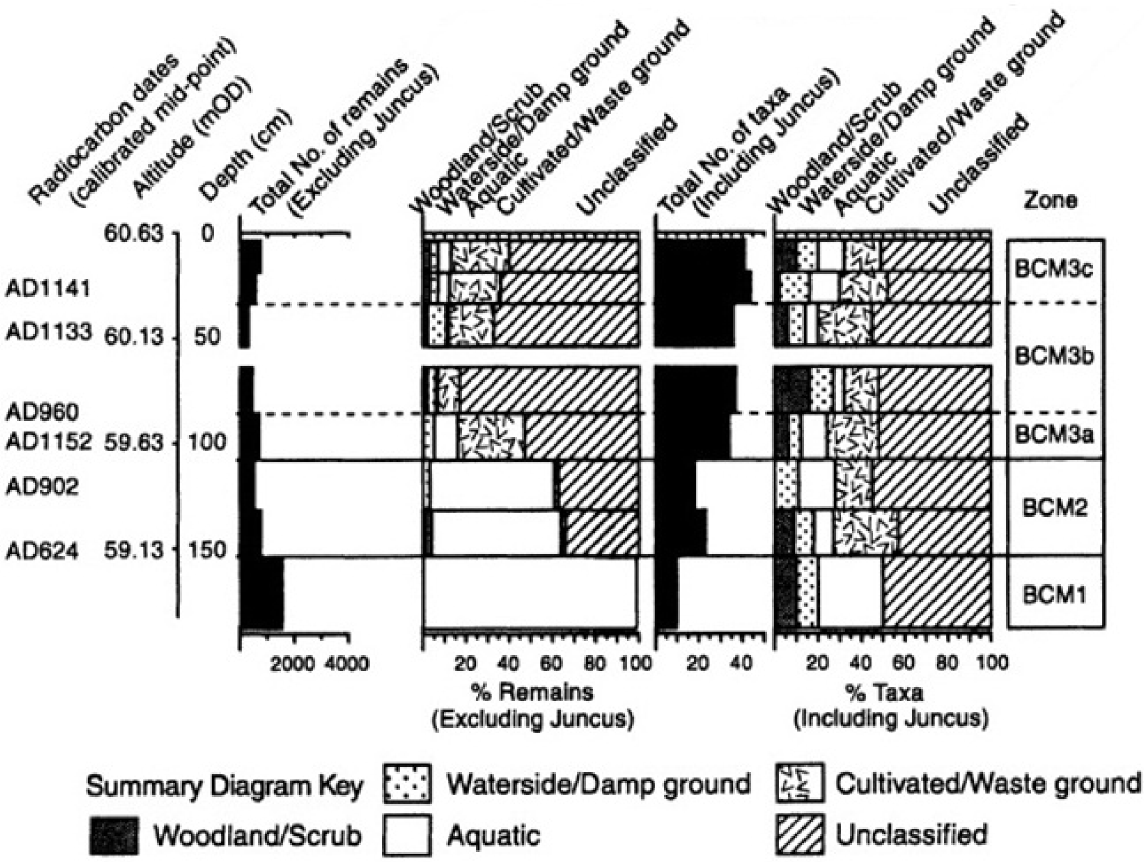


Figure 1.6.7 Summary macrofossil diagram of the Ballywillin core, modified from O'Brien et al (2005)

Cereal use at the lake margins or on the crannog is indicated by charred cereal grains of *Hordeum* sp(p.), *Avena sativa*, found together with cereal cultivation weed taxa (*Agrostemma githago* (common corncockle), *Chrysanthemum segetum* (corn marigold) and *Aphanes* sp.). Flax cultivation is suggested by the presence of *Linum usitatissimum* (flax) seeds. Evidence for foraging of edible plants, seeds and fruit stones is indicated by charred hazelnut shells, together with seeds and fruit stones of *Vaccinium myrtillus/oxycoccos* (bilberry/cranberry), *Rubus idaeus* (raspberry), *Rubus fruticosus* agg. (blackberry), *Chenopodium* sp. (goosefoots) and *Prunus spinosa* (sloe). The decrease in charophytes after AD 620 can be interpreted as a consequence of eutrophication (e.g. due to human activity), where *Chara* sp. would be both outcompeted both by other aquatic macrophytes with higher production rates and by increased shading from higher algal growth. Another theory might be that the charophyte reduction is caused by a drop in lake level, where intermediate depth would mean that the plants are likely to be outcompeted by other aquatic macrophytes. A drop in lake level could be linked to climatic instability, as indicated by several Central European studies (Magny, 2004b, Haas et al., 1998). Both eutrophication and lake level decrease are supported by the increased diversity of aquatic angiosperms.

The diatom assemblages (figure 1.6.8) are characterised by a high floristic diversity, which is most likely a result of the large variety of habitats and the ability of diatoms to successfully exploit the available niches. Generally the core is dominated by taxa of small *Staurosira*, *Staurosirella*, *A. minutissima* and *G. angustum.* Overall, the diatom assemblage is dominated by circumneutral and alkaline species (Selby and Brown, 2007). After c. AD 1150 several changes in the assemblage occur relating to the development of the crannog. Some of these changes are a decrease in eut-dystrophic species, followed by a rise in eutrophic species, circumneutral species, benthic taxa and later epontic taxa. An increase in nutrients could be explained by intensive livestock grazing, together with the nutrient efflux from the crannog.

The chironomid assemblages show very distinct changes after AD 900 and the assemblage is predominantly littoral. The sediment samples indicate shallow, mesotrophic conditions with abundant macrophytes. After c. AD 1100, taxa found on sandy substrates increased, such as *Cladotanytarsus* and *Pseudochironomus*. Furthermore sediment dwelling taxa increased, indicated by *Chironomus*, *Cladopelma*, *Polypedilum* and *Tanytarsus*, which indicate open areas of sediment. Together with the presence of plant and woody debris taxa (e.g. *Paraphaenocladius*, *Stenochironomus*) the structure and local elevation of the lakebed is indicated by the aforementioned changes. Several taxa also indicate higher nutrient conditions, likely originating from the crannog. Above 110 cm, a period of lower crannog activity is indicated by taxa associated with macrophyte vegetation (e.g. *Glyptotendipes* and *Polypendilum sordens)* which can be interpreted as an increase in local macrophyte vegetation. Furthermore *Cricotopus* indicates fringing reeds rather than submerged plants. From younger sediment samples (top 45 cm of the core) extensive macrophyte coverage and higher nutrient conditions can be inferred, though this is probably indicative of catchment changes, rather than crannog usage.

Coleoptera remains are rare in the oldest sediment samples (<AD 620), with some evidence for riparian vegetation (*Ceutorynchus* spp.), grasslands (*Dascillus cervinus* and *Phyllopertha horticola*) and cultural fields (*C. minutum* and *M. boletophagum*). After AD 620 the diversity and number of Coleoptera remains increases. Decaying plant and dung material is indicated by *Anotylus nitidulus*, *Aphodius*, *Ptenidium*, *Monotoma*, *Cryptophagus* and *Atomaria* spp., which can be interpreted as evidence for the crannog construction. Deadwood taxa (*Harpalaraea pygmaea*, *Hylesinus crenatus* and *Platyperus cylindricus*) may originate from old trees used in the crannog structure or mature trees near the lake margin. A reduction in numbers of water beetles and dominance of terrestrial taxa indicate shallowing and terrestrialization of the immediate lake margins. Post-900 AD the diversity and abundance of

Coleoptera is high, indicative of human activity, specifically *Aglenus brunneus,* which is indicative of floor layers (Kenward and Hall, 1995) and often recorded in synanthropic habitats.

The Derragh Lough lake-core (figure 1.6.5) was taken at some distance from the crannog, thereby its macrofossil record contained mainly aquatic plant fossils, with little evidence of terrestrial vegetation and human activities on the crannog. Low frequencies of cereal pollen indicate that cereal cultivation was probably not taking place to any significant degree in the catchment. Furthermore low values of microscopic charcoal indicate limited burning or clearing of woodlands in the catchment. As only three flax fruits were found in the lake core, these may have originated from the crannog, or may have been left over from 'retting' processes. Derragh crannog artefacts have yielded dates that range from the 10^{th} until the 11^{th} century AD.

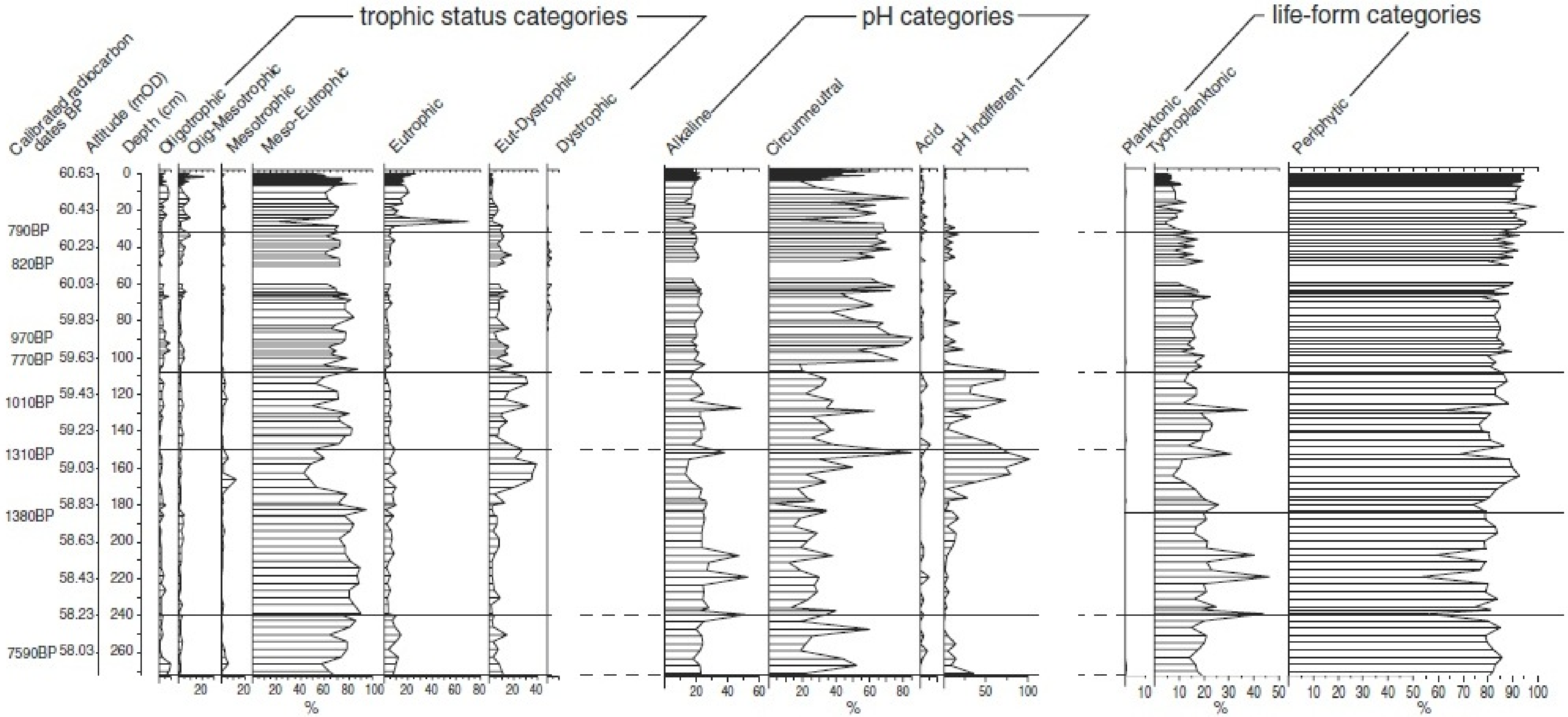


Figure 1.6.8 Summarised diatom diagram of the Ballywillin core, modified from Selby and Brown (2007)

The Tonymore lake-core (figure 1.6.5) was analysed for diatoms, indicating an overall dominance of alkaline species. In the lower parts of the core, below 150 cm depth, there is a steady increase in eutrophic species and tychoplanktonic species (up to 85% and 70%, respectively). Prior to c.5550 BC there is an increase in dystrophic species, possibly indicating fluctuating lake levels and an influx of humic/fulvic acids. Dominant species include *Achnantes lacus-vulcani*, *Achnanthes minutissima*, *Gomphonema angustum*, and *Fragilaria* spp. In the next part (62-146 cm depth) of the core, diatom valves are almost absent, possibly due to increases in sediment input to the lake. In the top part of the core (from 62 cm, dated to c. 280 BC), circumneutral species constitute occur up to 30% of the sample, against up to 80% of alkaline species, indicating a reduction in pH. There is again a short increase in dystrophic species (*G. angustum*), with an increase in mesotrophic species, against a reduction in eutrophic species. At about the same depth there is a notable reduction in tychoplanktonic species, with approximately a doubling of epontic and benthic species and a minor increase in planktonic species (*Cocconeis* spp.). This change could be interpreted as lake level changes. As the changes in diatom assemblages are somewhat similar to the Ballywillin crannog, the construction of the Tonymore crannog might be indicated in the top section of the Tonymore core. However, inconsistent radiocarbon results from this core make it impossible to know exactly when this occurred based on the environmental changes. Archaeological artefacts and structural timbers are dated to between the 9th and 12th century AD (Fredengren et al., 2010).

The highly detailed and complete studies of lake settlement history around Lough Kinale indicate that lake cores can provide a large amount of additional information on crannog usage. The environmental proxies show clear signs of ecological disturbance and human impact, allowing dating of for crannog construction and use. The construction age of the Tonymore and Derragh Lough crannogs is poorly understood, though it is probably between the 6th and 11th century AD. As there is some accumulation of cereal pollen and microscopic charcoal near the Derragh Lough crannog, there was probably little clearing of woodlands in the catchment. Ballywillin crannog was probably constructed around AD 620, as indicated in the macrofossil record by a change from aquatic assemblages to waterside and terrestrial herbs. However the highest level of human activity occurred after AD 1150, as indicated by all the fossil groups. Increased eutrophication is also indicated by the proxies during this period. Cereals, fruits and nuts were gathered and consumed on the crannog, while cereals were probably also stored. The main cereals were oats and barley, which were common in Ireland during the Early Medieval period. Between AD 960 and AD 1150 *Hordeum*-type pollen (including barley) was dominant (c. 50% of pollen sum). It is likely that cereal processing and storage are causes for these elevated values. Flax cultivation and retting may have been another use for the lake's surroundings.

The artefacts found on all the sites in Lough Kinale during the Discovery program date to between the 6th and 16th century (Farrell, 1989). Environmental investigations indicate that Ballywillin crannog was constructed in the 5th to 6th century AD, while archaeological evidence has limited evidence of occupation, with most of the artefacts dated to between the 8th and 15th century AD. These studies indicate that lake sediment analysis is able to complement the evidence from archaeological studies.

1.6.6 Case studies conclusions

The comparison of these four crannog examples (Oakbank, Llangorse, Buiston and Ballywillin) indicates the complexities of crannog usage and construction. At the moment there is a limited amount of environmental research on crannogs. The majority of these studies focused on cores from the crannog itself and often only looked at plant macrofossils and insect remains found within the occupation sediments. Examples of such a study are the Oakbank crannog (Miller et al., 1998) and the Llangorse crannog (Redknap and Lane, 1999). These analyses yield clear evidence of human impact, foraging of food sources and in some cases they are able to indicate the high status of some crannogs. Furthermore a pollen core from Oakbank crannog indicated high amounts of cereal pollen in the occupation deposits, which can be attributed to either cereal processing, storage or human/animal waste (Clapham and Scaife, 1988). Dendrochronological dating of the often well preserved timbers allowed a constrained estimation of the time of construction and occupation (e.g. Crone, 1988).

In several studies an attempt was made to include other proxies, such as in the case of the Buiston crannog (Crone, 2000), which compared archaeological evidence to nearby pollen studies from peat cores. Although this provided evidence of human activities in the area, these were difficult to link with the crannog's occupation phases. Coleoptera analysis of occupation sediments from the Buiston crannog allowed a representation of nearby vegetation, identifying the waterside plants, and indicating nearby meadows and the mixed woodlands (oak, hazel, birch and willow), which were likely used during the crannog's construction and for repair and the creation of structures during occupation.

Another approach was chosen during the analysis of crannogs in Lough Kinale (Fredengren et al., 2010). This lake actually contains three crannogs, probably dating back to between the 6th and 11th century AD. During this study lake sediment was analysed both in the vicinity of the Ballywillin crannog and at other places in the lake system, allowing a comparison between both regional and local environmental change. Analysis of lake sediments indicates limited creation of arable fields and woodland burning in the catchment. Most of the evidence of environmental change is derived from near the Ballywillin crannog, located in the south-east of Lough Kinale. The macrofossils indicate a clear (local) shallowing around AD 620, probably due to the construction of the crannog. A reduction of arboreal pollen with an increase in meadow-indicator pollen gives evidence of some clearing of woodlands in the catchment. Elevated cereal pollen indicate either cultivation or storage of cereals. Around the same time there is some evidence of eutrophication. Human impact is more pronounced from around AD 1150, with cereal pollen reaching up to 50% abundance (*Hordeum*-type). However, values this high probably indicate either storage or processing of cereals. Furthermore, the diatom record, which appears stable up to this point, indicates a shift in dominance from dystrophic to eutrophic and epontic species. This could be explained as either (re-) building or expansion of the crannog.

The Ballywillin crannog demonstrates the importance of a detailed environmental study on lake sediment. The lake-sediment analyses were able to date the construction to the early 6th century AD, which was the earliest in the date range based on the artefacts (6-10th century AD, Fredengren et al., 2010). One major advantage of lake sediments is that they are less likely to be disturbed by subsequent human activities than occupation deposits. Furthermore distinct occupational phases on the crannog could be determined.

Even after over 150 years of analysis and excavation, there are still many unknowns concerning crannogs. Fortunately, it is possible to draw some common themes from these studies. On nearly all sites there is strong evidence of cereal cultivation in the area during the time of crannog occupation. The significant wooden component in each site means that crannog dwellers were heavily dependent on the nearby woodlands (e.g. Crone, 2000). Furthermore the various wooden, metal and stone artefacts indicate they were skilled craftsmen. Most sites also indicate high values of cereal pollen within the crannog occupation sediments, most probably linked to either cereal processing or storage. Another aspect of crannog life is the nutrient flux from the crannog into the lake. This might be indicated in the Buiston crannog (Crone, 2000), and is more explicit for the Ballywillin crannog (Selby et al., 2005) as evidenced by the diatom and chironomid record. Finally macrofossil analysis indicates that at least some crannogs would have been high status dwellings, as indicated by imported edible foods (Holden, 1996, Miller et al., 1998). These high status environmental indicators are in line with the historical references of the Llangorse crannog, which is believed to have been a royal residence (Campbell and Lane, 1989).

The environmental evidence clearly indicates the potential applications of palaeoecological studies on both crannog sediments and lake sediments near crannogs. Such studies can identify construction processes and materials. It can also help to understand the use of crannogs, being able to identify edible plants that were imported or foraged. As only a few crannogs have been analysed for their environmental evidence, there is still a wealth of organic rich sediments that might be studied to shed more light on these prehistoric and medieval sites. Future research might focus on analysing whether more crannog sites show evidence of cereal storage and or processing, together with evidence of valuable resources. Cereals are considered to have been an important part of the diet of lake dwellers throughout Europe since the Neolithic (e.g.Jacomet, 2004) and are likely to remain indicative of human occupation. The variation in date and longevity of crannogs is remarkable with some evidently constructed during the Iron Age, while others are of medieval origin. This means that during the period that crannogs were being constructed, the British Isles were subject to major cultural and political disturbances, as a consequence of for instance Iron Age (Celtic,) Roman, Saxon and Viking influences (e.g. Cunliffe, 2009).

In the central European area there has been a focus on changing lake levels and the effect this had on lake dwellers (e.g. Magny, 2004a, Magny, 2004b, Menotti, 2009). As these lake dwellings were intermittently occupied since the Neolithic, they have provided researchers with an opportunity to study abandonment cycles in comparison with climate fluctuations. Another question that has been raised relates to the ritual/religious function of crannogs. In Ireland in particular it has been argued that crannogs can be part of the ritual landscape, with links to nearby sites (Fredengren, 2007) such as ráths or even features in the landscape (e.g. hills and mountains). Finally, it is uncertain, especially in the earlier Bronze and Iron Age crannogs, if these sites would have been occupied for the entire year. For comparison, the burnt mounds (Irish: *fulacht fiadh*), which are found across the British Isles, might have been used in a similar fashion, where these sites may have been visited on a seasonal basis.

From the case studies it can be derived that crannogs are expected to have some impact upon the landscape and the lake ecology in which they were built. These impacts can be, for example, increased erosion, deforestation, inwash of occupation deposits and eutrophication. A list of these crannog impacts are presented in table 1.6.3, together with the proxies in which they might be picked up.

Table 1.6.3 Crannog related responses in selected proxies

Crannog impact	**Proxy**	**Crannog response**
Construction of mound and superstructures	Pollen	Reductions in tree pollen, increases in herbs and grasses, disturbance indicator taxa
	Chironomids	Increases in wood/stone dwelling taxa
	Diatoms	Increases in periphytic taxa due to increased shoreline and submerged macrophytes
	LOI/MS/XRF	Increases in erosional indicators
Crannog occupation	Pollen	Cereal and other food plant pollen
	Plant macrofossils	Food plant remains (e.g. cereal grains, fruit stones, nut shells, animal fodder)
	Diatoms	A reduction in alkaliphilous taxa due to inwash of humic substances from the mound and occupation deposits
Erosion from the mound (continuous) and slumps (erratic)	LOI/MS/XRF	Fluctuations in in organic matter content, increases in erosional indicators (e.g. ferromagnetic, Ti, Zr, K/Rb ratio)
Eutrophication	Diatom	Increases in mesotrophic/eutrophic taxa

Chapter 2: Crannog distributions in space and time

2.1 Introduction

To assess the main construction phases and geographical regions of crannogs, a dataset of crannog locations and the dates of artefacts and deposits from these crannogs were gathered from historical sites and monuments databases. These could then be analysed for their temporal and geographical distribution. The idea is that the construction of crannogs is driven by the cultural movement of these sites and that the skills required to build them may have spread across Scotland and Ireland in a certain pattern, which might be analysed from the data set. From previous studies it is already apparent that the main occupation phase in south west Scotland is the Iron Age (Henderson et al., 2003, Henderson et al., 2006, Crone, 1993), while in Ireland and Northern Ireland there are concentrations of crannog constructions during the Bronze Age and the Early Christian period (Fredengren, 2002, O'Sullivan, 1998). This will be explored further in the sections below and compared to assess the connections between Scotland and Ireland.

A compilation of the radiocarbon dates described in the crannog databases and literature (see methods chapter 2.1) was analysed to determine trends in crannog construction and occupation phases. Care has to be taken with this interpretation, as the dataset is far from complete, with less than 7% of all the verified crannogs dated, as well as substantial differences in the number of dated crannogs per country (see table 2.1.1). For example, Ireland has by far the largest concentration of crannogs but also has the lowest percentage of dated crannogs, and with the exception of Wales, has the lowest number of dated crannogs. The number of dated crannogs can be extended by including knowledge derived from artefacts discovered during archaeological excavations. Although these data are less accurate than the dendrochronological or radiocarbon dating techniques, often the artefacts are dated to certain cultural periods spanning one or two hundred years, they may still support or contradict the evidence from the other dating techniques. It can be seen (table 2.1.1) that by adding the dating evidence from the archaeological record, it is possible to expand the number of dated crannogs to 141.

Table 2.1.1 Dated crannogs per country. In brackets is the total number of crannogs, but including unverified crannogs and those sites without any further information besides being classified as a crannog. Excluded are the Scottish "island duns" and fortified island dwellings (for a more extensive discussion see the methods section)

Country	Total crannogs	Dated crannogs	Percentage dated
Republic of Ireland	752 (1186)	16 (33)	1.9 %
Northern Ireland	148 (196)	30 (36)	16.9 %
Scotland	236 (312)	47 (80)	20.0 %
Wales	1	1 (1)	100 %
Total	**1137 (1695)**	**94 (150)**	**6.7 %**

2.2 Crannog databases and distribution

Since first discovered in the mid-19th Century, almost 1700 sites have been recorded as the site type “crannog” in monument and site databases from Ireland, Scotland and Wales. Problematically, over 300 of these sites have no description or reference of having been explored, leaving some doubt as to whether or not they are actually crannogs - these were grouped into a separate category. There are a less than 150 crannogs which have been dated, either by radiocarbon analysis or through cultural artefacts such as pottery or metal objects. The complete database can be found in appendix D. To allow a more holistic interpretation of the geographical and temporal distribution of crannogs, the databases from across the British Isles were merged into a single database for this analysis.

The Scottish sites were mainly identified from the Canmore database (RCAHMS, 2015), while a gazetteer of Scottish crannogs was compiled by Graeme Cavers (2010) during the South-West Crannog Survey, which contains several updates, such as new radiocarbon dates or detailed excavation descriptions and discussions. The Irish crannogs were identified using the Ordnance Survey Ireland web-interface (Department of the Arts Heritage and the Gaeltacht, 2015). Some of these sites were described in greater detail or were dated by Christina Fredengren (2002). The crannogs of Northern Ireland were collected from the Northern Ireland Sites and Monuments Record (NIEA and OSNI, 2006) and some of the crannogs described in a dendrochronological study by Mike Baillie (Baillie, 1982b, Baillie, 1979, Baillie, 1995) have also been added to the database, if they were not already included and / or dated.

It is important to note that many different types of island dwellings have been described on the Scottish isles. These are usually referred to as ‘Island Duns’ and not crannogs (e.g. Armit, 1992). For a discussion and comparison between crannogs and island duns, the work of Lenfert might be explored further (Lenfert, 2013, Lenfert, 2012), but for the purpose of this thesis they are considered the same, i.e. artificial island dwellings. The data collected for each site (if available) was location (National Grid reference and / or latitude/longitude), age, type and any literature sources. As several crannogs have multiple dates or occupation phases, it was decided to compare the oldest available date of the crannogs, to determine trends in the construction of these sites. To assess the distribution of crannogs both temporally and spatially, the crannogs were allocated to 500yr intervals, roughly corresponding to cultural periods (table 2.2.1).

Table 2.2.1 Radiocarbon intervals and corresponding cultural periods

Calibrated years BP	Cultural period
8500-3000	Pre-Bronze and Early Bronze Age
3000-2500	Late Bronze Age
2500-2000	Early Iron Age
2000-1500	Late Iron Age
1500-1000	Early Medieval
1000-500	Late Medieval
500-0	Modern

2.3 Temporal distribution of crannogs

First of all, the oldest dendrochronological and radiocarbon dates from crannogs have been compared (figure 2.3.1). The oldest radiocarbon dates in this dataset that are derived from crannogs in Ireland, and date to the Mesolithic. This is from a crannog in Lough Gara (KILA 015, Eastern Inch Island, 8160 ± 50 BP) and Moynagh Lough (52701 ± 60 BP). From other sources, there is already quite a significant amount of evidence of early Mesolithic exploitation of wetlands, such as at Lough Boora (Ryan, 1980), Lough Derravagh (Mitchell, 1972) and Moynagh Lough (Bradley, 1991). Although it might appear that crannogs originated in Ireland, due to the oldest crannog dating from there, it is uncertain whether or not this is the case. There is a fair amount of evidence of Palaeolithic and Early Mesolithic activity in Scotland, such as Howburn farm; Bridgend, Islay and Cramond (Edwards and Ralston, 2003). This indicates that people were at least seasonally present in Scotland since the Palaeolithic. The oldest example of an artificial island in Scotland is the Neolithic site Eilean Dòmhnuill in North Uist, although it is not entirely artificial (Armit, 1996). During the Neolithic some of the most pronounced examples of settlements and megalithic monuments have been found, while the Bronze and Iron Ages yielded less dramatic monuments, although the sites explored often yielded a wealth of artefacts and information, especially from wetland sites (O'Sullivan, 1998). The (pre-) Bronze Age crannog dates are not without controversy, as previous papers have rejected the Bronze Age levels as the start of occupation of Lagore (Lynn, 1986, Warner, 1986). Whether these early sites are in fact actual crannogs is hard to prove, as evidence of structures is limited or are the material is dated to younger periods (Lynn, 1986). There are very few crannog in Ireland and Northern Ireland dating the Iron Age (c.2500-1500 BP), and those sites appear to have a more extensive Early Christian occupation layers. From the Early Medieval Period onwards, the following periods can be considered more typical for crannog construction.

When looking at the separate countries, a number of differences can be observed. The Irish crannogs have two apparent maxima during c. 3000-2500 ^{14}C yrs BP and c. 1500-1000 ^{14}C yrs BP. Between these maxima the number of Irish crannogs decreases, possibly indicating a decrease in the construction of crannogs. This agrees well with previous studies of Irish crannogs (O'Sullivan, 1998, Fredengren, 2002). The Northern Irish crannogs are mainly younger than 1500 ^{14}C yrs BP, with only three crannogs that have occupation layers dated to the Late Bronze Age and the Iron Age. There appears to be a maximum in crannogs dated to the last 500 radiocarbon years, which might be related to the English conquest and reconquest of Ireland from 1536 AD. Indeed, some historical references mention the use of crannogs during the war. For instance the Island of MacHugh (Hennessy, 1887, O'Donovan, 1856, Brady and O'Conor, 2005) and Loughbrickland (Lett, 1905) appear to have been used as defensive positions for the rebels. For Scotland, however, the majority of the oldest dates fall between 2500 and 2000 ^{14}C yrs BP. This is in agreement with a previous study on the chronology of Scottish crannogs (Crone, 1993). Finally, there is the lone crannog in Wales, which probably was created due to Irish links with the ruler of the land (Campbell and Lane, 1989, see also section 1.6.2).

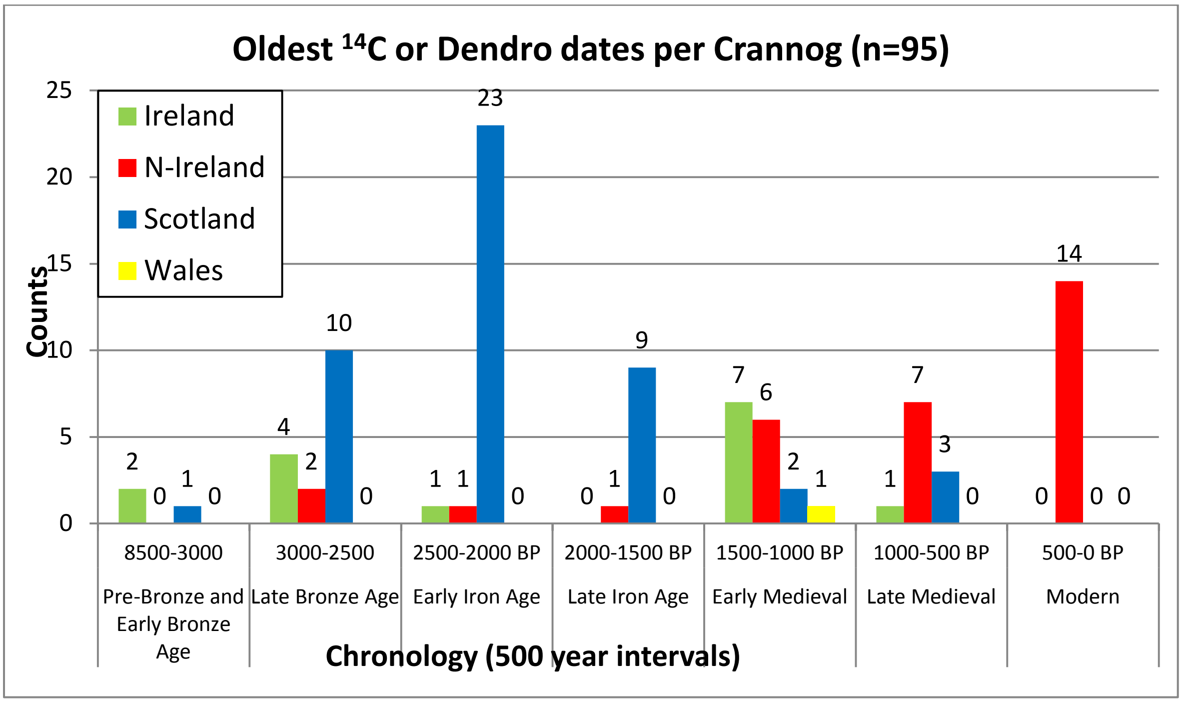


Figure 2.3.1 Compilation of the oldest radiocarbon or dendrochronological dates per crannog, grouped by country and divided into standardized intervals of 500 calibrated years. The oldest crannog construction dates have been grouped in 500 year intervals and matched with the main cultural period for reference

When comparing all the dated crannogs, including those dated by archaeological interpretation (figure 2.3.2), the pattern that emerged at the radiocarbon and dendrochronologically dated crannogs still remains intact. Overall, the number of crannogs per period increases, but the pattern remains fairly similar. The main difference is that a second occupation phase is evident in the Scottish crannogs, taking place in the Late Medieval period (c. 1000-500 ^{14}C yrs BP).

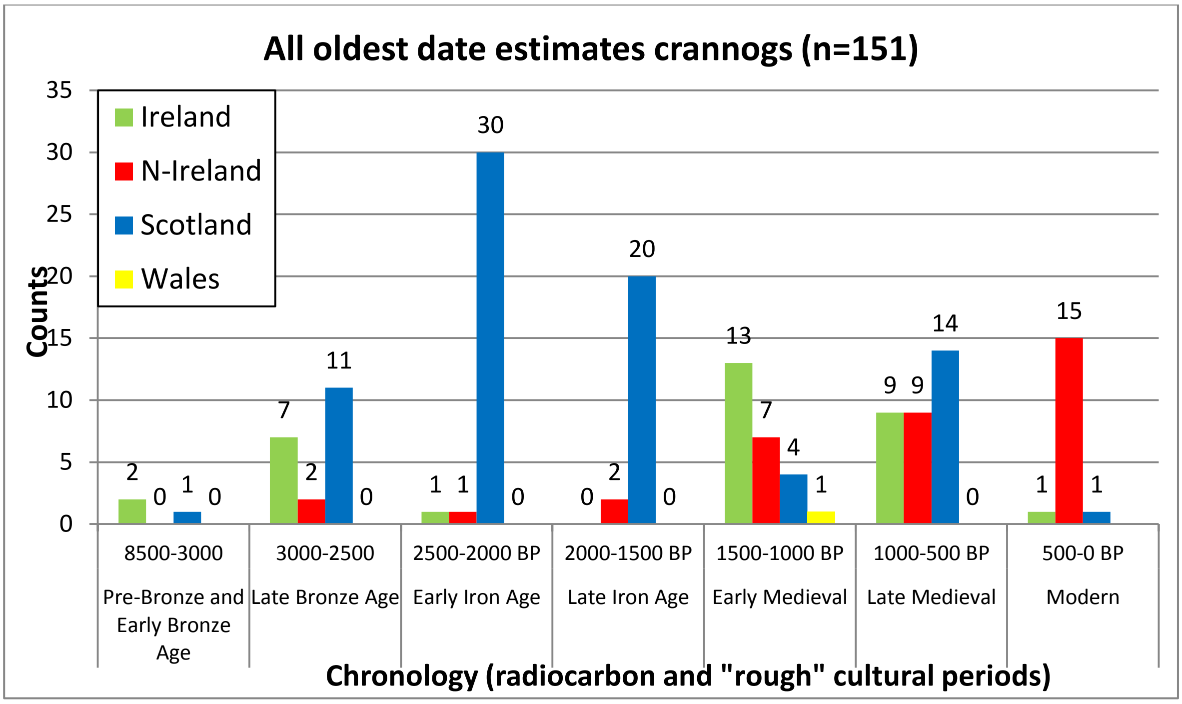


Figure 2.3.2 Compilation of the oldest radiocarbon or dendrochronological dates per individual crannog, as well evidence from the archaeological records, such as pottery and other artefacts. These age estimates were grouped by country and divided into standardized intervals of 500 radiocarbon years. The radiocarbon years have been linked with certain cultural periods, which define most of the radiocarbon interval

2.4 Geographical distribution of crannogs

When looking at the geographical distribution of the dated crannogs, it is evident that there has been a strong tendency for dating crannogs in certain areas (figure 2.4.1). Most of the Scottish dated crannogs are found in Argyll, Dumfries and Galloway and around the large lakes of Loch Awe and Loch Tay. These areas have a long history of crannog exploration. In south west and west Scotland in particular there has been a revival of dating the crannogs, some of which were explored for the last time over a hundred years ago (Blundell, 1912-1913, Munro, 1882, Piggott, 1952-1953, McArdle et al., 1973, Dixon, 1982b, Cavers, 2010, Henderson et al., 2006, Henderson et al., 2003). For Ireland, most of the dated crannogs are centred around Lough Gara, where there has been an extensive study of crannogs by Cristina Fredengren (2002). Quite a few crannogs which have been excavated in Ireland, were been excavated in the first half of the 20th Century by the Harvard Team (Hencken, 1942, Hencken, 1950, Hencken, 1936). At this time radiocarbon dating and dendrochronology were not among the techniques used to record the site. There is a very high concentration of crannogs the central part of Ireland. The reason is not greatly understood, but appears not to be related to the presence of water bodies, as the concentration is not unlike other parts of Ireland (Davies, 1942). Possible explanations might be that the border between Meath and Ulster was more heavily defended or just wealthier than other parts of Ireland. From a geographical point of view this central region is characterised by a high concentration of drumlins, which could have divided the landscape into smaller compartments (Fredengren, 2002). As noted before, a more detailed examination of lakes in southern Ireland may be beneficial (Woodman, 1978)

Finally, there is a lack of dated crannogs in the eastern part of Northern Ireland. Most the dendrochronological and radiocarbon dated crannogs of Northern Ireland are located in Co. Fermanagh, with a few examples spread across Co. Tyrone, Co. Antrim and Co. Down. When adding the crannogs which are dated using artefacts, it slightly improves. The majority of the crannog dating in Northern Ireland took place in the late 1970s in County Fermanagh by Michael Baillie and he was instrumental in establishing the current dendrochronological oak record of Ireland (Baillie, 1982b).

As previously described (see section 1.6.2) the single crannog in Wales reflects a link between the kingdom of Brycheiniog and their Irish heritage (Redknap and Lane 1994). Although most of England was under Saxon control from the 6th to 9th Centuries, the Welsh states remained independent during this time, with limited evidence of Saxon metalwork on the crannog, which is probably why the Irish influence was possible. Redknap and Lane (1994) interpret the crannog as a tool the Brycheiniog king used to reinforce his claims to Irish ancestry, as well as his political standing. Around the 4th Century AD a large group of settlers from Ireland moved to Wales, so whether this single Welsh crannog reflects a larger distribution is uncertain.

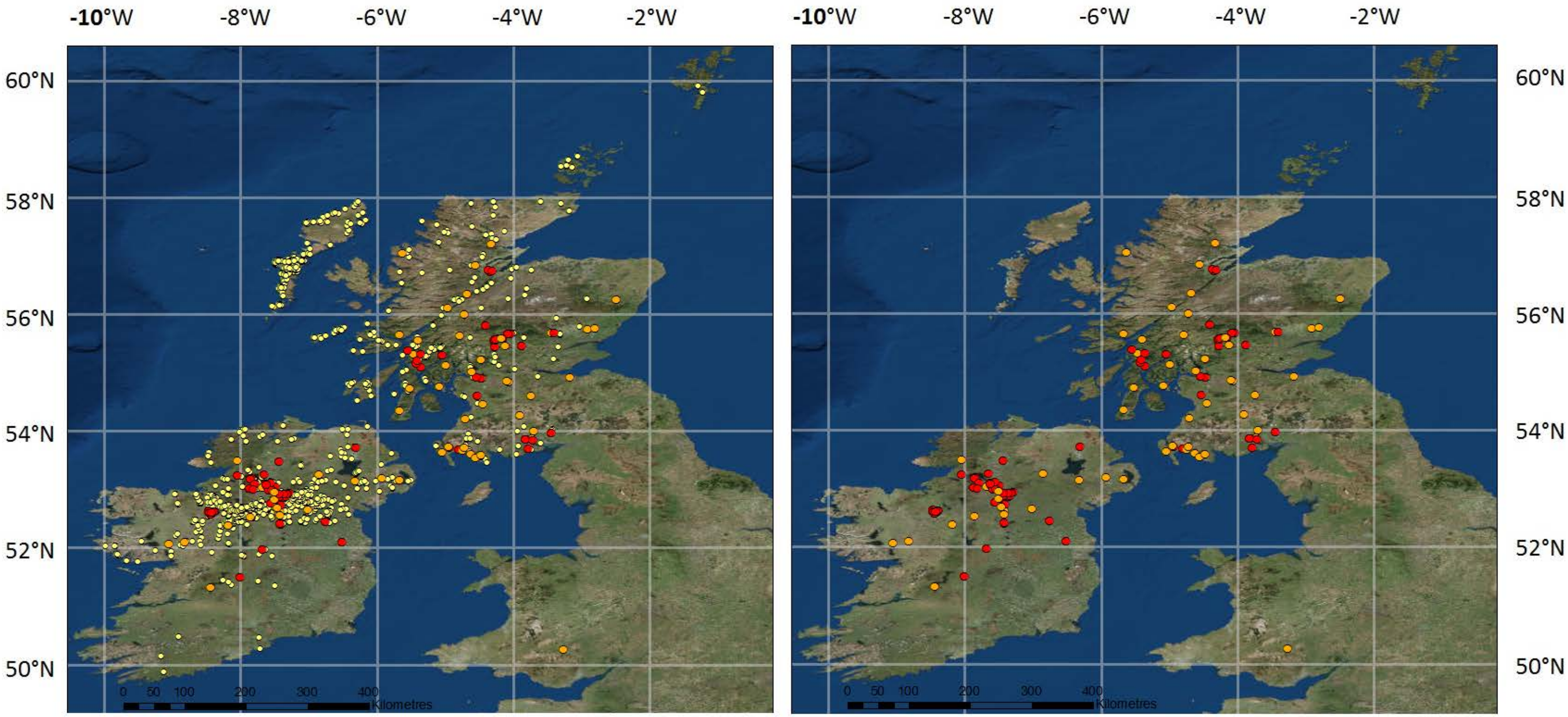


Figure 2.4.1 Crannog distribution across Ireland and the United Kingdom. **Left**: A map indicating all the known crannogs from the Irish, Northern Irish, Scottish and Welsh monuments and sites databases. In red are the dated sites (radiocarbon and dendrochronology) and in orange the crannogs dated by artefacts. The small yellow circles indicate the other, verified crannogs, including island dwellings such as the duns on the Scottish Isles. **Right**: A map indicating the dated crannogs either dated by radiocarbon dating and dendrochronology (red) or by artefacts and other evidence from occupation layers (orange)

2.5 Temporal and geographical distribution

It is also possible to compare the geographical distribution of the crannogs over time (figure 2.5.1). It shows that in most 500 year periods, the crannogs are fairly spread out. This indicates that although only a small number of crannogs have been dated, they were being occupied regularly over at least the past 5000 years and quite possibly longer. As mentioned in section 2.3 it is uncertain whether the sites dating prior to the Late Bronze Age were in fact crannogs at that time. In the second interval (3000-2500 cal. yrs BP) it appears that the crannogs are more concentrated towards the north of Scotland and northern part of the Republic of Ireland. However, towards the end of the prehistoric period (i.e. the Iron Age and Roman period, c. 2500-1500 yrs BP) there is a distinct shift towards crannogs appearing in the south western parts of Scotland (e.g. Argyll and Bute, Ayrshire and Dumfries and Galloway).

While there are many crannogs dated to this period in Scotland, they are virtually absent from Ireland. This might be related to the expansion of the kingdom of Dal Riata, originally in County Antrim in Northern Ireland (Charles-Edwards, 2000a). After 1500 BP most of the crannog in Antrim appear to have disappeared, while a few remain in south west Scotland (figure 2.5.2). This might be results of the battle in AD 632, when an army supported by the Dal Riata was defeated (Charles-Edwards, 2000a) and the seat of their kingdom became Dunadd in Argyll, Scotland (Campbell and Lane, 2000). This does not necessarily mean that crannogs were not part of the cultural tradition at this time, as it could also indicate that no new crannogs were being constructed at this interval and previous ones might still have been occupied or were re-occupied.

Around the time of the Medieval period (c. AD 500-1500), there are again a large number of crannogs in Ireland, with most being dated around the centre and the northern part of the island. This might be a response to Viking and Norman evasions between the end of the 8th Century and the late 12th Century, with increased need for fortified locations. Although crannog could have many functions, their defensive attributes are clear, with palisade and water to protect the occupants. In Scotland, crannogs appear to be slightly in disuse for the earlier part of the Medieval period, while they are spread out widely in the later part of the Medieval period.

Crannogs were less common in the last 500 years, indicating that although a few were possibly still in use through old traditions, they were not part of the main cultural heritage. However, there is good evidence of crannogs being used by rebels during the plantation of Ireland in the 17th Century (Brady and O'Conor, 2005, Ivens, 2001, Lett, 1905) as well as possible construction in Scotland (Morrison, 1985).

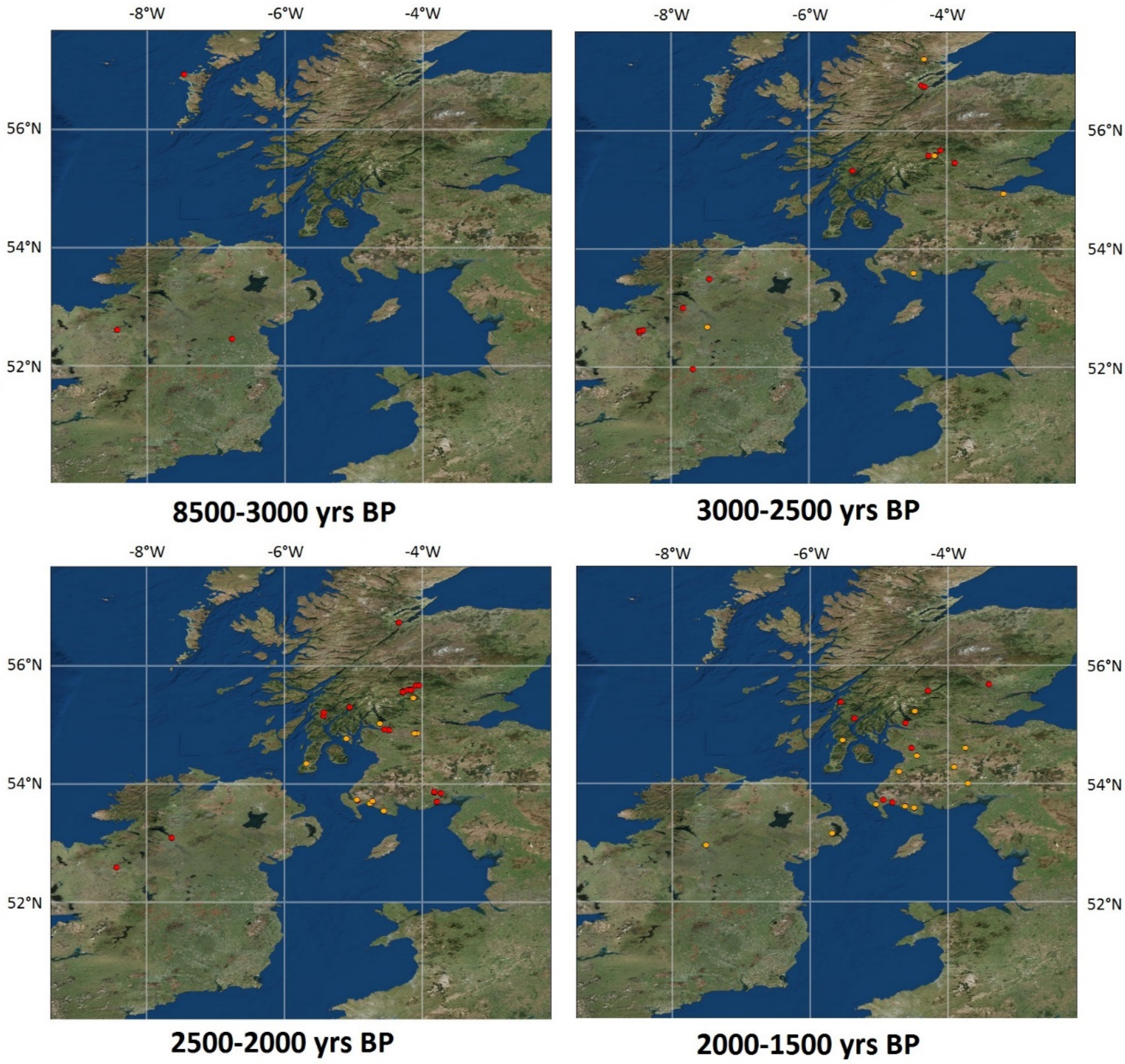


Figure 2.5.1 Geographical distribution of dated crannogs (oldest date) from 8500-1500 yrs BP. In red are the crannogs dated by radiocarbon or dendrochronology, while in orange are the crannogs dated by artefacts or other archaeological dating techniques

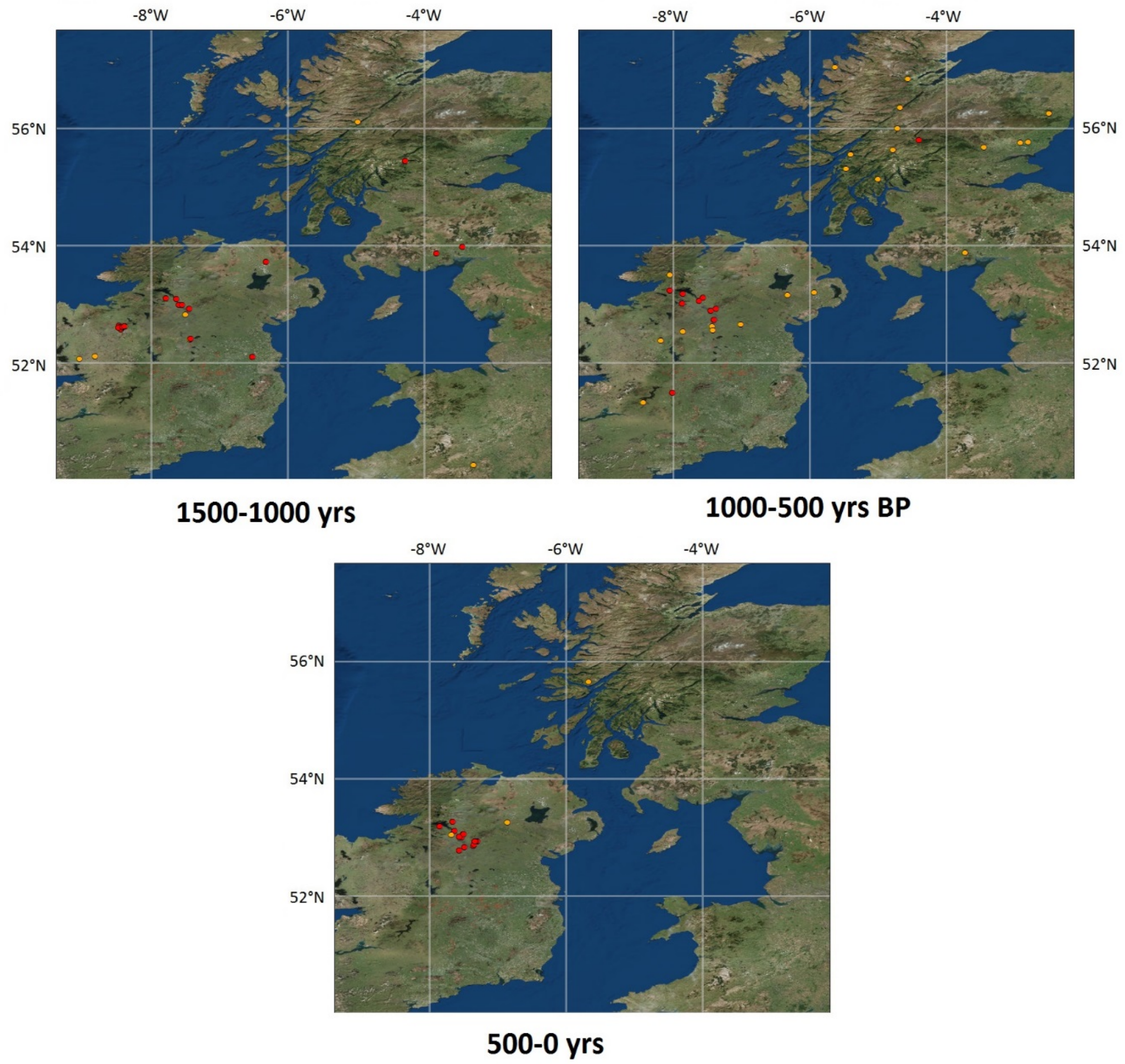


Figure 2.5.2 Geographical distribution of dated crannogs (oldest date) from 1500-0 yrs BP. In red are the crannogs dated by radiocarbon or dendrochronology, while in orange are the crannogs dated by artefacts or other archaeological dating techniques

Chapter 3: Methodology

3.1 Outline of methods

To gain a better understanding of the distribution of crannogs in both time and space, a crannog database has been compiled by gathering crannog site descriptions from archaeological databases. From this database a set of crannogs were selected. The coring sites were explored using a gouge corer to assess the lake sediment stratigraphy, before cores were recovered from the most suitable location. These cores were analysed for several geochemical and biological proxies to assess the environmental impact of the crannogs and to further interpret the long-term occupation history of these lakes. A complete flowchart of the process is detailed in figure 3.1.1. The individual steps outlined in this short methodology are described in more detail in the following chapter sections.

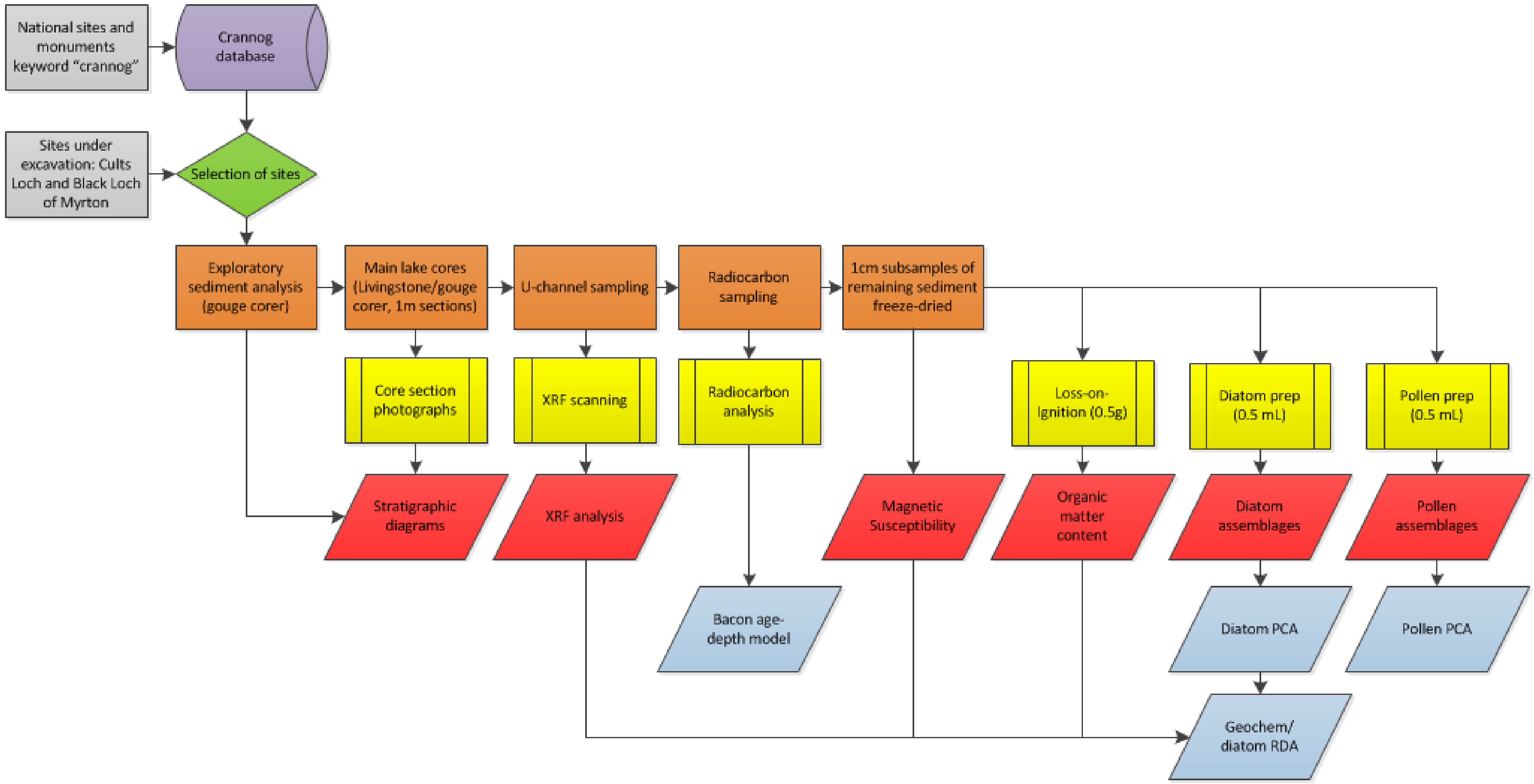


Figure 3.1.1 A flowchart of the methodology. In grey: archaeological literature study, purple: database construction, green: selection protocol, orange: sediment and sampling, yellow: lab work, red: data collection, blue: statistical analyses

3.2 Site selection

The cores were collected from lakes in regions near the Irish Sea, as the initial database highlighted a high distribution of dated crannogs (see also chapter 2). As many Scottish sites had already been partially or fully excavated in previous studies (Cavers, 2010, Henderson et al., 2006, Henderson et al., 2003) or were undergoing excavation around the time of this PhD, such as Cults Loch and the Black Loch of Myrton (Cavers and Crone, forthcoming, Crone and Cavers, 2009, Crone and Cavers, 2013), the selection of the majority of the Scottish sites was a relatively rapid process. However, the Northern Irish sites required a more detailed selection process. The crannog database indicated a concentration of dated crannogs in Co. Fermanagh, which was why this region was selected.

Apart from Cults Loch and Black Loch of Myrton, another Scottish site and two Northern Irish sites were selected using the following process:

1) A list of sites was compiled of dated crannogs that could be assigned to either the Iron Age in the south west of Scotland or the Early Christian Period in Co. Fermanagh (see section 2.1)
2) All those lakes that were small or medium sized, were explored in more detail, as these might be expected to have substantial impacts from the construction of the crannog
3) The sites were assessed for ease of access and accessibility from a central location.

This led to the selection of Barhapple Loch in Dumfries and Galloway, Scotland, while Derryhowlaght Lough and Ross Lough are located in Co. Fermanagh, Northern Ireland near Enniskillen. These sites were selected in addition to Cults Loch and Black Loch of Myrton (see figure 3.2.1).

3.2.1 Regional climate

The sites studied in this these lie within two regions, which lie at a similar latitude. Furthermore, within the regions, the sites lie less than 75km apart, indicating that within regions the lakes experienced very similar weather conditions. To assess the regional climate, the website for the Meteorological Office was consulted, as it has recent climate data for most parts of the UK (MetOffice, 2015), with the nearest weather stations in West Freugh (Scotland) and St Angelo (Northern Ireland). Both regions experience a typical temperate climate. The prevailing wind direction is southwest with over half the days with overcast. On average the coldest month is February (1.8° C), while the warmest is July, with West Freugh slightly cooler than St Angelo (18.5° C and 19.2° C, respectively). The average annual rainfall is around 1100mm, with West Freugh having less days with rainfall over 1mm (160 days) and a higher average wind speed (10 knots) than St Angelo, which has 184 days of rainfall over 1mm and an average wind speed of 7 knots. St Angelo has a few more days of airfrost than south west Scotland, 45 and 39.9 on average.

3.2.2 GIS and map based methods

In order to better understand the sources of lake disturbances, catchment maps were compiled in ArcMap 10.31. The hydrological catchment of the sites was constructed under the assumption that water travels downward along slopes. To assist in understanding the disturbances in the cores, historic occupation sites were added to these maps to understand the timing and extend of some of these disturbances. These occupation sites are from online historic monument datasets from CANMORE (RCAHMS, 2015) and NISMR (NIEA and OSNI, 2006), while Scottish map tiles and contours (see appendix E) were derived from Digimap (EDINA, 2015). The Northern Irish site contour lines are constructed using the Global Digital Elevation Model (GDEM) based on the Shuttle Radar Topography Mission (SRTM) 1 Arc-Second global dataset, retrieved from the EarthExplorer website (Earthexplorer.usgs.gov). The Northern Irish sites were also compared to the georeferenced catchment outline as indicated by the River Basin Interactive Map (DOENI, 2015). Geological maps were interpreted using the online BGS mapviewer (BGS, 2015), to assess potential sources of limestone input into the lakes and shifts in lake alkalinity, as well as the underlying bedrock. For a complete list of data and tiles used in the maps, see appendix E.

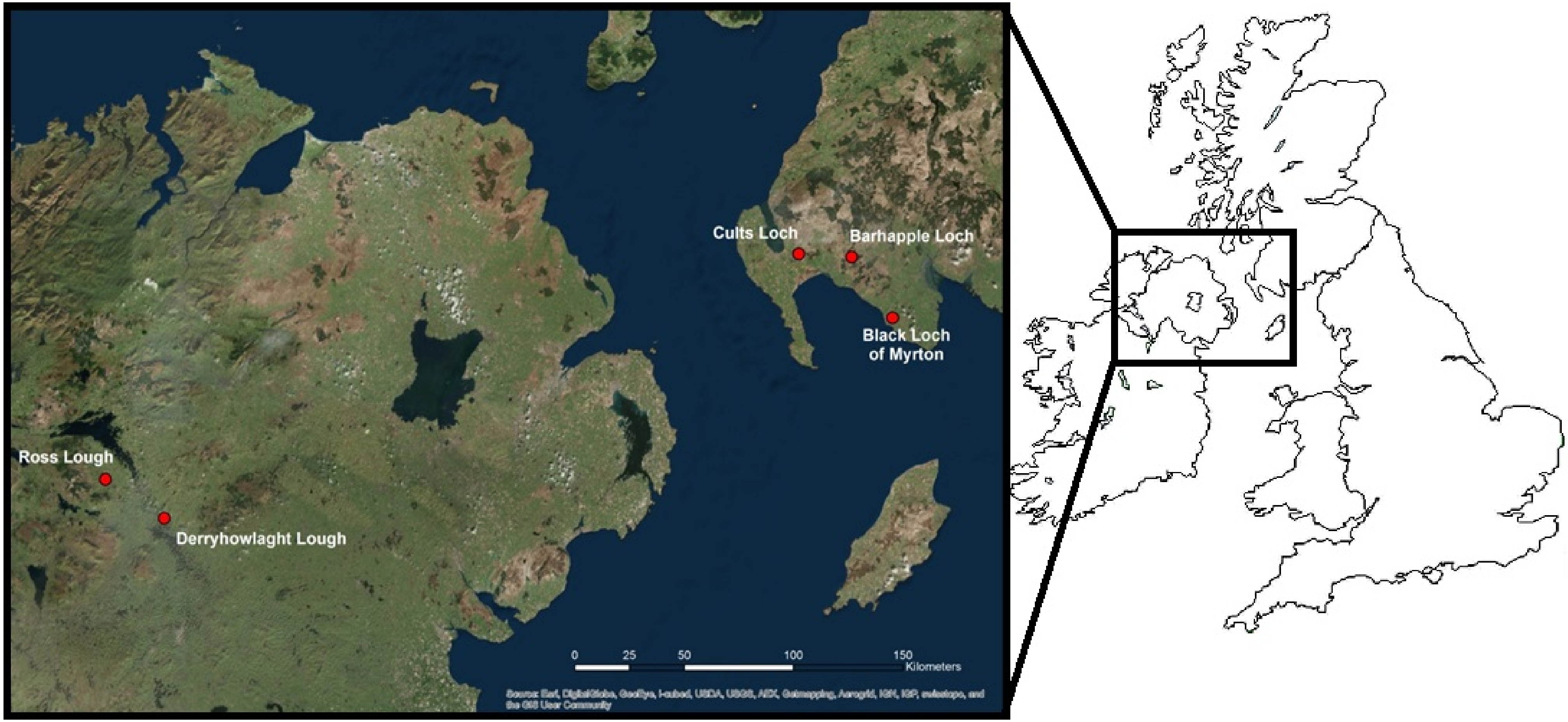


Figure 3.2.1 Location and aerial photograph of sites investigated in this thesis

3.3 Coring and sediment sampling

The lake sediments analysed in this study were collected from south west Scotland: Cults Loch, Barhapple Loch and Black Loch of Myrton, as well as from Co. Fermanagh, Northern Ireland: Derryhowlaght Lough and Ross Lough. These sediments were collected from the deepest part of the lake at each site, as well as nearest to the crannog as possible. The sediment was mainly collected using a Livingstone corer (5 cm diameter), which allows recovery of up to 1m intervals of sediment (Wright, 1967). The Black Loch of Myrton is drained and the upper sediments were composed of dried out clay, which is why a wide gouge corer (56mm diameter) was used to sample the upper metre. Cores were stored in guttering and wrapped in cling film. Cores were taken with at least a 20 cm overlap to reduce the chances of an incomplete core. The cores were stored in cool conditions (below 8 °C) at the University of Southampton, prior to sediment sampling.

Photos were taken of the core sections to aid with the sediment description. Following this, c. 50 cm long sediment samples were pressed in U-channels for XRF analysis, while the remaining sediment was cut into 1 cm slices. During this time the sediment was checked for large macrofossils useful for radiocarbon dating. These sediment slices were subsequently freeze-dried for better preservation. From these 1 cm slices, c. 0.5 gram of dry weight was used for loss-on-ignition analysis, while c. 0.5 mL was used for diatom analysis and another 0.5 mL for pollen analysis. Finally, the remainder of the dried sample was analysed for magnetic susceptibility. Pollen and diatoms were analysed at 16, 10 or 8 cm intervals, while loss-on-ignition and magnetic susceptibility was analysed at least at 2 cm intervals.

3.4 Regional land-use

Currently the vegetation in both regions is quite similar, as it is dominated by grasslands. However, the south west of Scotland has varying levels of pine plantations. Near Barhapple Loch and Cults Loch, pine plantations are more frequent and there are a few patches of deciduous trees between the grasslands. Furthermore, in the uplands near Cults Loch there are large areas covered by rough grassland, as well as patches of heather. However, around Black Loch of Myrton pine plantations are almost absent, apart from a few patches. Most of the land surrounding the site is grassland, with occasional patches of deciduous woodland, but also some areas with arable land. The Black Loch of Myrton is currently surrounded by wet woodlands and a reed fen and lies adjacent to a wet meadow (see figure 3.4.1). Barhapple Loch is surrounded by large areas with pine plantations, as well as bogs. There are a few small areas of grassland and some very small patches of woodland.

Co. Fermanagh similarly is currently covered by large amounts of grasslands, with occasional areas of pine plantation and occasional patches of deciduous woodlands. Ross Lough is near Fermanagh uplands and the Big Dog Forest, which lies on the Big Dog hill. On these mountains there are substantial patches of heather and rough grasslands as well as large sections of pine plantations. Derryhowlaght Lough is towards the south-east of Enniskillen, near the Belle Island estate and the river Erne (see figure 3.4.2). It is an inter-drumlin lake surrounded by grasslands and occasional patches of deciduous forest (Northern Ireland Forest Service, 2013).

Figure 3.4.1 Landscape images of crannog. Left: The excavation of the Cults Loch promontory, with the island crannog in the lake visible, as well as the surrounding meadows. Right: Overlooking the woodland of the Black Loch of Myrton, from the Fell of Barhullion, with the surrounding farmlands in the background

Figure 3.4.2 Left: Derryhowlaght Lough crannog, from the coring platform, with some woodlands and meadows in the background. Left: Ross Lough crannog, with the drumlin in the background, as well as the nearby pine plantation towards the right of the photo

3.5 Palaeoecological techniques

3.5.1 Physical and Geochemical proxies

The geochemical interpretation of the lakes sediments in this project is based up on LOI, MS and XRF. These are common analyses, widely available and relatively easy to interpret, as well as very cost efficient. It was not opted to analyse the sediments by for instance isotope or C/N composition, due to the limited amount of material available, the cost of the analysis and time-constraints.

Loss-on-ignition allows the estimation of the organic and carbonate components in the sediment. This can provide information on changes in the sediment deposition regime caused by, for instance, erosion or changes in lake productivity, circulation, and/or other limnological processes.

Following freeze-drying, the c. 0.5 gram subsamples were heated for 2 hours at 550 °C and for 4 hours at 950 °C (Dean, 1974). Before, between and after the heating phases the crucibles were weighed to determine the weight reduction due to combustion. This allowed the determination of the sediment composition with respect to organic content (LOI_{550}) and carbonate content (LOI_{950}). To determine carbonate content the percentage weight reduction following the 950 °C cycle was multiplied by 1.36. The ignition residue after two combustion steps can be classified as predominantly minerogenic material.

The remaining samples were freeze dried and used to fill 10 cm^3 magnetic susceptibility pots. Dual frequency mass specific magnetic susceptibility was measured using Bartington MS2 and MS2B (Dearing, 1994). This dual frequency equipment allows the detection of an important category of very fine ferrimagnetic minerals, described as superparamagnetic, found commonly in soils and in some rocks. Automatic corrections for the drift, pots and sample weight were applied using the Bartsoft program.

The inorganic elemental composition of the cores was analysed at BOSCORF at the University of Southampton. This was determined using U-channels and the ITRAX X-ray Fluorescence core scanner (Croudace et al., 2006). The ITRAX was equipped with a 3kW Mo X-ray tube set to 60 kV and 50 mA to analyse semi-quantitative variations of elements. As some errors might have been caused by plant fragments, a high water content or disturbances from the sampling techniques, the data was filtered. Sample depths with a particularly low count (below 20k total cps), a high error (>2.5 MSE), or those that were invalid as interpreted by the analysis program (Croudace et al., 2006), were excluded from further analysis. The remaining measurements were averaged by 1 cm depth intervals, to allow a comparison with the other physical and the biological proxies. The XRF records were normalised against total counts (e.g. Ti/kcps), erosional indicators (e.g. Fe or Ti) or as specific ratios (e.g. Fe/Mn or K/Rb).

3.5.2 Diatom analysis

A small subsample (0.5 mL) was taken from the freeze dried 1 cm sample to assess the diatom assemblages. The frustules were analysed at regular intervals of 10 cm (Barhapple Loch) or 8 cm (Cults Loch, Derryhowlaght Lough, Ross Lough and Black Loch of Myrton). Diatom samples were prepared by digestion with hydrogen peroxide (H_2O_2), following Battarbee et al (1986), after which they were mounted on microscope slides using Naphrax. At least 400 diatom valves were counted at x1000 magnification using a Nikon Eclipse 80i microscope. Images of selected frustules were captured using the Nikon Digital Sight DS-L2 and Nikon DS-Fi1 microscope attachments. Identification of the frustules follows the guides by Krammer and Lange-Bertalot (1999a, 1999b, 2000, 2004) with updated taxonomy following Round et al (2007) and compared to online databases (Spaulding et al., 2010, Guiry and Guiry, 2013, Kelly et al., 2005).

Difficulties occurred with the identification of small fragilarioid genera, as many features can only be identified under the Scanning Electron Microscope (SEM). As it is uncertain how much ecological information can be extracted from a higher level of taxonomy, in this thesis the smallest fragilarioid diatoms have been grouped together under *Staurosira* cf. *elliptica*, if they did not have features that allowed the frustules to be grouped within either *Staurosira construens* spp. or *Staurosirella pinnata*. Previous studies have encountered the same issues with identifying small fragilarioid under the light microscope and adopted a similar approach (e.g. Sayer, 2001).

3.5.3 Pollen and spore analysis

The pollen samples were treated following Faegri and Iversen (1989): Initially the samples were spiked with spore tablets (Stockmarr, 1971),dissolved with hydrochloric acid (HCl) to remove carbonates, potassium hydroxide (KOH) was added to deflocculate the organic matter, and then the residue was sieved through a 180µm mesh over a 10 µm mesh, keeping the 10-180 µm fraction. The sample was then treated with hydrofluoric acid to remove silicates and subsequently acetolysed to remove more resistant organic compounds. Finally the samples were stained with safranin and mounted in silicone fluid. At least 300 land pollen grains were counted under x400 magnification using a light microscope.

3.5.4 Statistical analyses

To compare the main changes in the diatom and pollen assemblages, a Detrended Correspondance Analysis (DCA) was performed (detrended by segments, nonlinear rescaling and down-weighting of rare taxa) using Canoco 4.5 (Ter Braak and Šmilauer, 2002). If the gradient length of the first DCA axis was less than 1.5, a linear ordination was deemed appropriate and a PCA was warranted instead (following Ter Braak and Prentice, 2004, Ammann, 2000). The samples were down weighted for rare taxa and centred on samples. Diatom and pollen zonation was based on the zones from a CONISS cluster analysis using Tilia 1.7.16. The analysis was stratigraphically constrained using the percentage data, and by square root transformation (Edwards & Cavalli-Sforza's chord distance, (Grimm, 1987).

The interpretation of the relationship between the diatoms and the geochemistry was analysed using a correlation to identify which geochemical variables were significantly correlated to the diatom PCA or DCA axis 1 and axis 2. Microsoft Excel 2010 was used to standardise the dataset, while R (R Core Team, 2013) and the PerformanceAnalytics package (Peterson and Carl, 2014) was used to identify significant correlations between the diatom PCA axes and the environmental variables (see appendix B). Then a multiple regression was constructed using the significantly correlated variables. The model was stepwise reduced using backward elimination, excluding the least significant variable until only significant variables remained, to identify which geochemical variables were of impact on the diatom assemblages. To support the multiple regressions, an RDA was performed in CANOCO (Ter Braak and Šmilauer, 2002) on the geochemical variables and diatom PCA axes, while a CCA was run in conjunction with diatom DCA axes. The results were then graphically represented in CanoDraw to aid interpretation of the relationships between species, samples and geochemistry.

3.5.5 Chronology

Plant macrofossils were handpicked from selected range-finder samples, to allow the construction of a simple age-depth model of the core. Particular attention was paid on picking terrestrial macrofossils, such as dicot plant matter or wood fragments.

There are multiple statistical packages available to construct an age depth model. Bacon age-depth models were constructed where multiple dated samples were available in the core. This software package (Blaauw and Christen, 2011) for R (R Core Team, 2013) uses Bayesian statistics to reconstruct deposition histories and produces a standard 1 cm resolution age-depth model of the core. Core depths were extrapolated to date the entire sediment depth interval analysed. Clam age-depth models (Blaauw, 2010) were produced as well, as the Bacon age-depth model assumes average sedimentation throughout the core, while Clam assumes linear interpolation to estimate the age of the sediment between dated samples.

As both the crannog and the age-depth model have their own error range, the maximum range at which evidence of each crannog can be calculated by determining the age distribution of the crannog radiocarbon date (95%) and the age distribution of each 1cm sediment slice (95%). Thus the maximum range of sediments possibly containing crannog sediments can be calculated, with an uncertainty of 0.0025 (α= 0.05 * 0.05), which will be displayed as the tails in the box plots. The sample with a mean age closest to the median age (Stuiver et al., 2005)of the crannog was also displayed in the boxplot as a guide. These crannog age depths were also used to add an additional probability density plot in red to the Bacon age-depth graph (see appendix C), while they are drawn as outliers in green in the Clam age-depth model. As the estimated depths of the two Bacon and Clam age-depth models can vary, both depth estimates coinciding with the crannog were produced to aid in the interpretation of the proxies, displayed as dashed screen behind the graph containing the proxies. The red screen is for the Bacon model and the green screen for the Clam model.

The crannog depth range estimate is used as a guide for the interpretation of the environmental changes, if any. For instance, if the crannog depth estimate falls within a pollen zone, an attempt will be made to determine if there is evidence of crannog related disturbances. This approach follows the expected crannog impact on proxies as summarised in table 1.6.3 (see page 70).

Chapter 4: Site and sediment descriptions

In the following sections the locations where lake sediments were collected in each loch will be described, as well as any additional information on the site, its catchment and the archaeology surrounding the lake. Furthermore a description of the sediment cores is given with the depths of the core sections analysed. Only the upper four core sections of the Scottish lakes and the upper three core sections of the Northern Irish lakes were analysed, as it was estimated that these sections should be able to capture the Scottish Iron Age and the Northern Irish Early Medieval period. This estimation assumes that 1 meter of lake sediment is deposited in about 1000 years, which is comparable to Holocene accumulation rates of several lakes in the British Isles (Edwards and Whittington, 2001).

4.1 Cults Loch

4.1.1 Site description

Cults Loch (lat/long: 54.9036, -4.9321, NGR: NX 1202 6058) is a very small lake (area 0.06 km^2), which contains two crannogs (see figure 4.1.1). It is a kettle lake which can be divided into distinct halves (figure 4.1.2), which are separated roughly from the northwest (tip of the promontory) towards the southeast across the island crannog (see also bathymetry). The western side is shallow (less than 3m) and near the central island crannog, the water depth is just under a metre. The eastern basin had a maximum water depth of 7.65m at the time of core collection. Currently the surrounding land is mainly used for raising cattle.

In the centre of the lake lies one crannog (Henderson et al., 2006), radiocarbon dated to the Late Iron Age (GU-10919 1790 ± 50 BP). It is a mound of c. 24m in diameter and 3.5m high. On the northern shore a promontory site was discovered, with further prehistoric activity in the vicinity indicated by a set of palisaded enclosures c. 100 m from the eastern shore, as well as several other archaeological sites in the immediate vicinity of the loch (Crone and Cavers, 2010).

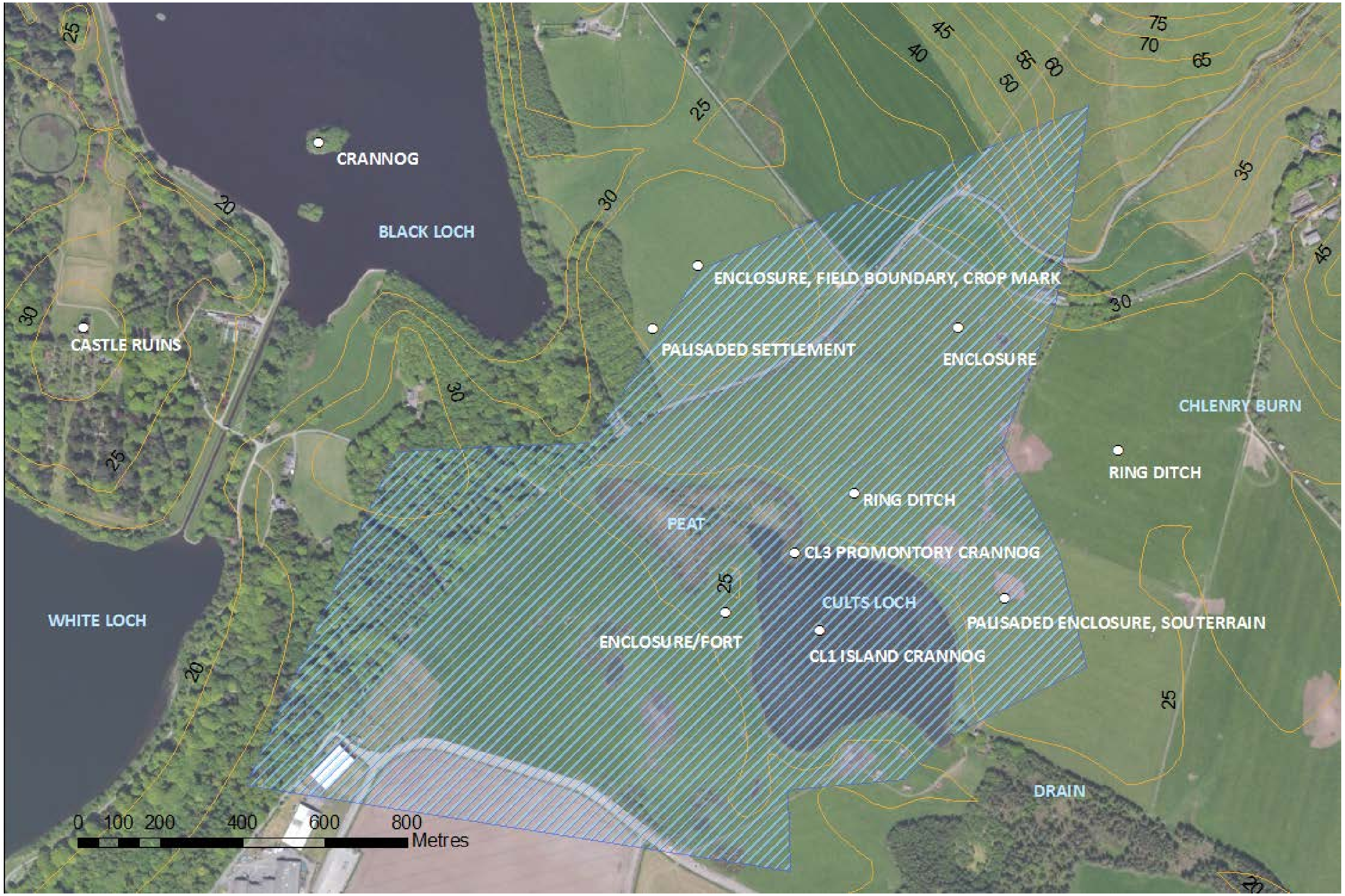


Figure 4.1.1 Catchment map of Cults Loch. Light blue text indicates water bodies and streams, black numbers indicate contour lines and white markers indicate archaeological sites

However, the excavations have focussed on the promontory crannog on the northern shore, dated to 2340 ± 50 BP (GU-12138). This is a man-made feature, with stakes and planking forming a barrier at the neck of the promontory. The promontory site was excavated between 2007 and 2010 by AOC. It yielded a great deal of horizontal timbers and piles, as well as two possible structures (Cavers and Crone, forthcoming). These structures were indicated by hearths, as well as the organization of the timbers, piles and occupational layers (see appendix A, figure A.1.1). Furthermore, there is a substantial amount of evidence of prehistoric settlement surrounding the lake, with the existence of several enclosures (figure 4.1.2).

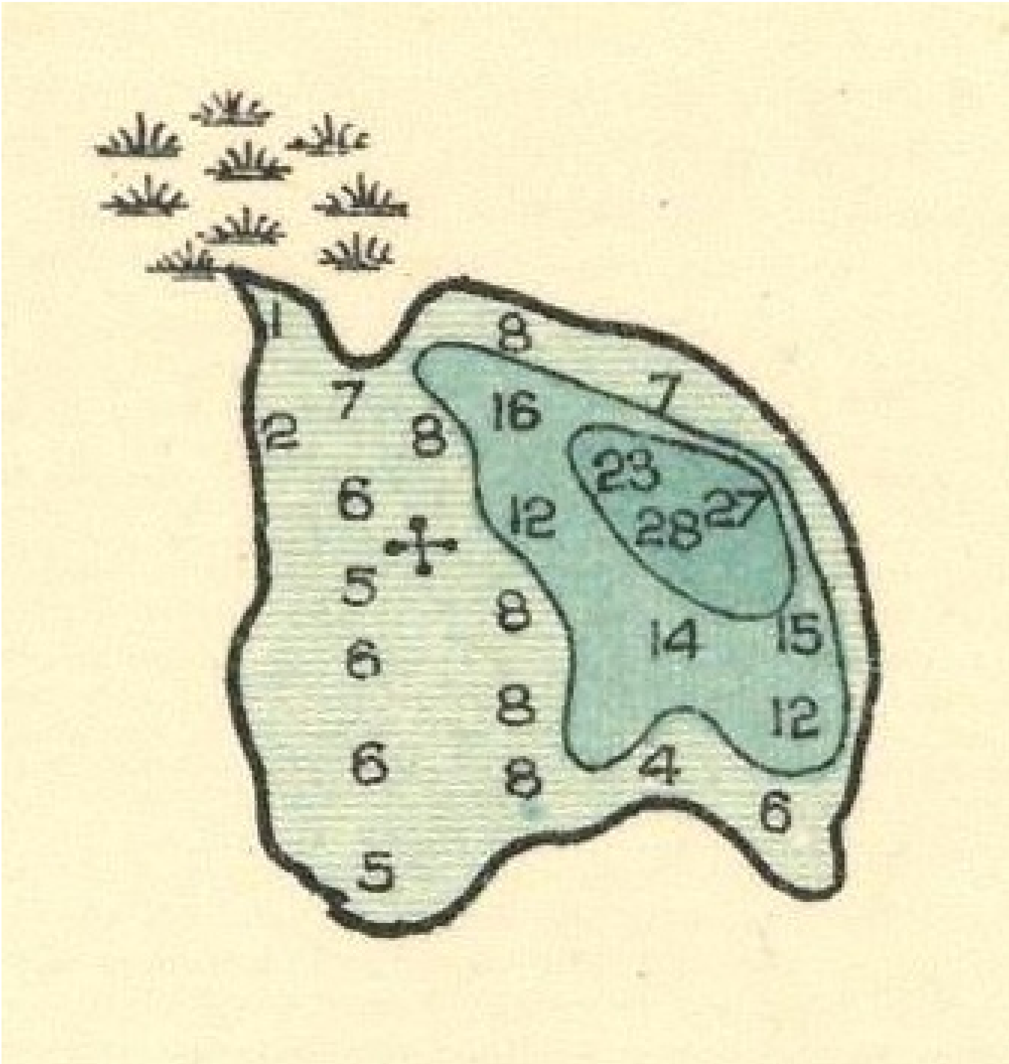


Figure 4.1.2 Bathymetry of Cults Loch, from Murray and Pullar (1910). The numbers reflect the depths in feet, while the cross indicates the position of the crannog. The width of Cults Loch is approximately 400 meters

4.1.2 Core descriptions

Lake sediments were collected at three coring locations (figure 4.1.3). As cores TCL 2 and TCL 3 were much shorter before hitting bedrock (1.6 and 5 m, respectively), the core selected to analyse was core TCL1, which has sediments collected up to almost 6m sediment depth (see table 4.1.1). However, the overlap between sections TCL 1.2 and 1.3 (c. 0.86-1.86m) failed to collect more than 30 cm and attempts to re-core this section failed. Thus it was chosen to core the next interval (1.35-2.32m), which was successful. The sediments can be described as highly organic (black) silty lake sediment, or silty dark grey gyttja (Ld^2, Ag^2) and there are few visual differences within the core sections (see figure 4.1.5), which contain occasional plant macrofossils, such as fragmented leaves and hazelnut-shells. The upper sediments in the core are slightly less organic, as evident from a lighter colour, which appears brown in the imagery.

Figure 4.1.3 Cults Loch coring sites. The core discussed in this thesis is TCL1

Table 4.1.1 Core section depths of core TCL1.

Section	Depth (cm)	Length (cm)
TCL 1.1	0-86	86
TCL 1.2	60-137	77
TCL 1.3	135-229	94
TCL 1.4	235-329	94
TCL1.5	285-384	99
TCL 1.6	335-426	91
TCL 1.7	385-471	86
TCL 1.8	435-535	100
TCL 1.9	495-594	99

Below are images from the upper four core sections (figure 4.1.4) which were analysed in this thesis (grey shading). The images were captured by the ITRAX core scanner. Due to sediment instability the third section did not capture the full metre of lake deposits in the chamber and there is a small hiatus in the record between 229 cm and 235 cm. This section is visible as a gap in some diagrams in chapter 5 and 7, where applicable.

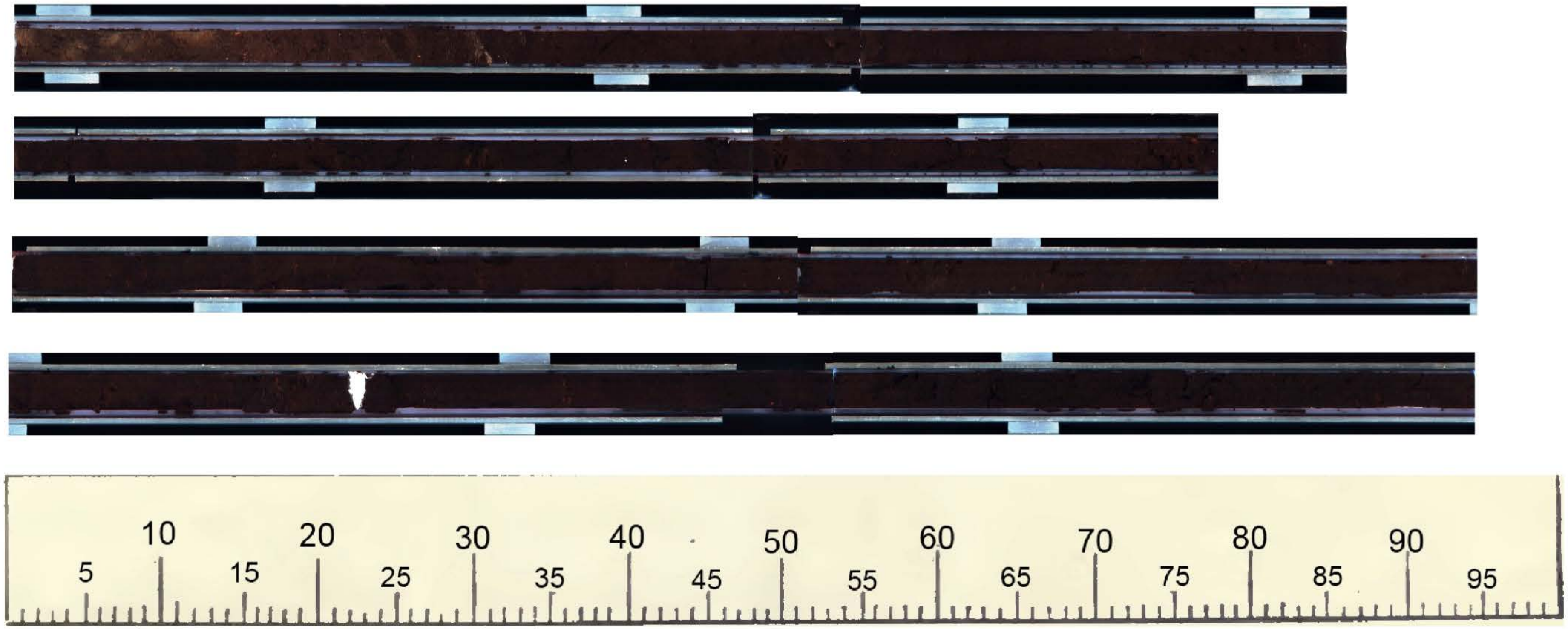


Figure 4.1.4 ITRAX scanner surface images of the sections of core TCL1. From top to bottom are sections TCL1.1 to TCL 1.4, with a ruler for scale (100cm). The white tag in the bottom core section indicates a depth where the core was sampled for radiocarbon dating, leading to a small gap in the sediments

4.2 Barhapple Loch

4.2.1 Site description

Barhapple Loch (lat/long: 54.8965, -4.7150, NGR: NX 2595 5915) is a very small and shallow lake (area 0.06 km^2), which lies just south of o the A75 between Stranraer and Newton Stewart, a short distance from Glenluce (see figure 4.2.1). The lake lies between two hills, the Barhapple and Dirlaughlin Hill. The lake is very shallow, with a maximum water depth of 0.7 metres and is covered by widely spaced reed beds, indicating it should probably be defined as a fen, rather than a lake. The immediate area surrounding of Barhapple Loch is covered by wet meadows and mosses.

A potential archaeological site was first discussed by the Rev. George Wilson (Wilson, 1871), who was informed of a structure by one of his deacons who was cutting peat in Barhapple Loch. Following drainage of the lake in 1878, the Society of Antiquaries Scotland explored the loch further (Wilson, 1882). A crannog was described at about 85 metres from the western shore and dimensions were c. 53.5 metres by 38.7 metres, as measured by the surrounding row of oak piles. Several pieces of mortised timber were found on the site, as well as worked piles and a channel coal ring, c. 4 cm in diameter. The crannog had a gangway that led from the south west of the crannog to the eastern shore. Currently the surrounding land is used for sheep farming. In the nearby bog 20-30 flint arrowheads were found (Maxwell, 1889), however these have since been lost.

The site was re-explored during the South west Crannog Survey (SWCS) in 2003 and 2004 (Henderson et al., 2006, Henderson et al., 2003). When the original 19th Century literature was compared with the recent survey, it became apparent that the reeds and heavy silting had obscured parts of the crannog noted during the original excavations (Henderson et al., 2003). Neither of the previously described gangways could be located. In the 19th Century description it was already noted that some of the wooden planks used in the construction of the crannog had already started to decay and plant roots were growing through them. It was assumed that due to the shallow lake level (mostly <0.5m) many of the timbers were within the photic zone and influenced by decay and biological attack, as well as desiccation from the fluctuating water table (Henderson et al., 2006, Henderson et al., 2003).

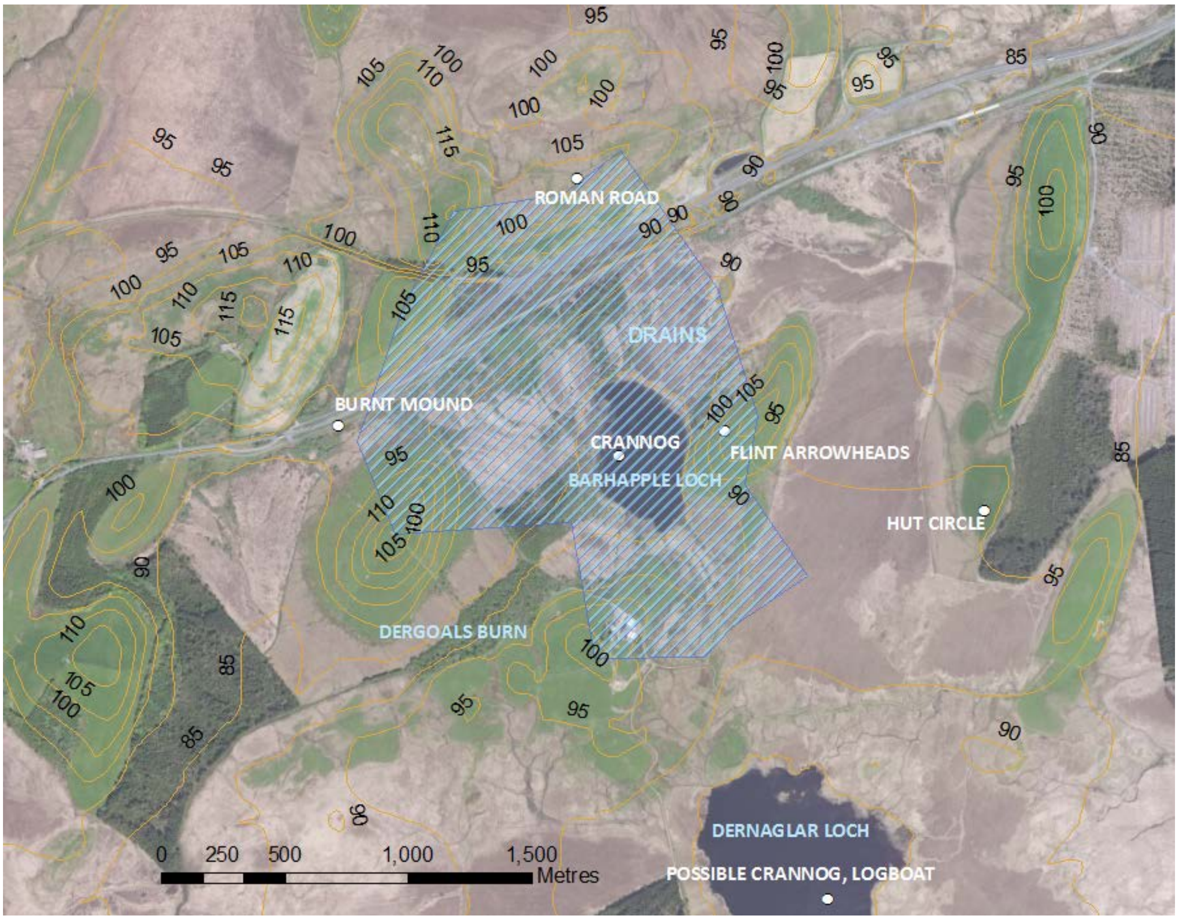


Figure 4.2.1 Catchment of Barhapple Loch (hatched area), based on the contour lines (black text). The white dots indicate evidence of prehistoric settlement, while the blue text indicates the names and location of water bodies, drains and streams

Radiocarbon analysis on one of the piles yielded a date of 2130±50 BP (GU-10920, 360-42 cal. BC, 95.4%), placing it in the Early Iron Age. For the location of the identified piles and timbers, see figure 4.2.2.

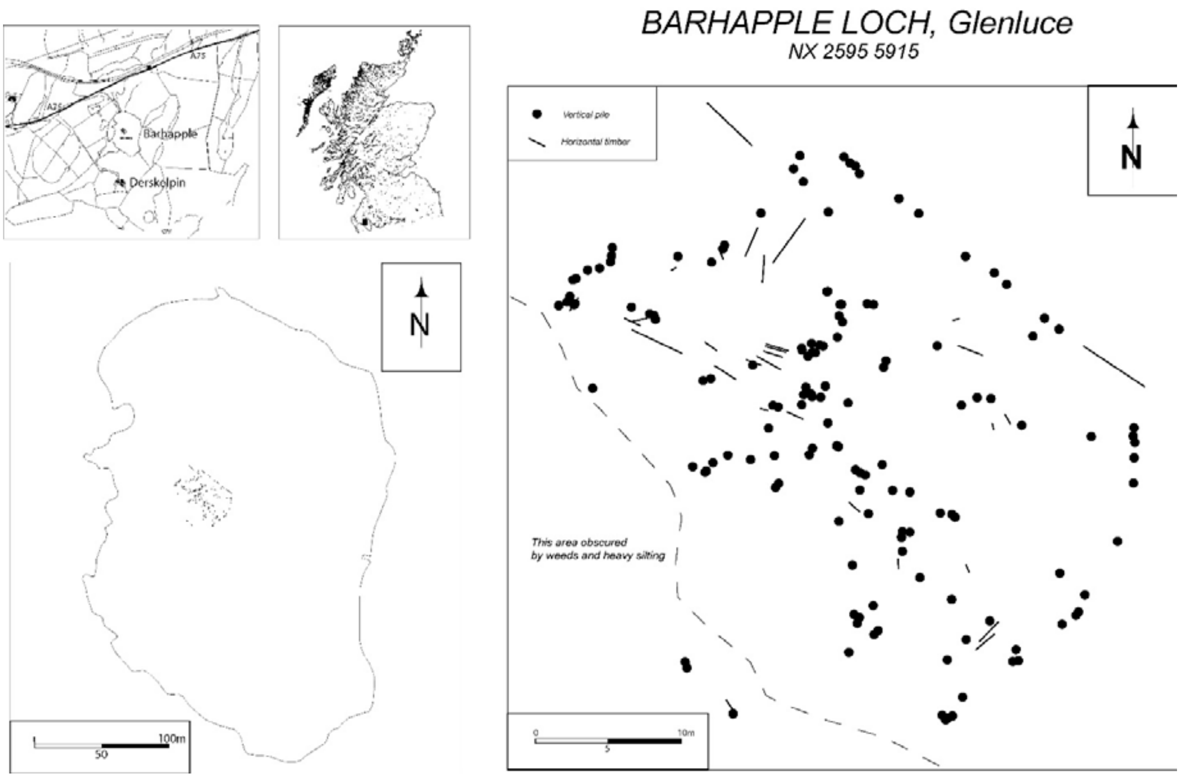


Figure 4.2.2 Archaeological description of the location of identified piles in Barhapple Loch (from Henderson et al., 2006). The lower left image reflects the outline of the loch and the location of the piles, with a close-up of the piles on the right

Although the catchment is very small, it does contains some other settlement features, with a burnt mound towards the west, some flint arrowheads on Barhapple hill, a hut circle towards the west and evidence of a Roman road parallel to the current A75. Furthermore, a logboat was described in Dernaglar Loch, which lies just south of Barhapple Loch.

4.2.2 Core descriptions

Over the course of a three day interval in August 2011, the lake sediment was explored and suitable locations for core collection were determined. Three locations were cored with a gouge corer (2 cm diameter) for initial sediment analysis (Trans 1-3, see figure 4.2.3 for locations and the stratigraphic diagram in appendix A.2), while two cores were collected from the central part of Barhapple Loch using a Livingstone corer (10 cm diameter, BL04 and BL05, see figure 4.2.3). The sediments (figure 4.2.4) appear to consist of mainly of very organic silty peat, with frequent reed plant fragments. Below the silty peats are distinct sandy intervals. The fen is heavily populated by reeds that are growing in clusters across large parts of the lake. The combination of the reeds and the shallow water depth make for difficult coring conditions. Core BL05 is next to the crannog, while core BL04 is slightly further away. However, during the coring expedition it was difficult to identify the location of the crannog, as the piles that were noted in the records were difficult to locate.

Given the amount of archaeological activity on the crannog thus far, there is a substantial risk of disturbed sediments. Thus it was decided to focus analyses on BL04. Future analysis on the site could be a comparison of the cores BL04 and BL05, to see how they compare and if there is any difference in the degree of disturbances near the crannog and slightly further away. Core BL04 probably represents a very long period of the Holocene, as the bottom of the core, around 4 metre depth, contained smooth bluish grey clays, which are indicative of Early Holocene sediments (e.g. Shennan et al., 1995, Griffiths, 1988).

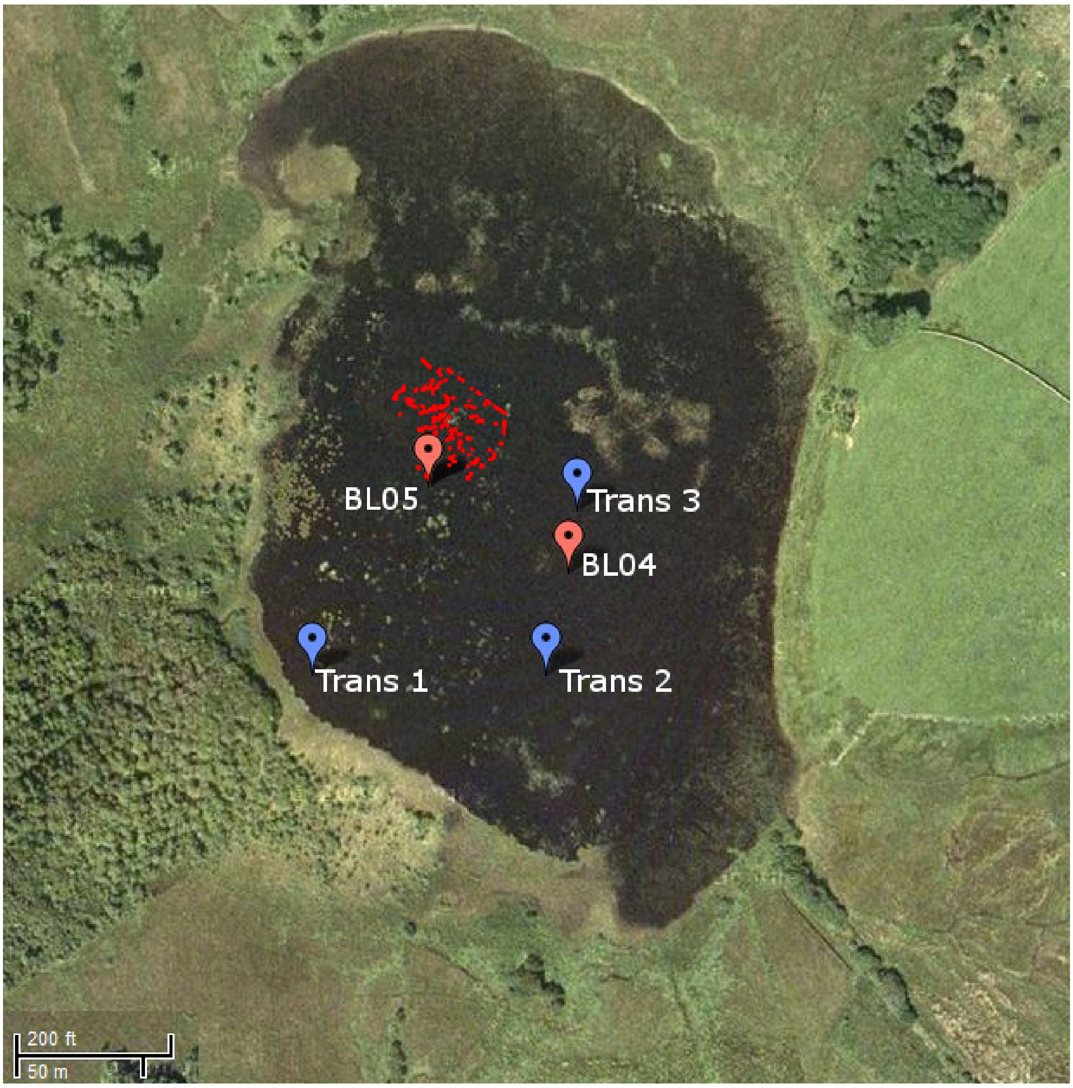


Figure 4.2.3 Aerial image (Google Earth) of Barhapple Loch coring locations (BL04 and BL05) and explored (Trans 1-3). Overlain in red is the location of the piles and timbers identified during the 2003/2004 excavations

Table 4.2.1 Sediment depths and description of core BL04. The shaded section indicate the section analysed in this thesis

Core section	Depth (cm)	Core Length (cm)
BL04S1	10-110	100
BL04S2	90-190	100
BL04S3	170-270	100
BL04S4	250-350	100
BL04S5	330-430	100
BL04S6	410-510	100

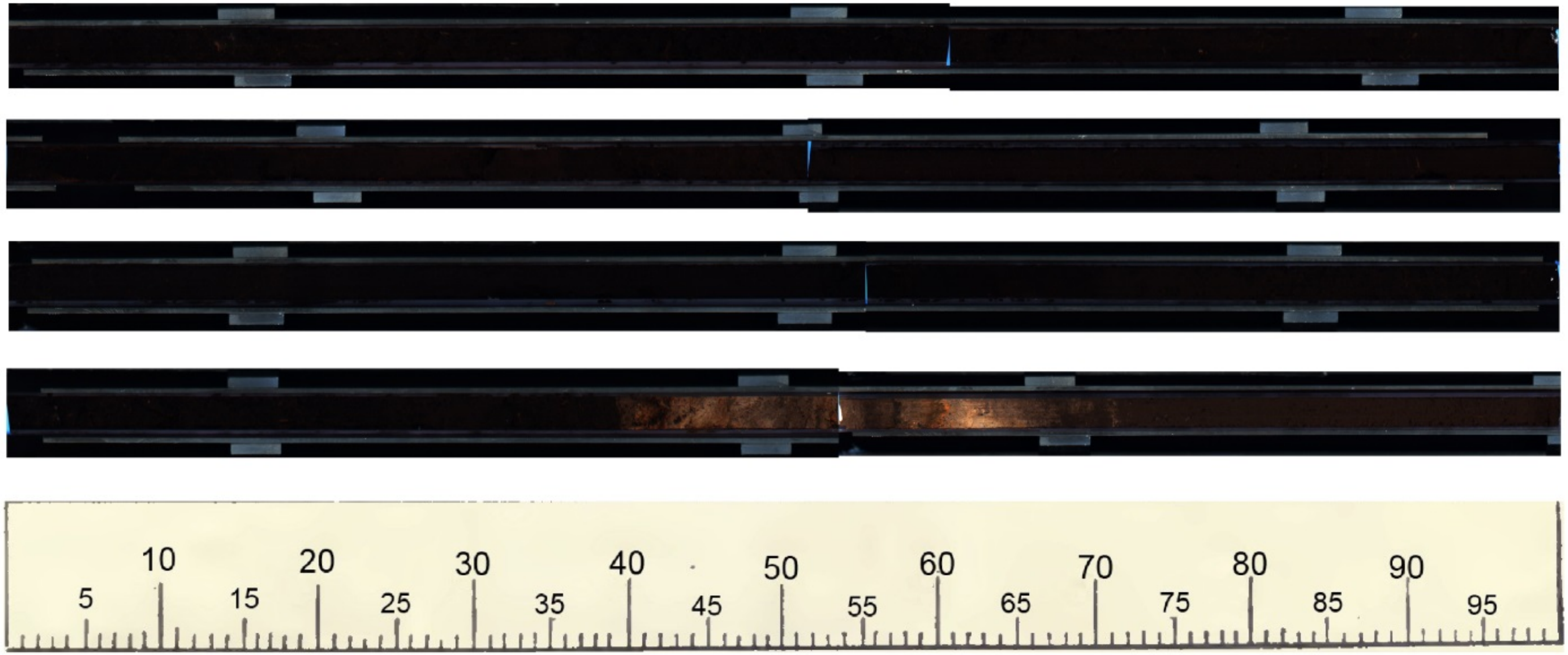


Figure 4.2.4 Core imagery of core sections BL04S1 to BL04S4, with the core-section tops towards the left of the graph. The blue marks represent edges of subsections, rather than actual sediment. Up to c. 287 cm depth (37 cm from top in core BL04S4) the sediment consists of blackish brown peat with frequent plant fragments (mainly *Phragmites* leaves and roots). Although not clearly visible in the photos there is a more humified interval in BL04S3, 30-40 cm, 200-210 cm composite depth). There is a short diffuse transition towards a brownish silty interval containing rare plant fragment. From c. 285-310 cm depth (35-70 cm in core BL04S4) the sediment appears more yellowish, containing high proportions of silt and sand components. Below the core sections described above there is another section (not analysed, BL04S5, c. 3.3-4.3 m) containing brownish silty sediment, overlying a bluish silty sediment below 4 meters depth. The sediments are discussed in more detail in the results section 5.2.1

4.3 Black Loch of Myrton

4.3.1 Site description

The Black Loch of Myrton (BLM) is a drained lake (lat/long: 54.7538, -4.5483, NGR: NX 36104 42835), lying within the Monreith estate, near Port William, which is currently covered in pasture and plantation woodland. This site was initially explored by Sir Herbert Maxwell, who had shown a potential site to Robert Munro. Explorative excavations identified 8 or 9 mounds, with flat stones laid in clay, about 9 feet in diameter, with fire marks and enclosed by ashes and cinders. He also found several white quartz grinding stones, some beach pebbles and corroded iron and vitreous slag (Maxwell, 1889). The extent of the drained lake is not well defined and extensive coring in the area surrounding the excavation indicated that reedy peat was ubiquitous (see appendix A3). Therefore, the lake probably was little more than a shallow fen, covered with reed beds. Furthermore, the coring was unable to locate a definite stratigraphic boundary underneath the settlement deposits, nor evidence of a timber structure, indicating that it is unlikely the site was built upon an artificial mound. The current interpretation is that the site is a lakeside village, similar to Glastonbury and Meare in Somerset (Coles and Minnitt, 2000) and Balluycagen Lough, Isle of Man (Bersu, 1977).

As the site (figure 4.3.1) can be classified as a fen, with a small body of open water near the centre, it can be assumed that the Monreith Burn, which flows just south of the site, is a major water inflow source for the site. This dramatically increases the catchment of the site, as the Monreith Burn has its source near Glasserton (see figure 4.3.2).

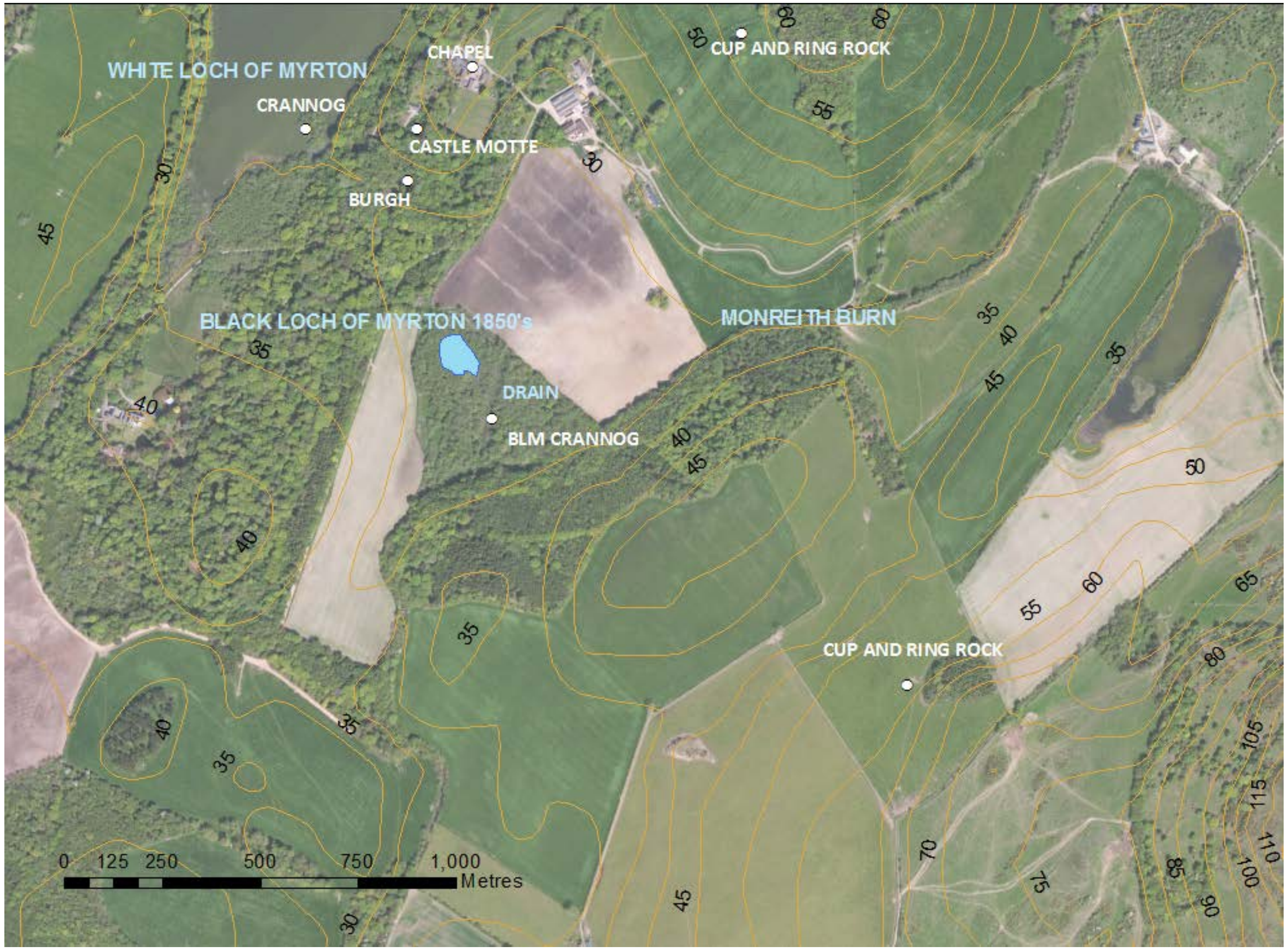


Figure 4.3.1 Local area of the Black Loch of Myrton. The blue outline indicates the extent of the Black Loch of Myrton as indicated on the first revision OS map. The location of archaeological monuments (including the BLM crannog) is indicated by the white dots

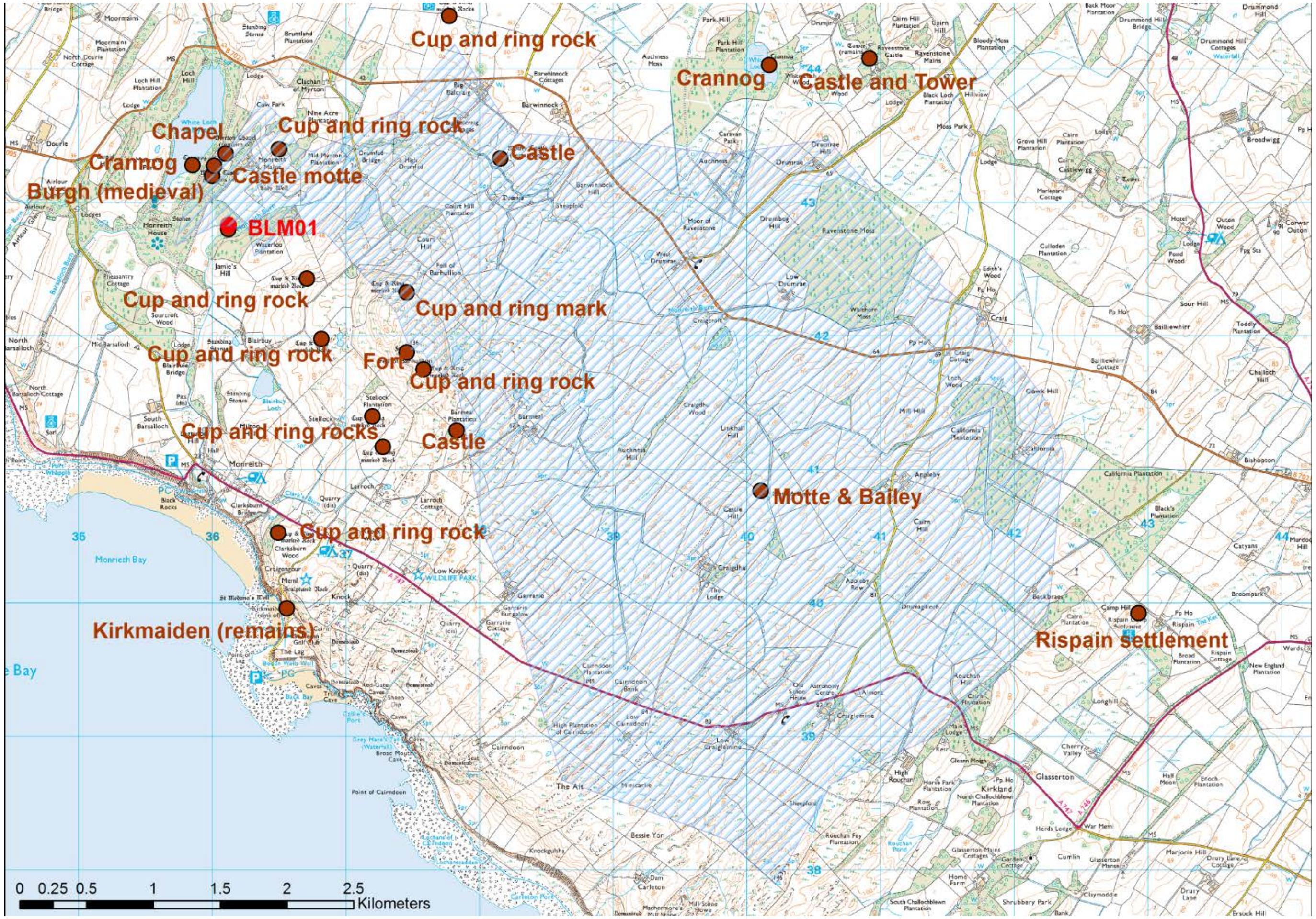


Figure 4.3.2 The catchment map of the Black Loch of Myrton, with the extent indicated by the hatched blue area. The brown dots indicate the location of archaeological monuments in the catchment, while the coring location is indicated by the red dot

4.3.2 Sediment description

A 90 cm core was recovered from the settlement site near the Black Loch of Myrton using a wide gouge corer (56mm diameter). The sediments are composed of silty peat with a varying humification, peat and silt content (see figure 4.3.3). As the excavation indicated that the archaeological deposits were concentrated in the upper metre of sediment (Crone and Cavers, 2013), the analyses have focused on these upper sediments. The bottom 15 cm of the core is composed of silty peat (90-70 cm, Th^3, Ag^1), while between 70 and 30 cm the core has a lower peat component (Th^2, Ag^1). The upper sediments are increasingly siltier (30-25 cm, Ag^2, Th^2 and 25-5 cm, Ag^3, Th^1). The increased levels of silty sediments in the upper part of the core are probably related to drainage activities that took place at around 1800 AD (Munro, 1885), as peat deposits are more likely to be preserved when they are below the water table. Therefore, care has to be taken with the interpretation of the upper sediments, as perturbation of the peat stratigraphy is likely in drained peatlands (Holden et al., 2006).

Figure 4.3.3 Image of BLM01, with the top of the core indicated towards the left. The entire length of the core is 90 cm. See text for a detailed description of the sediments

4.4 Derryhowlaght Lough

4.4.1 Site description

Derryhowlaght Lough is a shallow (max depth c. 2.5 m) and small lake (lat/long: 54.276077, -7.540098, NGR: H3003036360) towards the south-east of Enniskillen, along the river Erne, near Belle Island. The lake is very shallow and the surrounding land is currently used for cattle grazing. The lake is fed by an inflow from a tributary of the river Erne, with a source near Lisbellaw (see figure 4.4.1), while a secondary source flows in from Lough Corban, originating from near Cloon. Furthermore, the map indicates there are 9 ráths in the catchment, while there is another crannog in Lough Corban (Baillie, 1982a), indicating the extent of Early Medieval archaeology in the catchment. The catchment also contains a several burnt mounds and other archaeological sites (see figure 4.4.2). The name Derryhowlaght is derived from *daire* / *doire* and *taimhleacht* and means “the oak-grove of the plague-grave” (Joyce, 1869), which might be a reference to the burial features located nearby on the western shore of Derryhowlaght Lough.

When the lake water chemistry was measured in May 2015, it indicated that it had a pH of 8.3 and a conductivity of 279.8 µS/cm, while the evening water temperature was about 14.4 °C and the water appears to be fully oxidised (100% saturated, 11.36 mg/L). The surface deposits of the catchment are mainly composed of old lake sediments, as well as mixed limestone and siltstone (appendix A.4, figure A.4.1).

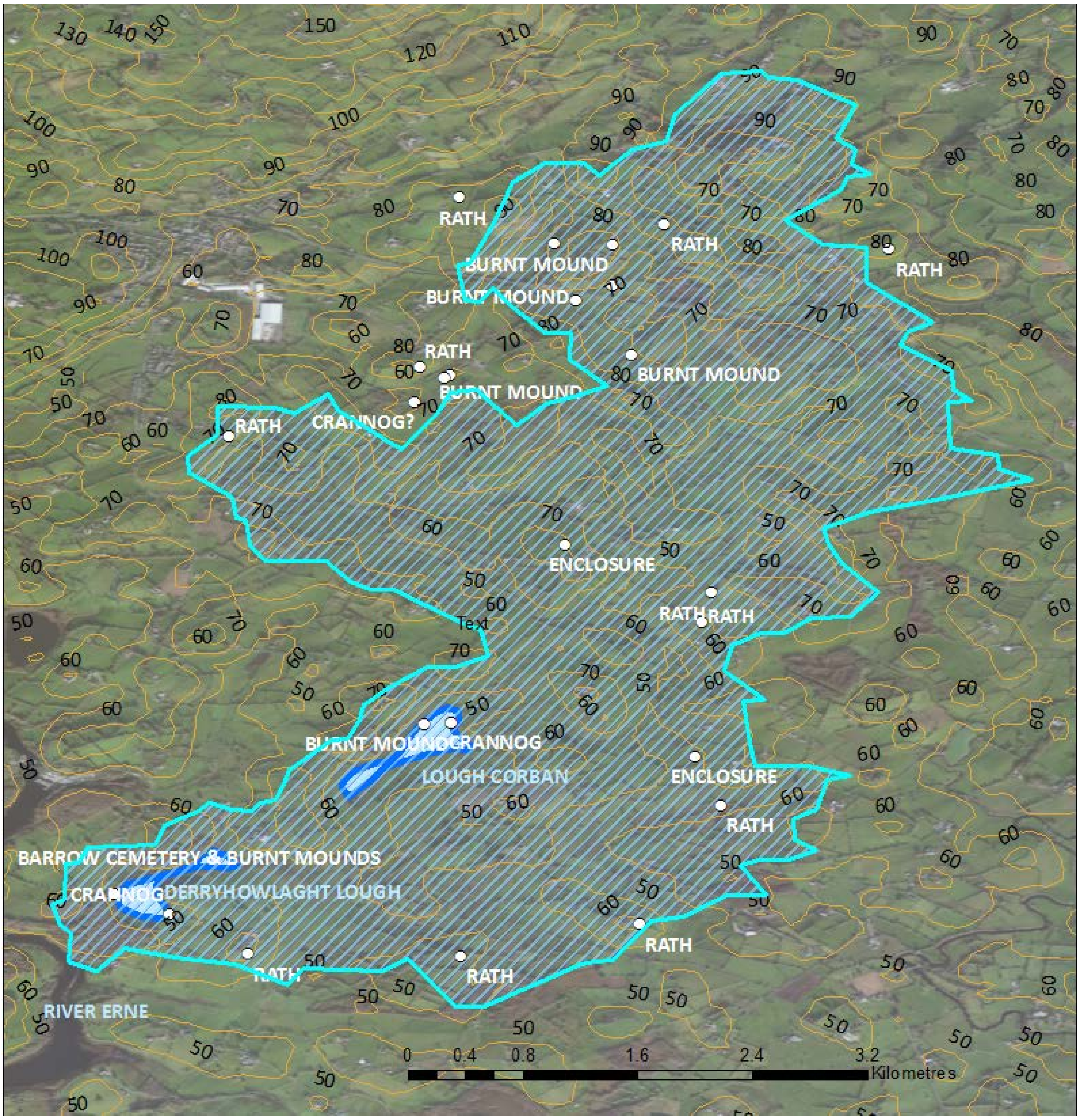


Figure 4.4.1 River Erne tributary catchment of Derryhowlaght Lough (hatched area) with prehistoric and Early Medieval archaeological sites indicated by the white dots. The blue outlines indicate the position of Derryhowlaght Lough and Lough Corban in the catchment. The black text indicates the height of the contour lines, reflecting landscape dominated by low drumlins. ©Northern Ireland Environment Agency & Land and Property Service Copyright 2006

Derryhowlaght Lough was explored by Brian Williams (1993), who describes some wooden structures (timbers and possible wattle panels) as well as a few artefacts:

> "This site is situated towards the southern shore of Derryhowlaght Lough, an inter-drumlin lake in the Upper Erne basin. The crannog is not marked on any OS map edition, perhaps because the water level was several metres higher than the present level within living memory. It now appears as an irregular oval island 10.5 m north-south by 8.2 m east-west and standing only 0.3 m above the surface of the water.
>
> Underwater inspection revealed a submerged wooden outer perimeter indicating the original extent of the structure was some 23 m east-west. On the exposed weather side of the crannog in an arc from north-north-west to west to south west, erosion has revealed a jumble of round-sectioned timbers, each on average 1 m long and 0.15 m in diameter. Only two of these timbers have indications of mortising. The timbers were left in situ with the exception of one fragment which has been identified as alder. This showed traces of having been cut with a sharp axe. A sample submitted for radiocarbon dating (UB 37119), gave a result of 1262 ± 38 BP and with 95% probability lies within a date range of AD 666-872. Elsewhere on the sheltered side of the crannog the lake-bed was more silted and timbers were fewer in number.
>
> Off the south side, below 0.3 m of silt, is an area of extensive complicated woodwork with indications of vertical wattle panels. This extends out 19 m from the centre of the crannog but could not be surveyed as it was not visible and diver activity was damaging to the fragile structures.
>
> Careful searching, using metal detectors, of the crannog and surrounding lake-bed led to the recovery of some artefacts and animal bones. A complete rotary quern and two fragments were recovered from the water. A fragment of iron slag, a piece of burnt clay and an iron object were recovered as was a jaw-bone of a horse and a single pig bone. A gridded search of the entire lake-bed indicated deep silting and no archaeological objects were recovered."

As the lake is located very close to Upper Lough Erne, it is probably influenced by changes in water level, as water level has been controlled in the Erne lakes following the 1842 Drainage Act. Another major water management scheme took place after 1950 following the Erne Drainage and Development Act. This included maintaining the water levels to support summer recreation, as well as to support a hydro-electric station near Ballyshannon. Furthermore, the historic maps indicate that parts of the nearby woodland were cut down in the 19th Century (see appendix A.4, figure A.4.2).

4.4.2 Sediment description

Lake samples were collected from the lake during August 2011, in an attempt to locate disturbances in the sediments related to the nearby crannog. Sediments were collected approximately 6-7m from the crannog (figure 4.4.3). The location was selected as the coring location was the deepest location, without going up on to the crannog slope. Water depth measurements and sediment descriptions indicated that further away (c. 15 m) the water depth and sediments were identical. The core was collected up to 377 cm depth (see table 4.4.1) and can be described as brownish grey silty clay (figure 4.4.5). Only the upper four core sections were analysed, as the crannog dated back to the Early Medieval period and it is unlikely that the final section provides sediment contemporary with the crannog. For example Lough Augher had accumulation rates between 0.3 and 2 mm yr^{-1} (Anderson, 1990b), so assuming the quickest accumulation rate (2 mm yr^{-1}) for Derryhowlaght Lough, the crannog would be around 257 cm depth.

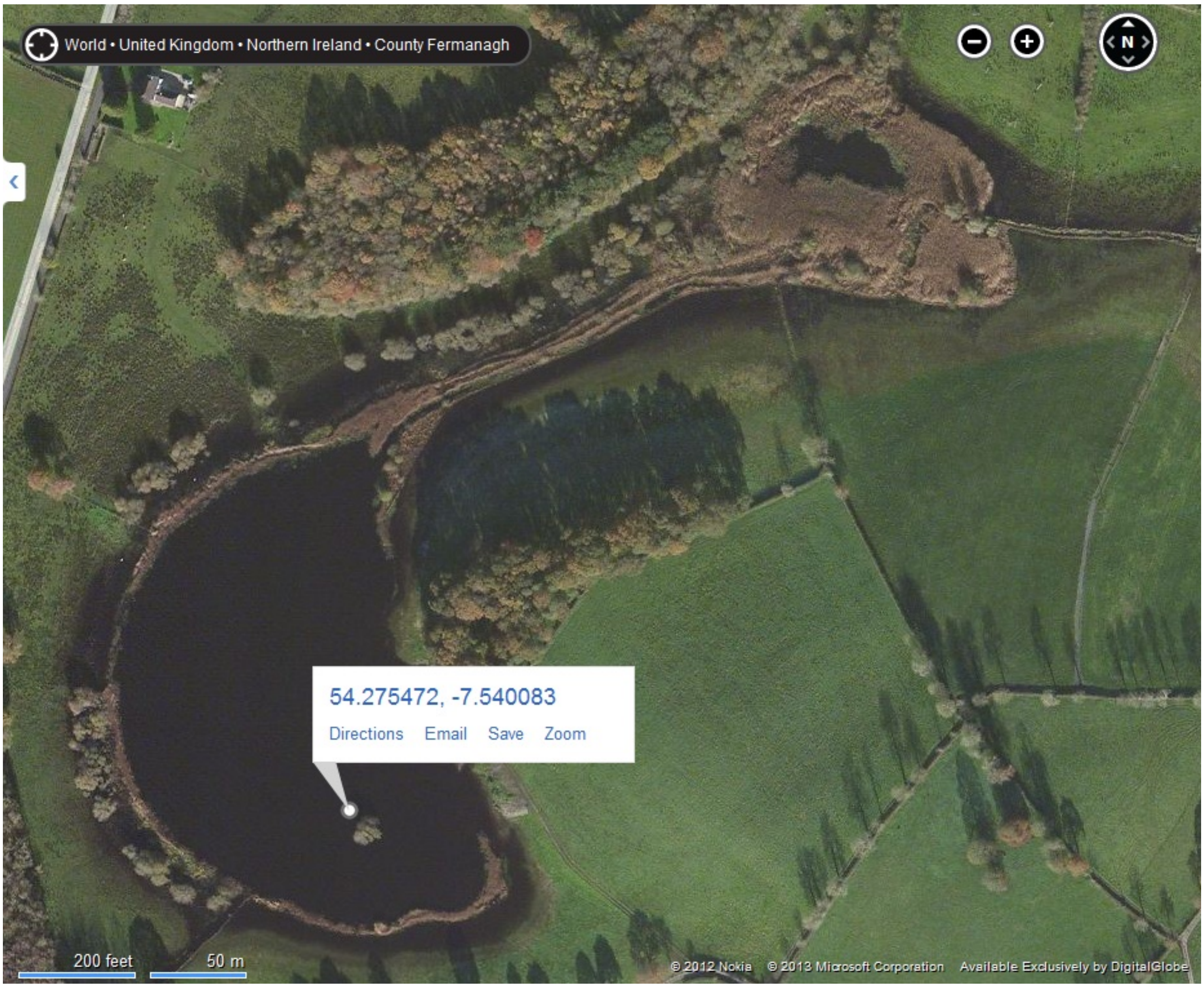


Figure 4.4.2 Coring Location in Derryhowlaght Lough, District Fermanagh, Northern Ireland (adapted from Bing Maps)

Table 4.4.1 Sediment depth of core DL01

Section	Depth (cm)	Length (cm)
DL01S1	0-67	67
DL01S2	61-140	79
DL01S3	136-217	81
DL01S4	206-297	91
DL01S5	277-377	100

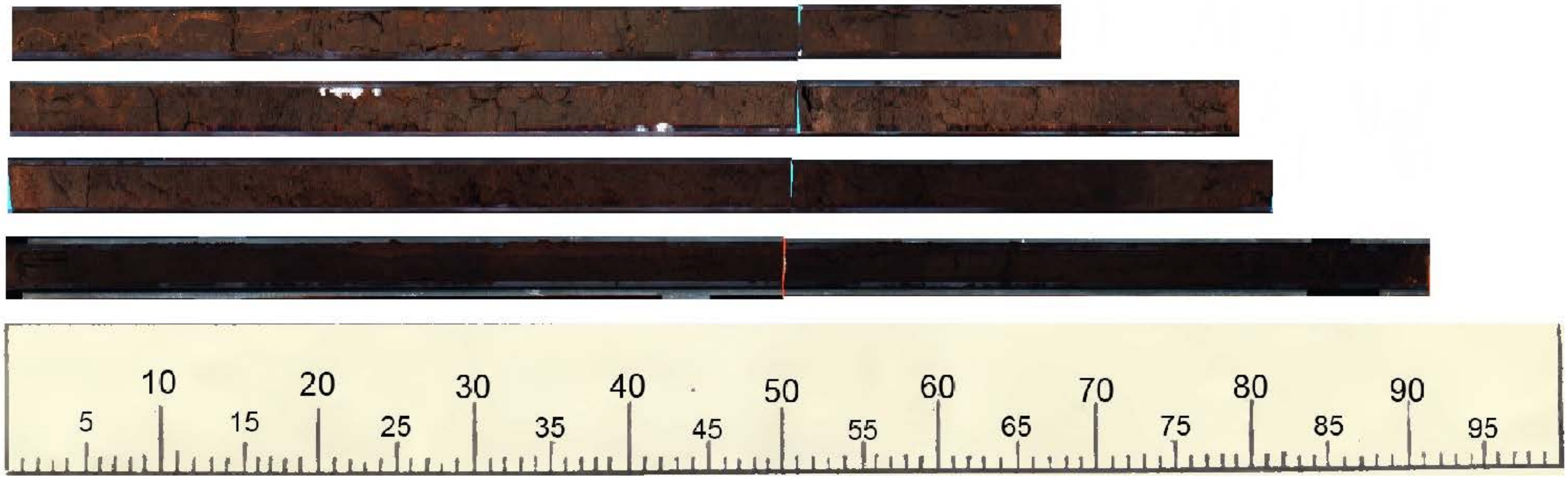


Figure 4.4.3 Core images of DL01S1-4, as captured by the ITRAX scanner. The bright blue and orange colours are artefacts from the core scanner

4.5 Ross Lough

4.5.1 Site description

Ross Lough (lat/long: 54.3685, -7.7910, NGR: H1429046780) is a shallow (<2 m maximum depth) medium sized (0.8 km^2) lake located towards the south of Lower Lough Erne, near Monea and Springfield. The hydrology of the lake is complex, as the lake has two inflows. The Sillees River originates near Lough Achork in the Lough Navar Forest and flows for 27.6 km before reaching the western side of Ross Lough. This catchment of the Sillees River up to Ross Lough is almost 10,000 ha, while the entire Sillees river catchment is 16,630 ha. However, the eastern part of the lake, where the crannog and the core are located, is fed via Carran Lough and originates from near Monea castle. This probably indicates that Ross Lough has a distinct eastern and western basin (see figure 4.5.1). The eastern catchment contains a wealth of archaeological sites (see figure 4.5.2), with at least 6 ráths, 3 burnt mounds towards the south of Carran Lough, a crannog in the lake near the plantation castle of Monea, one possibly towards the north-west of Carran Lough and two castle ruins.

The geology of the catchment is similar to that of Derryhowlaght and mainly composed of lake sediments and mixed limestone and siltstone (appendix A.5, figure A.5.1). The water chemistry of the lake was measured in May 2015, indicating an alkaline conductivity of 238.4 µS/cm and a pH of 8.4, while the water temperature near the surface was 13.3°C and the water appears to be fully oxidised (100% saturated, 11.4 mg/L).

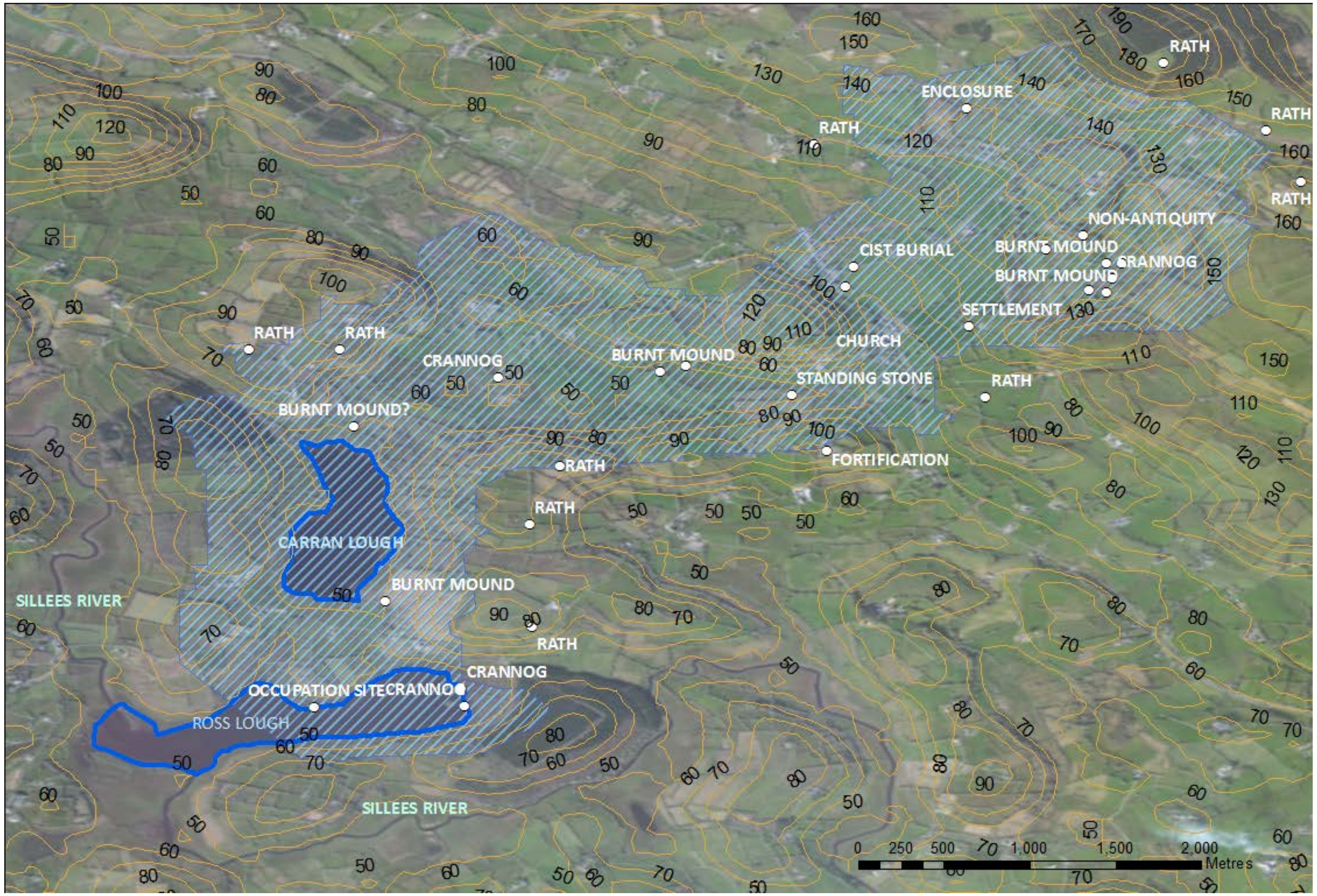


Figure 4.5.1 Hydrological catchment of Ross Lough, as indicated by the hatched blue outline, with Early Medieval and earlier archaeological sites indicated by the white dots, while Ross Lough and Carran Lough are outlined by a blue outline. The black text indicates the height of the contour lines

4.5.2 Core description

A core was collected from the eastern part of Ross Lough to infer changes in the lake ecology related to the crannog (see figure 4.5.3). The sediments are uniform and composed of fine silts with some organic matter (Ag^3, Ld^1). When the sediments were cored, they were described as greyish blue with possible darker black lenses, but back in the lab it appeared uniformly dark brown, indicative of oxidation. Only the upper three sections were analysed (see table 4.5.1). The geological map of the site indicates that superficial deposits are composed of lacustrine clay (appendix A.5, figure A.5.1), while the bedrock is composed of the Tyrone Group, which is a mixture of limestone, mudstone, sandstone and siltstone (Brandon, 1977).

Figure 4.5.2 Ross Lough coring location, c. 30m from the crannog

Table 4.5.1 RL01 sediment section depths. The shaded core section were analysed in this thesis.

Section	Depth (cm)	Length (cm)
RL01S1	0-100	100
RL01S2	80-180	100
RL01S3	160-260	100
RL01S4	240-340	100
RL01S5	320-420	100

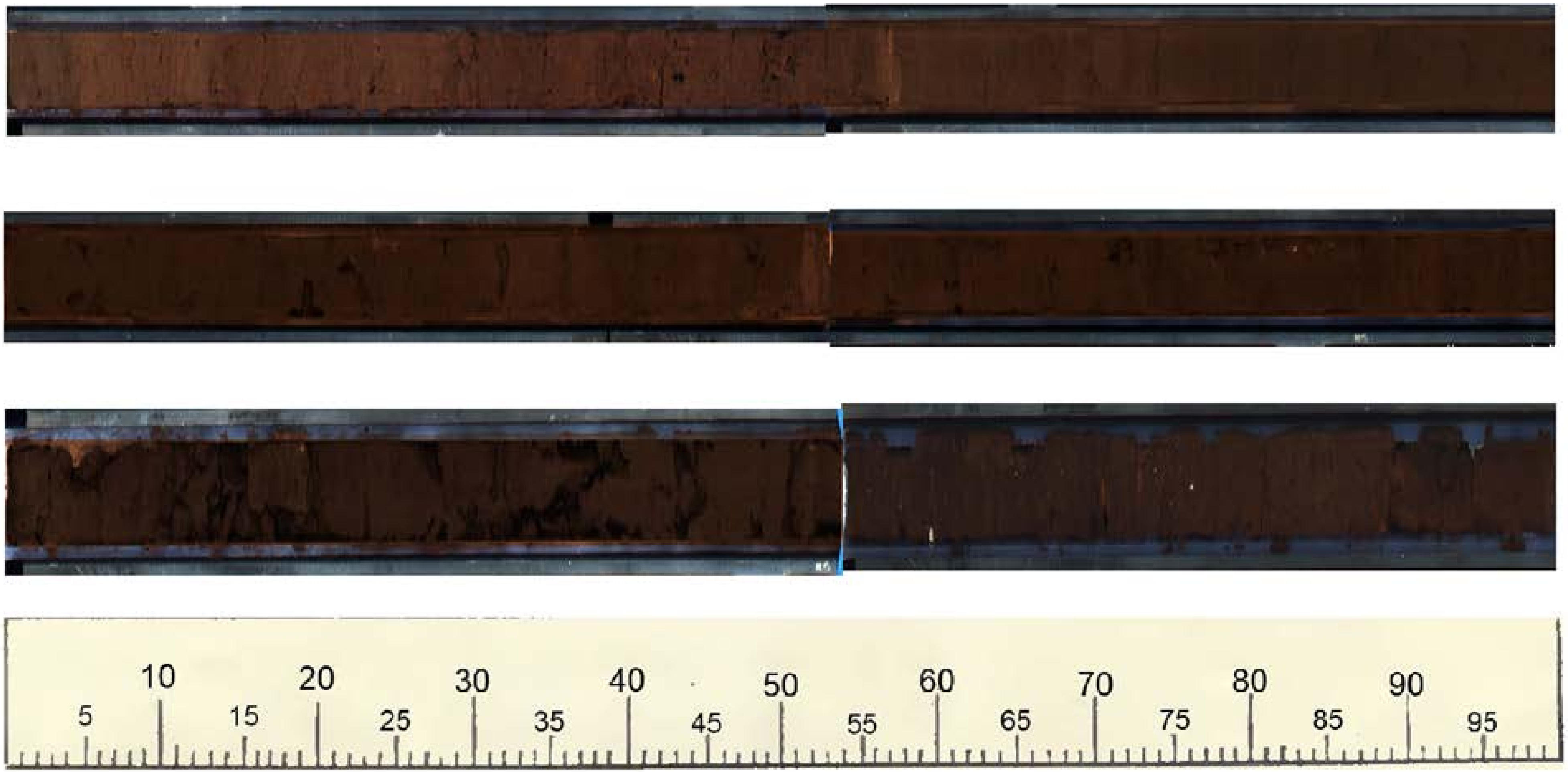


Figure 4.5.2 Core images from RL01S1 to RL01S3, captured using the ITRAX core scanner

Chapter 5: Results and discussion – Crannogs in south west Scotland

5.1 Cults Loch palaeoecology

5.1.1 Chronology

The radiocarbon dates were calibrated using the Bacon age-depth model (Blaauw and Christen, 2011) and using the most recent calibration curve (Reimer et al., 2013). The results are displayed below (table 5.1.1 and figure 5.1.1), along with previously dated radiocarbon samples from the adjacent peat and material from the crannog and the promontory. These results indicate that the top part of the core contains material older than the sediments further down. As it is unlikely that this reflects the actual deposition, it is more probable that one or more of the radiocarbon samples is not indicative of the age of the sediment. This can be due to reworking of old carbon, as well as the opposite, where younger carbon is being transported downward into the sediment (e.g. Bronk Ramsey, 2009b). Both processes could lead to the apparent age reversal. In populated areas in the western world erosion rates are known to have increased dramatically in the last 2000 years, due to deforestation and land management practices (Rose et al., 2011). Thus the age reversal is more likely caused by reworking of old carbon washed into the lake by catchment erosion. A similar pattern emerged when the peat cores were analysed however, these failed to recover sediments younger than c. 2700 cal. yrs BC (table 5.1.1). As care was taken to recover the core, it is probable that (most of) the top was recovered. Therefore it is assumed that if the lowermost radiocarbon date is correct and that the top of the core consists of recent sediments, an age-depth model can be constructed (figure 5.1.1). A possible future analysis might be either lead dating or SCP analysis to confirm the age of the core top.

Table 5.1.1 The radiocarbon and calibrated dates from Cults Loch. Several peat core dates were dated, as it was initially assumed that they might be ideal for palaeoenvironmental reconstructions (Crone and Cavers, 2009). However, the peat proved to be too old.

Sample code and info	Material	$\delta^{13}C$ (‰)	^{14}C yrs BP	Calibrated Age (yrs BC/AD)
GU-25026 TCL1 29-30 cm	Botanical remains	-28.1	6545±30	5558-5472 BC (95%)
GU-25027 TCL1 150-151 cm	Botanical remains	-30.4	4225±35	2909-2679 BC (95%)
GU-25798 TCL1 301-302 cm	Leaf matter, wood fragments, hazelnut shell	-25	4680±30	3624-3369 BC (95 %)
GU-12138 Cults Loch crannog	Oak pile	unknown	1790 ± 50	92-380 AD (95%)
GU-10919 Cults Loch promontory	Oak pile	Unknown	2340 ± 50	735-213 BC (95%)
GU-21808 Peat core 1A 49-50 cm	unknown	unknown	4145 ± 35	2880 BC-2610 BC (95%)
GU-21815 Peat core 3B 449-450 cm	unknown	unknown	8525±40	7597 BC-7525 BC (95%)

As seen in figure 5.1.1 (left), the Bacon age-depth model rejects the second radiocarbon date (150-151 cm, 2909-2680 BC). The model indicates that somewhere between the top of the core and c. 150 cm there was an increase in the accumulation rate, which will be investigated further in the multi-proxy analysis. Using the weighted mean age of the sediments and the median age of the crannog radiocarbon dates, the Bacon age-depth model estimates that the promontory and crannog are most likely at **121** and **90** cm, respectively. These depths are indicated in the graph by red solid lines, this colour will be used to highlight these depths in the palaeoenvironmental analysis. However, when look at which sediments have a 95% chance to

The Clam age-depth model (figure 5.1.1, middle) was set up in a similar fashion, rejecting the second radiocarbon date. It produced a slightly different age-depth model, with the most likely depth of the promontory and the crannog at **100** and **137** cm depth, respectively. These depths are indicated in the graph by green solid lines, with green as the colour indicating the Clam estimated depths in the palaeoenvironmental graphs.

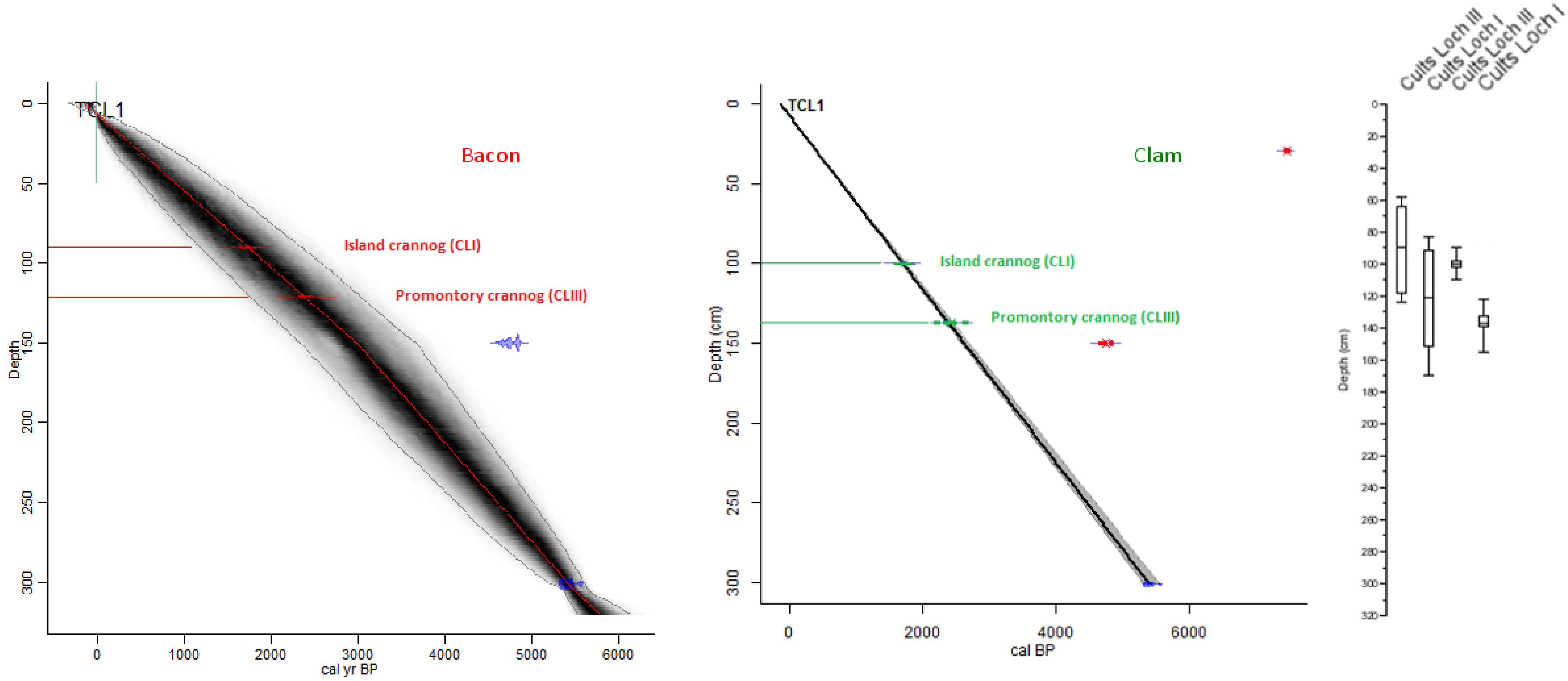


Figure 5.1.1 Radiocarbon age-depth of samples from TCL1 using the Bacon age-depth model (right), where the red lines indicate the most probable depths of the promontory and island crannog. The middle graph represent the Clam age-depth model, with the green lines the Clam based crannog depth estimates. On the right boxplots represent the uncertainty of the age models and the crannog radiocarbon dates. The tails (or whiskers) indicate the full range of sediments which might be dated to the crannog (α=0.0025), while the boxes indicate sediments that might be dated to the median age of the crannogs (α=0.05). The horizontal lines near the middle of each of the boxes represent the samples with a mean age closest to the median age of the radiocarbon date of the crannog

To highlight the full uncertainty of the age-depth model and the crannog age estimates, a boxplot has been created (figure 5.1.1, right). The maximum 95% certainty extent is visible as the tails of the box, while the box itself is the 95% range of sediments with the same age as the median age of the crannog radiocarbon date.

5.1.2 Geochemistry

The upper 3 metres of sediments from core TCL1 were analysed for their components by means of LOI, magnetic susceptibility and scanning XRF. The dashed lines in figure 5.1.2 indicate the most likely depths of the crannogs in the Bacon and Clam age-depth model (see also figure 5.1.1). The LOI analysis indicates that the majority of the sediments were rich in organic matter with most of the core containing over 75% organic matter (figure 5.1.2). The upper c. 30 cm has a distinctly lower organic matter content (c.40%), indicating increases in minerogenic matter (Dean, 1974, Heiri et al., 2001). This is probably related to increased erosion rates, derived from increases in allogenic material entering the lake (Engstrom and Wright Jr., 1984). This could be explored further by looking at the other geochemical analyses. Around the time of the archaeological sites, there are minor fluctuations in the record. However, as these fluctuations are not easily distinguished from the background variations, it is unlikely that the construction of the promontory or crannog significantly influenced the LOI.

The magnetic susceptibility analysis shows a similar pattern (figure 5.1.2), with low values of mass specific magnetic susceptibility throughout the core, indicating diamagnetic material and high amounts of organic matter (Dearing, 1999). However, the upper c. 30 cm shows a steady increase in the MS, with a sharp peak at c. 10 cm, indicating a reduction in diamagnetic material and increases in ferromagnetic or canted antiferromagnetic material, which is related to increased erosion rates from the catchment (Dearing, 1999). This supports the evidence from the LOI analysis. However, it also indicates that the MS reached maximum values slightly later. A possible explanation might be that although the sediment composition did not change until the depth indicated by the peak in the MS, decomposition within the sediment has altered the LOI to a greater depth. This assumes that the MS peak is not driven by increases in diamagnetic matter but rather increases in ferromagnetic or antiferromagnetic material.

From the XRF analysis it became apparent that some depths were very likely to produce erroneous results (>2.5 MSE and/or <20k kcps) and these were excluded from the analysis (depths 130-135 cm, 224-229 cm, 225-226 cm and 301-302 cm) which led to some small gaps in the record. Overall the XRF analysis indicates that although the core is uniform in sediment composition (black highly organic gyttja throughout), there are distinct fluctuations (figure 5.1.2). Below 230 cm the Fe/Mn and Fe/Ti values are relatively high, indicating reduced circulation and some hypoxia in the lake. The high Fe/Mn can be interpreted as hypolimnetic anoxia, driven by relatively increased mobilisation of soil manganese in the authigenic fraction and is supported by a high Fe/Ti ratio (Boyle, 2001). However, care has to be taken as iron can accumulate in sediments from various sources, for instance, the inwash of humic substances is a possible source of increased iron in the sediments (Engstrom and Wright Jr., 1984), which the radiocarbon dates indicated might be a complication in the core (see section 5.1.1). During the next phase, from 225 cm, the Fe/Mn drops, mainly driven by increases in the Mn/Ti and Cu/Ti, indicative of more oxidized sediments and the occurrence of diagenetic reactions (Rothwell et al., 2006). One of the phases with an increased Mn/Ti ratio appears to coincide with the age estimates of the crannog promontory, around 130cm depth, potentially indicating a disturbance of the lake ecosystem and changes in the deposition regime.

In the core there are several phases with elevated Fe/Rb, K/Rb and Ti/Rb, occurring at the bottom of the core (c. 320 cm and 290 cm), but also in the middle and upper parts of the core (c. 150 cm, 90 cm, 70 cm and 50 cm). This is mainly related to reductions in clay content (as indicated by the Rb), relative to more resistant minerals (as indicated by K, Ti and Fe), which is indicative of changes in sediment-source/provenance (Rothwell et al., 2006, Croudace et al., 2006).

At the upper part of the core there are distinct increases in minerogenic indicators (Zr/kcps, Rb/kcps, and Ti/kcps) at around 105 cm depth. A highly likely explanation is be that erosion rates in the lake increased with the construction of the island crannog, as both age models indicates it was probably constructed around this time. Deforestation and catchment disturbances might have increased around this time also.

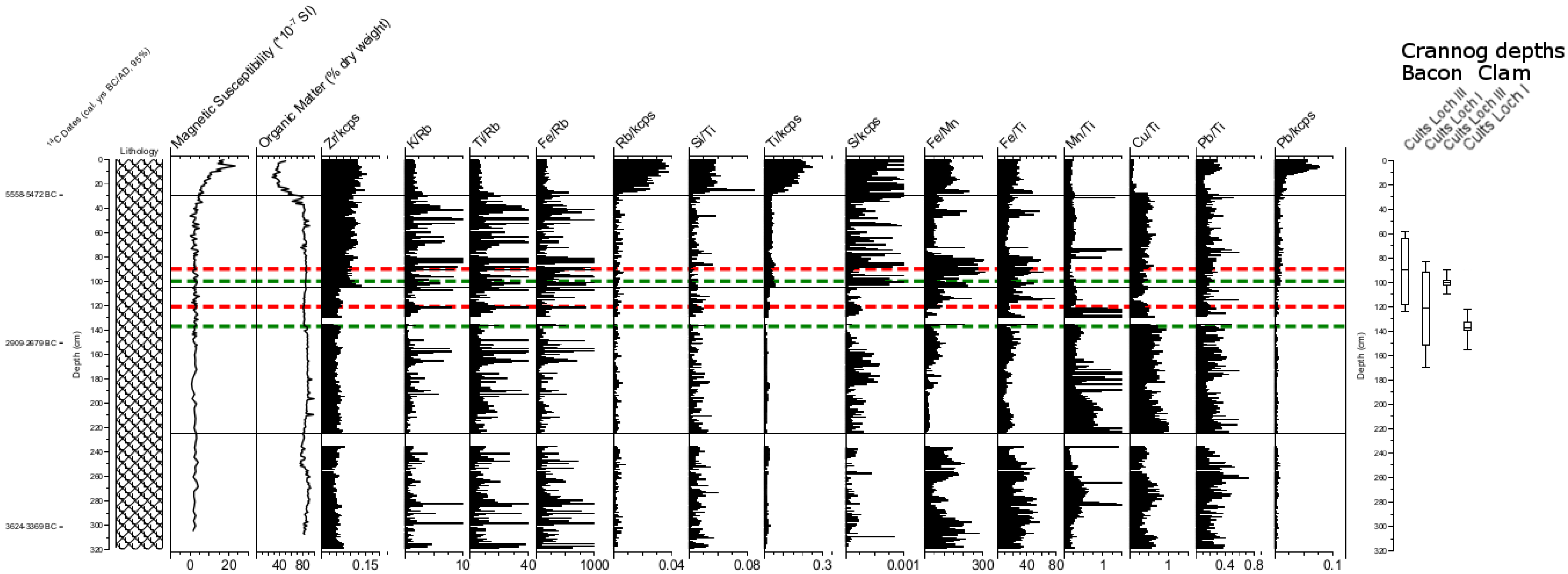


Figure 5.1.2 Magnetic susceptibility, loss-on-ignition and selected XRF analyses from core TCL1. The dashed lines indicate the depths of the promontory (bottom) and island (top) crannogs (red: Bacon, green Clam), while the black lines indicate shifts in the geochemistry

At around 45 cm depth there is a short-term increase in the Si/Ti ratio, which is indicative of increased biogenic silica production (Boyle, 2001) A phase of increased lake productivity and reduced mixing might be indicate here, as the Fe/Mn ratio is markedly higher during this interval. Further evidence from other proxies is required, as both the Si/Ti and the Fe/Mn record fluctuate distinctly throughout the core and the age-depth models are inaccurate due to dating issues (see section 5.1.1).

The upper part of the core (above 30 cm) has a distinctly higher Fe/Mn ratio, indicating reduced oxygen availability in the hypolimnion. This is likely related to the increase in the erosional indicators, with additional nutrient loading to the lake creating a higher level of oxygen consumption. This is explored further in the diatom analysis (section 5.1.3).

Finally there is a maximum in both the Pb/kcps (and Pb/Ti) around 5 cm depth at the top of the core, tentatively dating these samples to the mid-20th Century, when atmospheric lead emissions of industry and cars were at their highest in Northern Europe (Farmer et al., 1997, Brännvall et al., 2001). This supports the assumption that the top of the core was preserved and the peak in the lead concentration (6.5 cm depth) would coincide with the maximum in lead deposition around AD 1970.

5.1.3 Diatoms assemblages

In core TCL1 diatoms were counted to determine changes in the aquatic palaeoenvironment of Cults Loch (figure 5.1.3). Most of the core is characterised by low species diversity, there is a distinct lack of diatoms between 234-140 cm. The assemblages consist mainly of fragilarioid taxa *Staurosira* cf*. elliptica*, *Staurosira construens* (*f. construens* and *f. venter*) and *Staurosirella pinnata*. Lakes with a high araphid to centric diatom ratio are considered indicative of moderate total phosphorous and low alkalinity (Hall and Smol, 1999, Brugam and Patterson, 1983). Phosphorous and diatom correlations are to be used with caution and care has to be taken when using diatoms as trophic indicators in sites of low alkalinity with abundant araphid diatoms (Fritz et al., 1993, Hall et al., 1997). There are regular occurrences of tripolar fragilarioids, which are considered the morphotypes *Staurosira construens* var. *exigua* and *Staurosirella pinnata* var. *trigona*. A search through the literature revealed very little about the ecology of these morphotypes, so interpretation is limited.

At the bottom and very top of the core, there are high numbers of *Aulacoseira* sp. These diatoms produce heavily silicified frustules with high sinking rates and need circulation in their life-cycle, indicating that the lake was not continuously stratified during the period of occurrence of this genus. Another species which appears dominant throughout the core is the small benthic *Mayamaea atomus*, which was split from the genus *Navicula* (Lange-Bertalot, 1997). This taxon has a high nutrient and organic matter optimum, indicative of higher saprobity. In the bottom part of the core *Aulacoseira* taxa occur more frequently (e.g. *Aulacoseira subarctica* up to c. 35%, 297-254 cm depth). Based on a CONISS cluster analysis, 4 distinct zones have been identified.

<u>Zone TCL1D1 (300-252 cm)</u>

The bottom of this zone was radiocarbon dated to the Neolithic (300 cm depth, 4680 ± 30 ^{14}C yrs BP or 3624-3369 cal. yrs BC). This zone is characterised by a high amount (up to 40%) of tychoplanktonic diatoms, mainly *Staurosira* cf*. elliptica* and *Staurosirella pinnata,* together with *Aulacoseira subarctica*. Towards the middle of the zone *Aulacoseira subarctica*, a mesotrophic taxon able to thrive under high nutrient and low-light conditions (Gibson et al., 2003), increases further. The remainder of the diatom valves in this zone consist of relatively high counts of *Mayamaea atomus*, *Staurosira* cf*. elliptica* and *Staurosirella pinnata*. There is a reduction in periphytic taxa while *Aulacoseira* sp. remains relatively stable at c. 20%, coinciding with a short term fluctuation in tychoplanktonic diatoms.

<u>Zone TCL1D2 (252-234 cm)</u>

The second zone shows a rapid increase in the fragilaroid taxa *Staurosira construens var. venter*, *Staurosiroid tripola* and *Staurosirella pinnata,* followed by an increase in *Staurosira* cf. *elliptica.* At the same time there is a decrease in *Aulacoseira* sp. and periphytic taxa. This could be interpreted as a shallowing of the loch, driven by reductions in tychoplanktonic *Aulacoseira* taxa. The expansion of fragilaroid taxa is difficult to interpret, as increases in araphid diatoms are often misinterpreted as indicative of eutrophication and in low alkalinity lakes in particular might be related to pH shifts. This zone precedes the hiatus in the diatom assemblages and the high occurrence of *Staurosira construens* f. *venter* might be interpreted as a shift towards higher alkalinity conditions, as this taxon is often found in medium to high alkalinity shallow lakes. The occurrence of about 20% tripolar morphotypes fragilarioids is curious. This type of fragilarioid is not often found and appear to be variants of the common *Staurosira construens* and *Staurosirella pinnata*. There is little information available regarding these types and it is not certain if they are morphotypes or actually have unique ecological preferences. Studies on *Phaeodactylum tricornutum*, which is a polymorphic raphid pennate diatom (Wilson, 1946), have indicated that a clone can change between morphotypes during its life cycle, indicating that these are indeed morphotypes and not mutations (De Martino et al., 2007). When the culture is grown in low nutrient conditions, the triradiate form will reduce in abundance over time, even if the starting culture is 100% triradiate (De Martino et al., 2007). Whether this means that the triradiate form is better adapted to higher nutrient conditions is unknown, but a change in the valve outline from elongate to triradiate would increase the volume to surface ratio, increasing their sinking rate. It might strengthen chains, as it would have a large area with spines to which the next frustule could attach.

234-140 cm

Between 224.5 and 136.5 cm depth intact diatom counts proved too low to be reliable (n<50) and a high amount of dissolution was apparent, as the samples consisted of mainly fragmented diatom valves, in particular the central areas of naviculoid taxa. An attempt to increase the concentration of the diatom valves did not yield significantly higher counts, indicating that diatom production rates must have dropped dramatically at this time. Possible explanations for this could be:

1) The diatoms were outcompeted by other algae, limiting their production rates as nutrients and sunlight are taken up by other algae, such as cyanobacteria (Sterner, 1989, Joehnk et al., 2008).
2) A massive increase in sediment accumulation (e.g. slumping) making natural valve accumulation too dilute to be visible in the slides.
3) A high amount of dissolution prior to deposition of the valves (e.g. a high demand vs. supply ratio of silica).

Option 1 requires further analysis which could be achieved via pigment analysis. The geochemistry shows a low Fe/Mn ratio at these depths, indicative of increased oxygenation (Boyle, 2001). Option 2 might be resolved by improving the resolution of the chronology, as that could identify changes in the accumulation rate. The XRF analysis does not indicate consistent increases in erosional indicators (e.g. K/Rb, Zr/kcps, and Ti/kcps), so it is unlikely that the accumulation rates have changed dramatically throughout these samples. Option 3 is difficult to determine, although as this interval contains a high amount of partially dissolved large naviculoid valves centres, it could indicate that more delicately ornamented valves (e.g. most centrales and/or fine fragilarioids) may have fully dissolved. There is some evidence of an increase in the pH, as *Staurosira construens var. venter* has a higher pH optimum than *Staurosira elliptica* and *Staurosirella pinnata*. Diatom dissolution is known to occur more intensely during very alkaline conditions (Ryves, 1994, Ryves et al., 2001).

Zone TCL1D3 (140-44 cm)

This zone is dominated by small fragilaroid taxa *Staurosira* cf. *elliptica*. *Mayamaea atomus* is abundant at the base of the zone, but appears to steadily decrease towards the top of this zone, while *Staurosira construens var. venter* and *Staurosirella pinnata* are slowly increasing. The bottom of this zone probably dates to around the same time as the promontory, which probably impacted the lake ecology. The high abundance of Mayamaea atomus might reflect a organic matter content in the lake, derived from both the construction and the occupation of the crannog. Between 118.5 and 88.5 cm depth there are small increases in *Aulacoseira subarctica*, possibly indicating a small increase nutrient level and reduced oxygen availability. There is an increase in periphytic diatoms around 100 cm depth, coinciding with the age models estimated promontory depth (100 cm (Bacon) and 90 cm (Clam)). A similar pattern occurs from 84 cm depth. As there are many small changes taking place during this interval, it is difficult to relate any single one to these archaeological events, but they are highly likely driven by human disturbances, such as additional organic matter and nutrient loading to the lake. Between 75 and 55 cm depth there is a reduction in *Mayamaea atomus*, coinciding with increases in *Staurosira* cf. *elliptica* and subsequently *Staurosirella pinnata*, indicating increased turbidity and a slight increase in nutrients, which can possibly be linked to the within-lake disturbances. It could indicate the abandonment of the crannog, while most of the catchment continued to be used for pastures, leading to increased erosion and higher nutrient input.

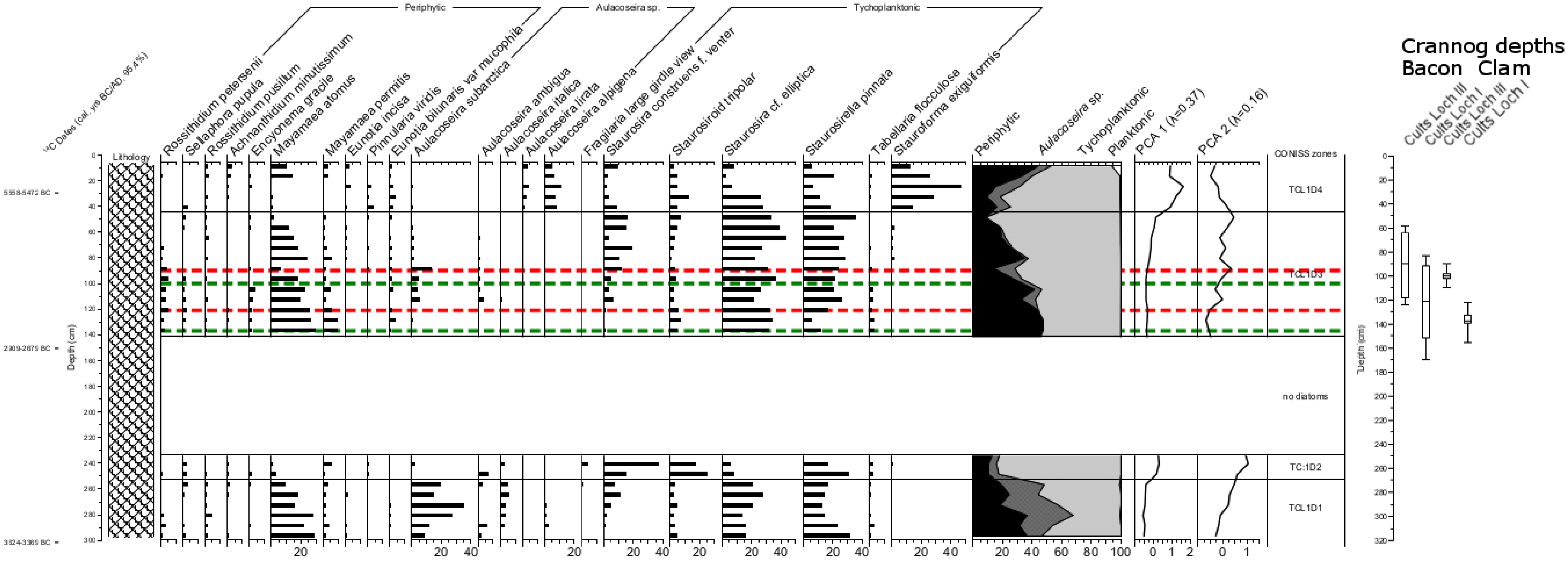


Figure 5.1.3 Diatom taxa occurring at least 3% in a sample, PCA axes and CONISS zonation of TCL1. The red lines indicate the Bacon depth estimates for the crannog, while in green are the Clam age estimates. The boxplots on the right indicate the uncertainty of the crannog estimates

Zone TCL1D4 (44-0 cm)

The top zone is characterised by increases in *Aulacoseira alpigena*, *Aulacoseira lirata* and *Stauroforma exiguiformis*. These species are more oligotrophic and acidophilous than *Mayamaea atomus*, *Staurosira* cf. *elliptica* and *Staurosirella pinnata* and could possibly be related to a reduction in nutrient levels and pH. As recent diatom assemblages in Scotland have indicated increased acidification following acid rain deposition (Battarbee et al., 1984, Jones et al., 1989, Flower et al., 1987), it appears likely from the combination of increased Pb accumulation in the upper sediment (indicating recent sediments, see section 5.1.2) and increases in acidophilous diatoms, that the uppermost sediments represent material deposited during the late 19th to 20th centuries.

5.1.3.1 Diatom PCA analysis

To determine general changes and trends in the diatom assemblages, a PCA analysis was performed (figure 5.1.4). As the DCA analysis indicated that the first axis had a short gradient length (1.9), a PCA analysis was warranted (Ammann, 2000, Ter Braak and Prentice, 2004). The first axis (λ= 0.37) describes the major changes in the assemblages, with the diatom zones (TCL1D1-TCL1D4, black, purple, green and yellow markers respectively) shifting from the left towards the right of the graph with decreasing depth. This shift is mainly related to a shift from *Aulacoseira subarctica* and *Mayamaea* sp. to large benthic taxa (e.g. *Pinnularia* sp. and *Stauroneis* sp.), as well as *Aulacoseira alpigena* and *Stauroforma exiguiformis*. This shift might be interpreted as acidification. For example *Pinnularia* sp., *Stauroneis* sp., *Stauroforma exiguiformis* and *Aulacoseira alpigena* are commonly found in bogs and are indicative of a low pH (Van Dam et al., 1994). The exception of this PCA axis 1 shift is zone TCL1D2 (purple X, 248.5 and 240.5 cm depth), which has a strong shift towards the top of the second PCA axis, aligned with *Staurosira construens f. venter*. Zone TCL1D3 actually drops to the bottom of PCA axis 2, before returning to a position similar to TCL1D2 in the graph. The final zone (TCL1D4) is situated towards the right of the graph, with high values on the first PCA axis. The second PCA axis (λ=0.16) is more difficult to explain, as it appears to mainly separate *Mayamaea atomus* and *Staurosira construens* f. *venter*.

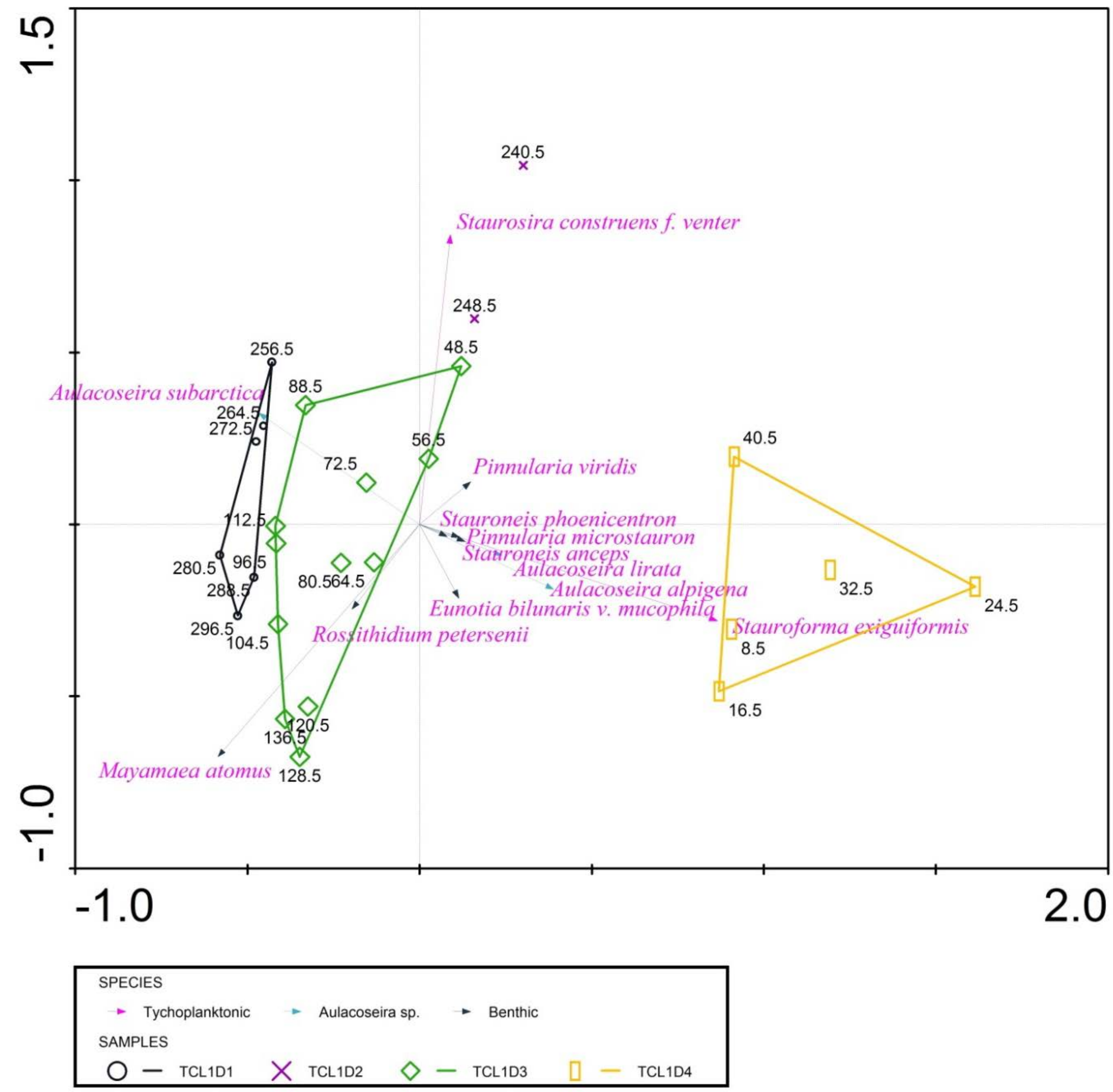


Figure 5.1.4 Diatom PCA analysis of core TCL1, indicating the samples and taxa in the assemblages

These taxa probably represent secondary shifts in the diatom assemblages, with Staurosira construens f. venter representing increases in tychoplanktonic taxa and Mayamaea atomus representing periphytic taxa. This is supported by a higher amount of periphytic taxa in the lower part of the graph. The samples most likely contemporaneous with the crannogs (c. 137-90cm) appear to have lower scores on the second PCA axis within zone TCL1D3, driven by the higher abundance of Mayamaea atomus. The crannogs might be seen as an element that disrupted the long term trend indicated on the first PCA axis, generating a shift in diatom assemblages mainly on the second PCA axis. However, overall the disturbances related to the crannog did not impact the diatom assemblages that much.

5.1.3.2 Cults Loch diatoms as environmental indicators

By categorising diatoms with their environmental preferences (Van Dam et al., 1994), as recorded from modern datasets, it is possible to group diatom assemblages with respect to environmental variables, such as nutrient status, pH and saprobity. As different taxa have different requirements, it is possible to see how the diatom composition changes over time, possibly relating changes in the environment to changes in the diatom assemblages. Araphid taxa, especially small fragilarioid diatoms, are known to have a wide trophic range, which complicated the development of transfer functions in lakes where these taxa dominated (Sayer, 2001). Furthermore, some of these environmental variables are known to have strong secondary gradient effects, which might lead to spurious interpretations of the assemblages (Juggins, 2013). Therefore, it was chosen not to investigate the trophic status of the diatoms further and the diatoms were categorised according to pH preference to investigate the apparent shifts in the diatom assemblages, especially at the top of the core.

Overall the diatom assemblages are dominated by alkaliphilous taxa (*Staurosira* cf*. elliptica, Staurosira construens* and *Staurosirella pinnata,* figure 5.1.5). However, in the bottom and top of the sections analysed (TCL1D1 and TCL1D5) there are somewhat lower abundances of alkaliphilous taxa, coinciding with increases in circumneutral and acidophilous taxa. In the top zone, this is likely caused by increased acid rain deposition, which has been commonly attributed to higher abundances of diatoms with a lower pH preference, as described for instance in Round Loch of Glenhead (Battarbee et al., 1984, Jones et al., 1989, Flower et al., 1987). This shift towards more acidophilous diatoms supports the interpretation that the top of the core is recent, when acid rain accelerated and let to a series of environmental measures to reduce the impact of acid rain (Wetzel, 2001).

There is some evidence that samples most likely contemporaneous with the crannogs are associated with shifts in diatom pH preferences, as the lower part of zone TCL1D4 contains a slightly higher abundance of acidophilous diatoms, between 130 and 85cm depth, possibly indicating abandonment of the crannogs.

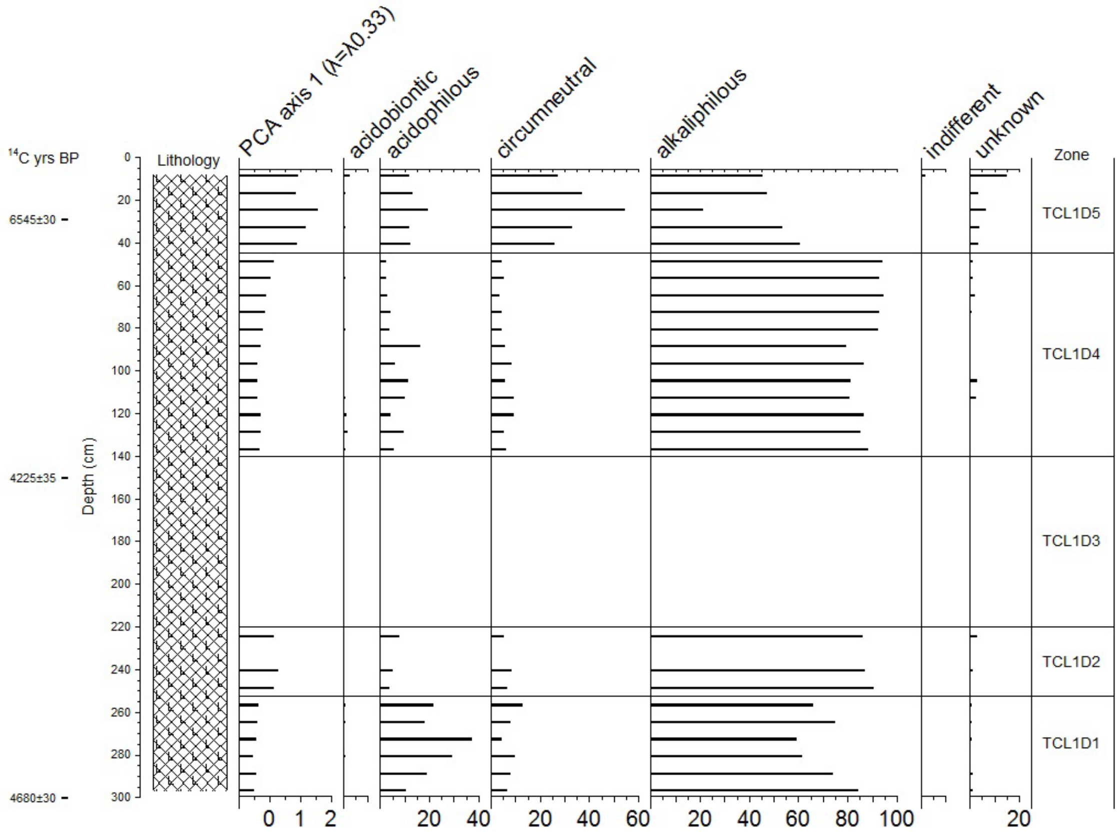


Figure 5.1.5 TCL1 Diatom PCA Axis 1 plotted with diatom pH categories

5.1.3.3 Cults Loch diatoms and geochemistry RDA

To better understand the relationship between the geochemistry and the diatom assemblages in Cults Loch, correlations and a multiple regression were run (see methods section 2.6 and appendix B.1). This identified Zr/kcps, Si/Ti and Fe/Rb as the main significant variables influencing the diatom PCA (see table 5.1.2). Using all the significantly correlated variables (appendix B.1), an RDA was undertaken (figure 5.1.6, 40% species fit). An RDA was selected as the first axis had a short gradient axis (<2SD), warranting the use of a linear gradient analysis (see section 5.1.3.2). In this approach, the geochemical variables are used predictively to explain diatom variability. The first RDA axis describes a shift from the lowest samples at the upper left to the youngest samples at the upper right. The second RDA axis mainly describes the samples dominated by *Staurosira* cf. *elliptica* at the upper end of the graph and the *Aulacoseira*, *Stauroneis sp.* and *Stauroforma exiguiformis* taxa at the lower end of the graph. As the minerogenic indicators (Si/Ti, and Zr/kcps) follow a similar split, it might indicate a difference in dominant sediment source between samples at the upper and the lower end of the graph. Finally in the upper left of the graph there are also more indicators of changes in increased oxidation of the lake and therefore changes in the lake circulation, with the Fe/Rb more closely related to the samples in that quadrant. The significant variables (table 5.1.2) indicate a strong relationship between the occurrence of minerogenic matter (Si/kcps and Ti/kcps, figure 5.1.6) and the occurrence of specific diatom taxa (e.g. *Aulacoseira alpigena*, *Stauroforma exiguiformis*). However, it is more likely that as both acidification and erosion rates increased in the upper samples, they respond synchronously rather than have a similar cause and effect.

Table 5.1.2 Statisics on geochemical variables used in the RDA and multiple regression in core TCL1

Significantly correlated environmental variable (correlation)	**Multiple regression significance level**	**Multiple regression coefficient**	**RDA significance**
OM (-0.71)			
MS (0.58)			
Fe/Rb (-0.4)	0.044	-3.714	0.147 (3^{rd})
Si/Ti (0.62)	0.021	0.079	0.001 (2^{nd})
Si/kcps (0.70)			
Ti/kcps (0.55)			
Pb/kcps (0.62)			
Zr/kcps (0.59)	<0.001	0.314	0.001 (1^{st})

When comparing the RDA to the diatom PCA, a similar shift is observed along the first axis as the sample depth becomes shallower. However, the second RDA axis is different, as is visible by the lower central position of samples 248.5 and 240.5 cm in the RDA, while it is at the top of the graph in the PCA. Furthermore, zone TCL1D3 is stretched along the first RDA axis, while it is more compressed towards the left of the graph in the PCA analysis. *Staurosira* cf*. elliptica* has a strong negative loading on the second RDA axis, while it is absent from the PCA analysis (40% species fit). On the other hand, *Staurosira construens var. venter* has a strong positive loading on the second PCA axis, while it is absent from the RDA analysis (40% species fit). Both *Staurosira* cf*. elliptica* and *Staurosira construens var. venter* are relatively small fragilarioid taxa, although *Staurosira* cf. *elliptica* is noticeably smaller, but with an elliptic rather than rhombic outline, with both taxa probably indicative of similar changes in the lake circulation.

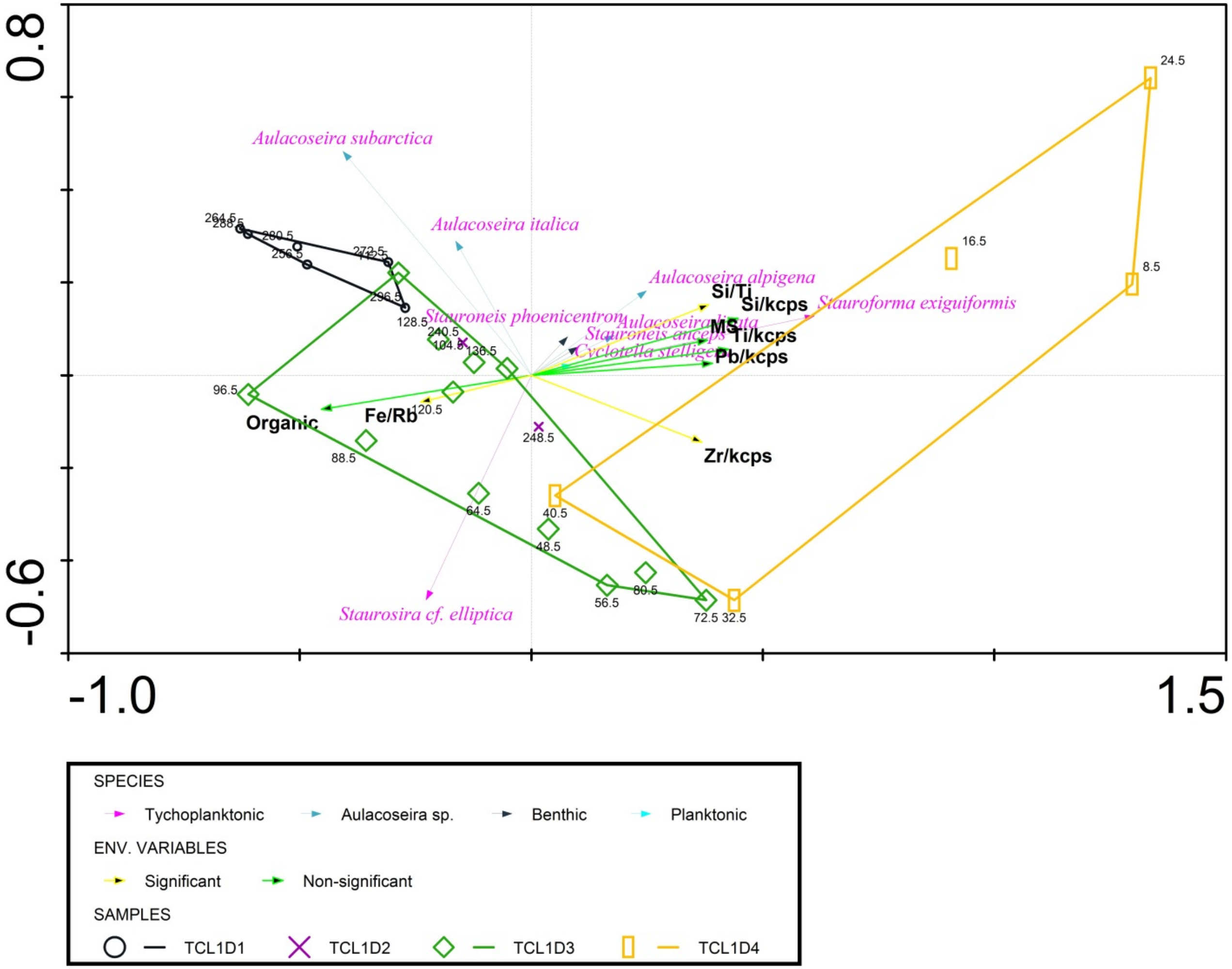


Figure 5.1.6 RDA analysis of geochemical and diatom analyses from core TCL1

Finally, one of the planktonic taxa in the assemblages, *Cyclotella stelligera*, has a weak positive loading on both RDA axes aligned with Si/kcps and Ti/kcps, as well as other diatom taxa (i.e. *Aulacoseira alpigena* and *Aulacoseira lirata*). Although having an abundance of only c. 2.5%, *Cyclotella stelligera* might be indicative of another change in the ecosystem. This taxon is facultatively littoral or planktonic and oligotrophic (Tibby, 2004, Leahy et al., 2005) and so might prefer a low phosphorous to silica ratio. It only occurs in low abundances (<3%) so may not be entirely representative of changes in the dataset. However, it represents the beginning of a shift from araphid diatoms towards planktonic taxa, similar to what has happened around the border between boreal forest and tundra in Canada. There, recent environmental changes led to the replacement of small *fragilarioid* taxa by mainly *Cyclotella stelligera*, which the authors relate to changes in ice cover, a longer growing season and/or stronger thermal stratification patterns (Rühland et al., 2003).

5.1.4 Pollen

Pollen assemblages and spores were analysed from samples in core TCL1 to understand changes in the catchment vegetation (figure 5.1.7). Overall the core is high in arboreal pollen (i.e. oak, hazel, alder and heath) indicating that the site was located close to woodlands for most of the period analysed. The samples through the core have c. 10% herbs and grasses, therefore it is likely that the woodland was relatively open (Sugita et al., 1999) and the small amount of anthropogenic indicators indicate that meadows and pastures were probably nearby. To analyse changes in the catchment vegetation, the samples were clustered following a CONISS analysis and a PCA analysis was performed to determine general trends in the assemblages. The CONISS analysis indicated 4 zones which will be used to describe changes in the vegetation.

<u>Zone TCL1P1 (305-240 cm)</u>

The bottommost zone is relatively forested, but as it contains up to 10% grasses, herbs and anthropogenic indicators, it indicates it was fairly open. This takes into account the fact that arboreal pollen tend to overestimate the arboreal catchment vegetation. As the Dumfries and Galloway region has a large concentration of late prehistoric sites it is likely that human impact initiated early in this area. Examples of some of the rich prehistoric heritage (RCAHMS, 2015) of the area are: Cairn Holy chambered cairns (Neolithic), Dunragit Temple Complex (Neolithic), Drumtroddan cup and ring marked rocks and standing stones (Bronze Age), as well as the Early Christian priory of Whithorn

Zone TCL1P2 (230-150 cm)

From around 236 cm depth the amount of herbs and grasses decreases and both hazel and oak appear to increase. As the *Lycopodium* amount increases around the same time, it indicates that overall pollen accumulation decreased during this period. This indicates that the sediment accumulation rate was very high at that time and/or not much vegetation was producing pollen in the catchment. Both of these can lead to overrepresentation of a few oak and hazel trees, as they tend to produce large amounts of pollen.

Zone TCL1P3 (150-70 cm)

The lower part of this zone (from c. 146 cm) indicates that grasses and anthropogenic indicators return to levels similar to those observed at the bottom of the core, with reductions mainly in hazel, while oak remains fairly stable and heath pollen returns to previous levels as well. Around the inferred depth of the promontory crannog (130-90 cm depth) there are minor increases in the abundance of anthropogenic indicator pollen, while oak appears to slightly increase towards the top of the zone. At the very top of the zone (from around 76 cm) anthropogenic indicator pollen increase further in abundance, with increases in the abundance of heath and grass pollen, indicating substantial deforestation in the catchment. This increase in abundance is above the estimated depths of the Cults Loch crannogs, so it is more likely associated with land-use change around the lake rather than crannogs themselves.

Zone TCL1P4 (70-20 cm)

The trend of increased landscape openness continues and in the final upper two samples, herbs, grasses and anthropogenic indicators rise to 30% in the pollen assemblages. Cereal type pollen starts to appear in this zone, indicating that cultivation, processing or storage of cereals must have taken place nearby. This might indicate that intensified cultivation took place, possibly related to later Medieval activities on the nearby Castle Kennedy.

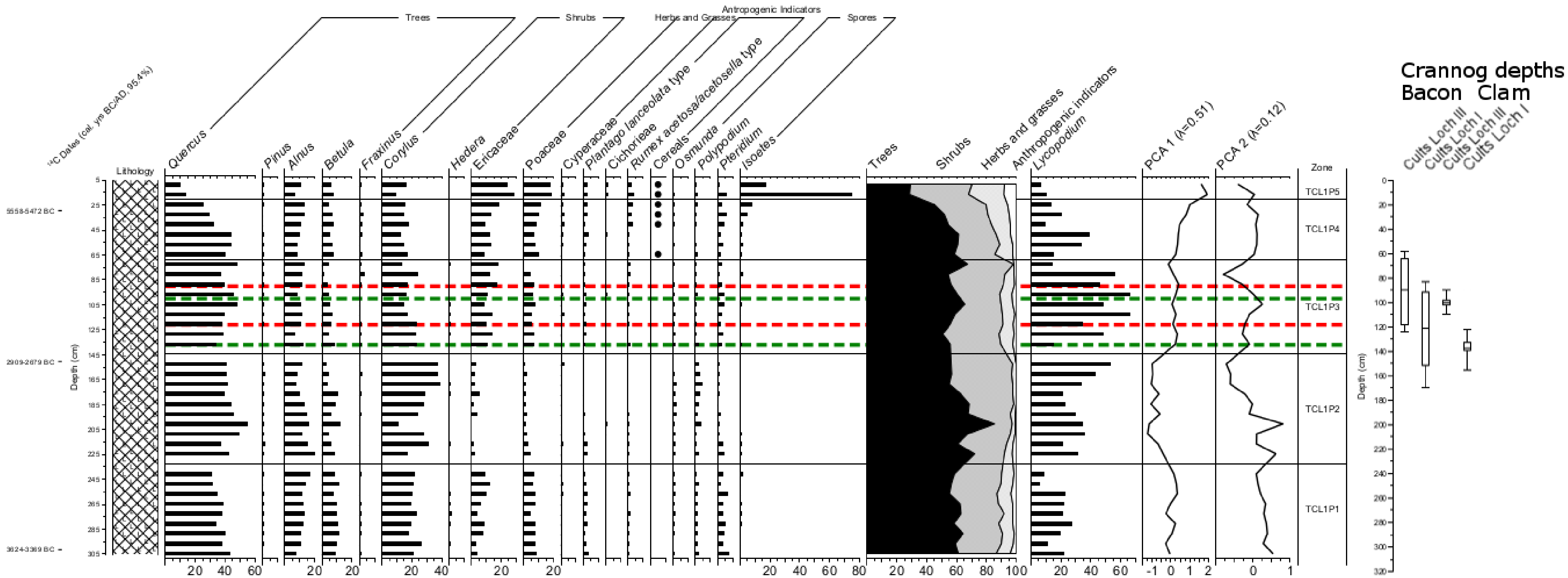


Figure 5.1.7 A diagram of TCL1 with the pollen and spore taxa occurring at least 3% with the presence of cereal pollen, the first two PCA axes and the CONISS zonation. The dashed lines indicate the most likely depths of sediments contemporaneous with the crannogs (red: Bacon model, green: Clam model). The boxplots on the right indicate a larger part of the uncertainty

Zone TCL1P5 (20-0 cm)

There is no evident pine increase at the top of the core and therefore the pollen assemblages cannot be used to determine if the very top of the core is preserved. Pine plantations have expanded dramatically in Dumfries and Galloway since the 1920s (Gilbert and Wright, 1999) and pine has the potential to produce large amounts of pollen which disperses over vast distances. In palaeoecological analyses from nearby sites pine is known to remain relatively low (Jones et al., 1989). Heath and grass pollen increase in this zone, together with increases in *Isoetes* (quillwort). These increases are probably related to a reduction in woodlands and the expansion of meadows. Currently there is a large area of heathland in the nearby Galloway Hills. The increases in *Isoetes* might be related to drainage activity in the catchment, as *Isoetes* requires clear and shallow water (Preston et al., 2002, Stace, 2010).

5.1.4.1 Cults Loch Pollen PCA

To determine general trends in the pollen assemblages a PCA analysis was performed, indicating that most of the variance can be explained in the first axis (λ=0.51). Changes in the pollen assemblages of Cults Loch are displayed in the figure below (figure 5.1.8). The first axis is mainly related to a change from a more forested landscape to vegetation types typical of open land, as oak and hazel are on the left of the graph, while anthropogenic indicators (i.e. *Plantago lanceolata* and *Rumex acetosa*/*acetosella*), as well as heath and grasses, are on the right of the graph. The lowermost samples are in the middle of the graph, indicating that these samples are probably composed of both forested and open vegetation.

The second PCA axis is more difficult to interpret, as it contains a combination of forest and meadow indicators on either side of the graph. However, at the bottom of the graph mainly shrubs are present influencing the second PCA axis, (i.e. hazel and heather), indicating that this axis is possibly related to unstable periods when the vegetation was recovering from disturbances, with a combination of pioneer and gap closing vegetation. Furthermore, although heather is often attributed to dryer intervals, the PCA analysis indicates it is closely related to increases in sedges, which are indicative of wetter intervals. Therefore the increases in heather are unlikely to be driven by climatic changes. Rather, it is more likely that the correlation of heather to the first and second PCA axes can be attributed to human impact, as pastoralism and associated grazing might have reduced the regeneration of woodlands.

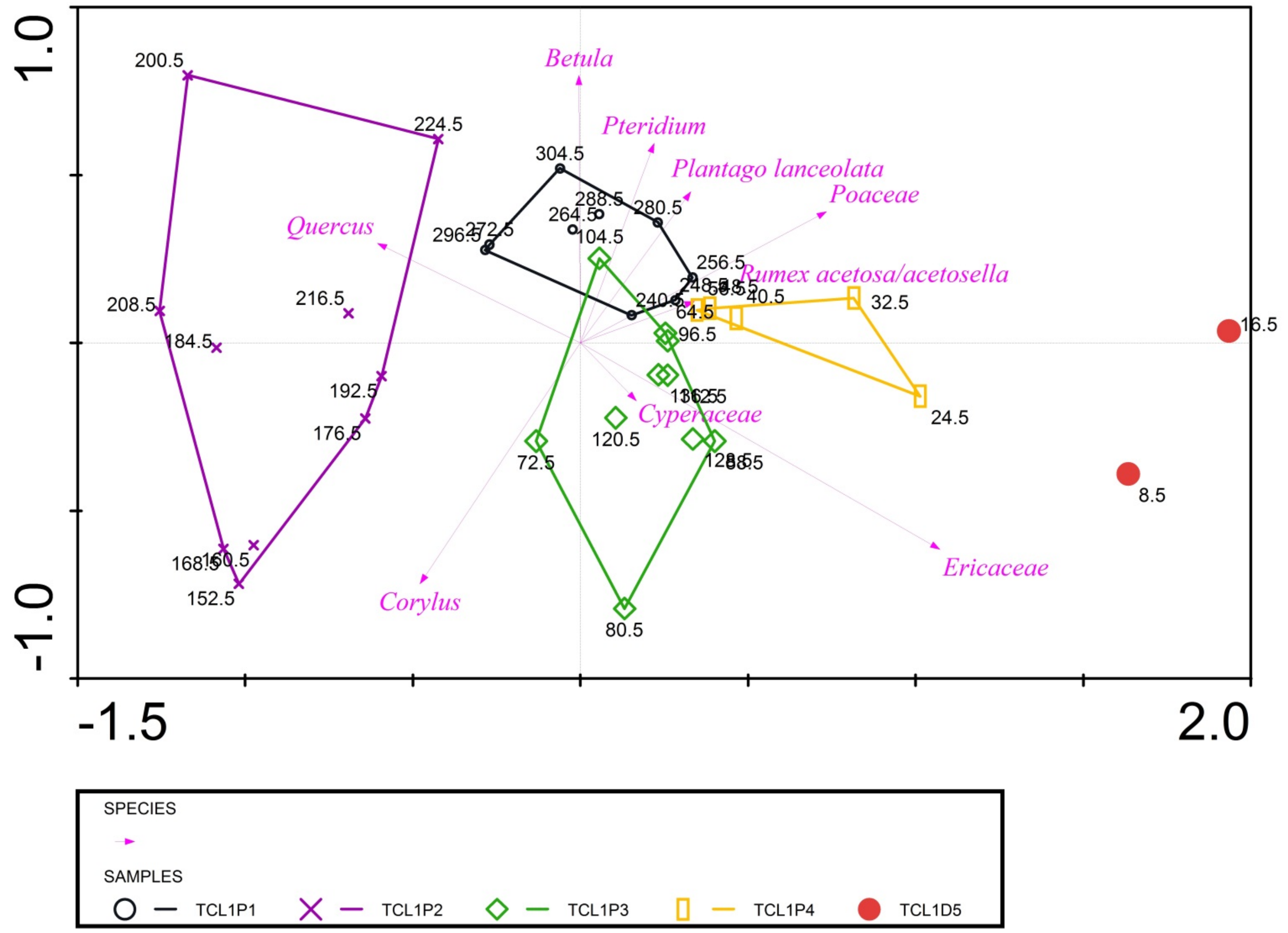


Figure 5.1.8 PCA analysis of Cults Loch pollen and spores

5.1.5 Cults Loch conclusions

Cults Loch proved to be a complex site, as traditional chronological tools were unable to unambiguously determine the age of large parts of the sediments. The upper two radiocarbon dates are disputed, with an age-reversal and change in the accumulation rate evident, based on the three radiocarbon samples. The age-reversal was probably influenced by the inwash of organic macrofossils from the adjacent peatlands.

As the sediment geochemistry indicates increases in erosional indicators from 105 cm depth (figure 5.1.9), it is likely that there has been an increased influx of allothogenic sediments, which casts doubt on the radiocarbon date around that level. As there is a marked increase in lead at the top of the core, it is likely that the top radiocarbon date is incorrect and these sediments were probably deposited during the post-Industrial period, when lead deposition increased substantially (Yang et al., 2002). Furthermore, from c. 30 cm depth there are increases in erosional indicators (e.g. Rb/kcps and Ti/kcps) indicating that inwash from the catchment intensified. This coincides with increases in non-arboreal pollen, providing a tentative link between catchment erosion and pastoralism. Finally the diatom assemblages indicate reductions in alkaliphilous diatoms, probably associated with modern acid rain deposition (Battarbee et al., 1984).

The pollen assemblages do not show clear changes, linked to for instance Bronze Age deforestation, an elm decrease or a pine rise, and thus are unable to improve the chronology of the core by identifying key intervals. However, the pollen assemblages indicate a long history of catchment disturbances in the lake, with evidence of changes in the amount of woodland in the catchment. The arboreal pollen show distinct increases and decreases, related to deforestation and woodland regeneration, which are likely due to human influences on the landscape. Towards the top of the core in particular there is a marked increase in non-arboreal pollen (i.e. herbs and grasses), which can be interpreted as increased pastoral activity in the catchment, probably related to higher demands on the landscape as population and cattle numbers increased.

The diatom assemblages corroborate the geochemistry, as they show a shift towards acidophilous taxa, which is probably related to acidification of the lake. Similar acidification has been recorded from a number of studies in close proximity (Battarbee et al., 1984, Jones et al., 1989, Flower et al., 1987). Between 220 cm and 140 cm depth diatom accumulation is very low, probably related to dissolution. This coincides with a shift towards more arboreal pollen but low pollen accumulation rates. The geochemistry does not show clear increases in allogenic elements, therefore it is unlikely to be caused by higher sediment accumulation rates from catchment erosion.

A possible explanation for the low numbers of diatoms, driven most likely by dissolution, between diatom zones TCL1D2 and TCL1D3 could relate to increased circulation in the lake, as the geochemistry indicates that sediments deposited during this phase had a lower Fe/Mn ratio. However, *Aulacoseira* sp. taxa are known to cope with variable oxygen conditions and probably require some periods with higher oxygen availability, which usually happens during spring mixing. If somehow the mixing regime of the lake became disturbed and or decreased, that might have limited diatom production rates. Although most of the lake is quite shallow, there is a deeper basin, which might have been stratified for periods of time. Another explanation might be that dissolved manganese washed into the lake from the adjacent peatland during spring flooding (Björkvald et al., 2008). However, this would have lowered the pH, so it is uncertain how this would have negatively impact the diatom accumulation rates. Interestingly, diatoms are again in higher accumulation around the same time that the promontory was constructed. The pH preferences of the diatoms appear to support that a slightly lower pH might have contributed to this.

There is also evidence that diagenetic reactions have taken place in the sediment, as the Cu/Ti and Mn/Ti are much higher during the dissolution interval (Croudace et al., 2006, Rothwell et al., 2006). As frustules will degrade if left exposed to air for too long (Ryves, 2009, Ryves et al., 2006, Barker et al., 1994a), thus this could have contributed to the dissolution of the diatoms. However, it cannot be the sole driver of diatom dissolution, as other intervals with a high Cu/Ti ratio did contain reasonable amounts of diatoms. Therefore, it is more likely a combination of hypoxia and diagenetic reactions.

The proxies used in this study were able to reconstruct large components of lake and catchment disturbances as recorded in core TCL1. It indicates that the landscape surrounding the lake has been influenced by humans for the entire period of time covered by the analysed core, as evidenced by deforestation. This led to increased erosion rates in the catchment, which dramatically altered the lake-ecology and circulation. Finally, there is evidence of acidification in the lake, as evidenced from a shift towards acidophilous diatoms. Large scale landscape deforestation has probably obfuscated any disturbance signal further, as increased catchment erosion is apparent for large sections of the core. Due to several issues with the age-depth model of the core, the accuracy is uncertain of the estimated depths of the sediments coinciding with the construction and occupation of the crannog. There is some evidence of increases in NAP and periphytic diatoms around the estimated depths of the crannogs. Following these construction depths, there are increases in centric *Aulacoseira* sp., which might be related to eutrophication. As crannog were often occupied for only a few generations (less than 100 years), it might also be that the resolution was too low to robustly pick up crannog related disturbances.

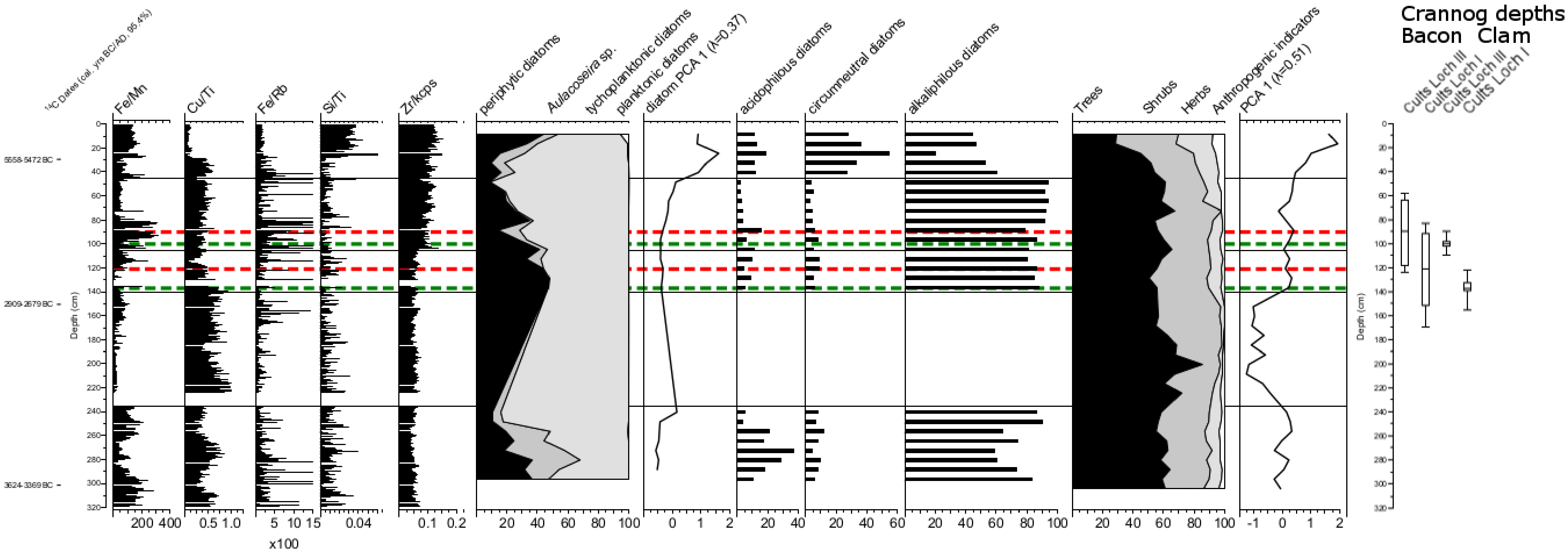


Figure 5.1.9 Summary data of core TCL: geochemistry, diatoms and pollen

5.2 Barhapple Loch palaeoecology

5.2.1 Sedimentology

The sediments of Barhapple Loch are highly variable, which is why they warrant a more in-depth discussion. The core contains smooth clays below 4 m depth, underneath sandy deposits, gyttja and finally *Phragmites* peat (see figure 4.2.4 and appendix A.2). Although these lower sands and clays have not been analysed, they probably reflect early Holocene deposits. A similar sequence has been described in Round Loch of Glenhead, which has been dated to reflect the Late Glacial into the Early Holocene. However, only the upper 3 metres of core BL04 will be analysed in this study (figure 5.2.1). Below 285 cm the core is composed of sandy silt, silty gyttja between 285 and 240 cm, sandy silt between 240 and 210 cm and finally silty *Phragmites* peat between 210 and 8 cm depth. The sediments between 240 and 210 cm are rich in sands and are deposited between more organic sediments. These sediments interrupt a classical hydrosere succession (e.g. Kangas, 1990), from initially sandy lacustrine deposits below 285 cm depth, indicating possibly shallow waters or a lotic environment, with evidence of charophytes. It then evolves into a reedy fen between 285 and 240 cm. However, the sediments then temporarily revert back to sandy deposits between 240 and 210 cm, before changing back again to a shallow reedy fen, possibly even shallower than the previous fen condition, with a high organic matter content and highly preserved plant macrofossils.

In an investigative study related to the construction of the A75 road, palaeochannel deposits were identified in the adjacent Tanieroach Moss (Moore, 2010), which might be a source for the sandy deposits. Barhapple Loch may have been part of a palaeochannel, connecting the Tarf Water via the Barlae Burn to the Dergoals Burn (appendix A, figure A.2.3). Logboats have been described in Barhapple Loch (Wilson, 1882) and the nearby Dernaglar Loch (Wilson, 1885), which may support the interpretation of the palaeochannel that it might have been actively travelled upon in prehistoric times. However, more recent exploration of the sites has been unable to identify these logboats (Henderson et al., 2003, Cavers and Henderson, 2002), and this could highlight the risk of decay of wooden artefacts.

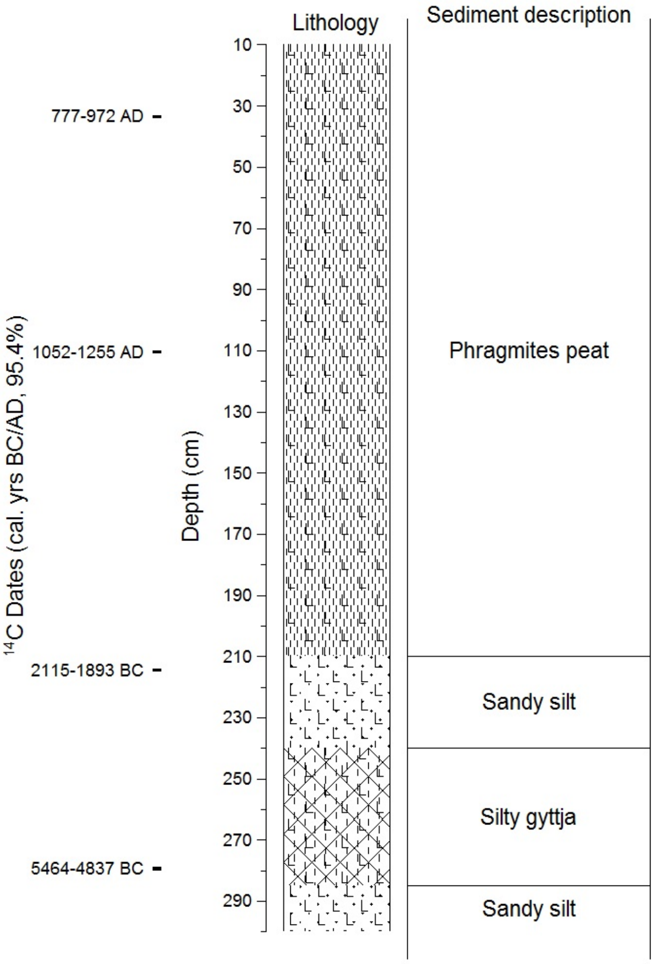


Figure 5.2.1 Stratigraphic diagram indicating the sedimentological units of core BL04. Several depths were radiocarbon dated to estimate their age

The occurrence of the palaeochannel might be related to climatic instability, as the radiocarbon dates indicate that these sediments ceased to be deposited around c. 2000 cal. yrs. BC, close to the 4.2k BP event, which is considered a diachronous interval in Scotland (e.g. Roland et al., 2014), but a consistently wet phase. The climate in Scotland is regionally distinct (Tipping, 1994, Lowe, 1993, Morrison, 1983), and was recently explored in a study by Langdon and Barber (2005), highlighting the importance of understanding the regional climate. In the south western part of Scotland the peatland records indicate a dry phase (Tipping, 1995, Birks, 1972, Barber et al., 1994), and so the sudden change in sedimentology of BL04 could be driven by wet and dry phases in the climate. An increase in sandy particles might also be related to a poorer nutrient status and a shift to charophytes, as indicated by the abundance of oospores/gyrogonites in the sand, which may be due to an active stream running through the lake.

A change in hydrology can be explored further by looking at the diatom assemblages (section 5.2.4). Apart from climate change, another potential source for the coarser sediments might be related to the catchment geology, as it indicates glacial deposits on the adjacent Barhapple Hill (appendix A.2). Increased erosion from the nearby hill is likely to be associated with deforestation in the catchment, which is explored further in the pollen assemblages (section 5.2.5), as well as the geochemical records (section 5.2.2). The combination of the Neolithic flint arrows (Maxwell, 1889) on Barhapple Hill and a burnt mound in nearby Knockishee (Moore, 2010), indicates human activity in the region during at least the Neolithic and the Bronze Age.

5.2.2 Chronology

Four picked macrofossil samples from the core were submitted to the Oxford Radiocarbon Accelerator Unit (see table 5.2.1). The calibrated radiocarbon dates indicate that the bottom of the core predates the crannog, which was dated to the Iron Age (358-42 cal. yrs BC. Table 5.2.1), while the top of the core is approximately 1000 years old. There appears to be an age reversal at the top of the core, as the uppermost radiocarbon sample (33-34 cm depth) appears to be about 300 years older than the next sample (110-111 cm). This could be related to the inwash of older organic material, possibly related to increased erosion rates (Bronk Ramsey, 2009b). In the last 150 years accumulation rates in lakes in Europe have increased dramatically (Rose et al., 2011), which is probably related to increased erosion rates and/or eutrophication related productivity. Age-depth models were constructed using both Bacon and Clam (Blaauw and Christen, 2011, Blaauw, 2010), which yielded almost the same depth estimates for the crannog (154 and 155cm, respectively). As the Bacon model is slightly robust it will be the main age estimate for this site, although both are visible in the graphs (red: Bacon, green: Clam). The uppermost sample was excluded, as the second sample from the top is more likely to be correct (figure 5.2.2). Using the lead concentration peak from the XRF analyses (6.5 cm depth, see section 5.2.3) an additional date of 1970 AD can be added. This is the maximum lead accumulation in NW-Europe (Farmer et al., 1997, Brännvall et al., 2001) and was included in the age-depth model, which also assumes that the top of the core is intact. Assuming the Bacon age-depth model is correct, sediments deposited during the construction of the crannog would be located at a depth of c. **154** cm.

Table 5.2.1 Radiocarbon dates from Barhapple Loch

Sample name and depth	Material	Radiocarbon date (yrs BP)	$\delta^{13}C$	Calibrated age range (95.4%)
(GU-10920) Barhapple Loch Crannog	Oak timber sample	2130 ± 50	-26.4	357-43 BC
OxA 28,896 (33-34 cm)	Indet. dicot plant macros	1148 ± 25	-27.2	777-972 AD
OxA 28,852 (110-111 cm)	Phragmites plant macros	858 ± 26	-28.3	1052-1255 AD
OxA 28,672 (214-215 cm)	Bryophyte branch cf. *Dicranales*	3617 ± 30	-31.1	2115-1893 BC
OxA 34,544 (279-280 cm)	Bryophyte branch cf. *Dicranales*	6190 ± 120	-26	5464-4837 BC

The age-depth models appear more or less similar, with the main difference below the radiocarbon sample of 214-215cm, leading to a difference in the models of around 500 years at c. 300cm depth. The sedimentology appears to indicate a shift in main sediment types around 215cm depth, which is best reflected in the Clam age-depth model.

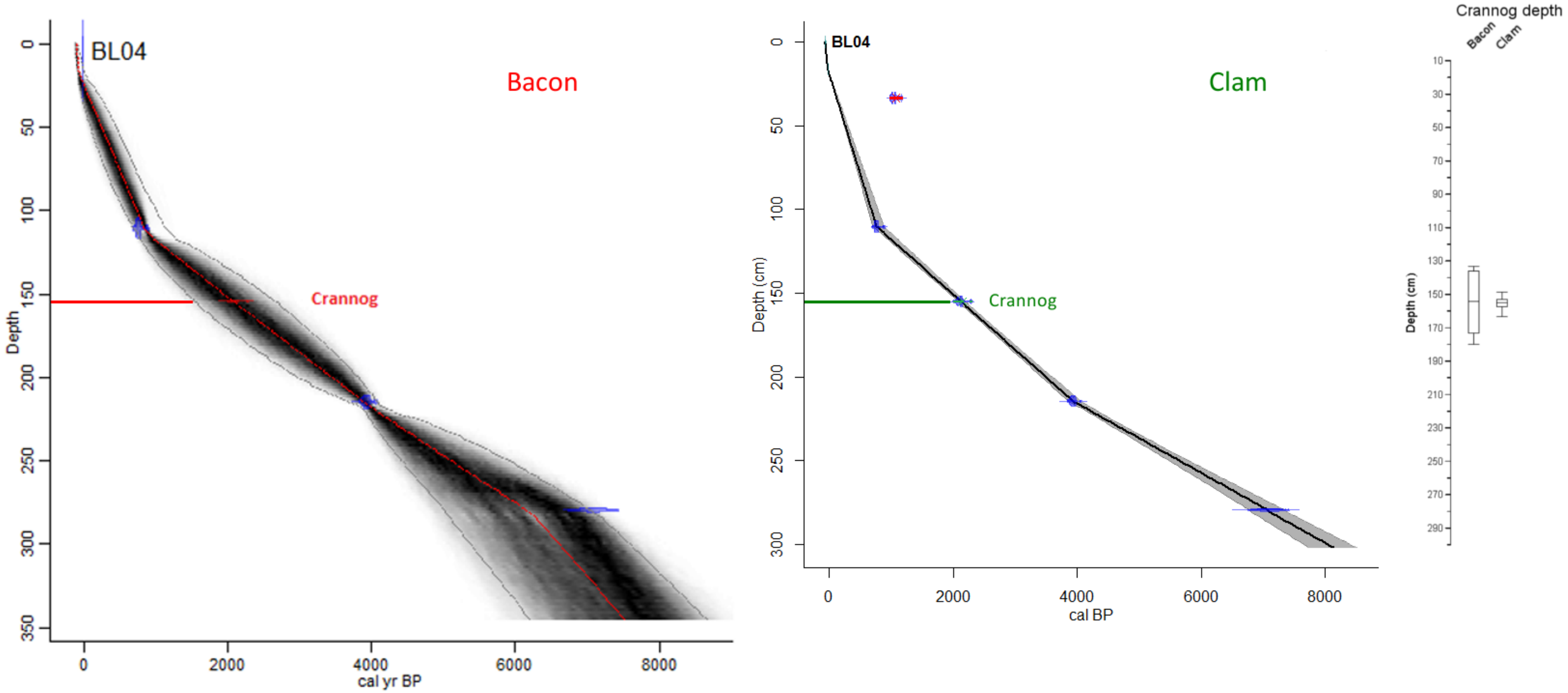


Figure 5.2.2 Radiocarbon age-depth of samples from BL04 using the Bacon age-depth model (right), where the red line indicate the most probable depths of the crannog. The middle graph represent the Clam age-depth model, with the green line the Clam based crannog depth estimates. On the right boxplots represent the uncertainty of the age models and the crannog radiocarbon dates. The tails (or whiskers) indicate the full range of sediments which might be dated to the crannog (α=0.0025), while the boxes indicate sediments that might be dated to the median age of the crannogs (α=0.05). The horizontal lines near the middle of each of the boxes represent the samples with a mean age closest to the median age of the radiocarbon date of the crannog

5.2.3 Geochemistry

The results from the loss-on-ignition and magnetic susceptibility analyses are summarised in figure 5.2.3 below, together with the XRF analyses. The lowest part of the core, below 285 cm, has a low amount of organic matter (c. 10%-25%), with the main component being minerogenic matter. The carbonate content is noticeably higher in the silty, less organic sections of the core, probably related to reduced OM burial (Dean, 1999). This shift is visible in the core photos (see methodology section), where there is a distinct change from yellow brownish silts to dark brownish peat. From c. 210 cm depth the lake shows a stable accumulation of peats, indicated by the high organic content and the peaty sediment. This upper part of the core is relatively rich in organic material (c. 50% - c. 80%). Between 210 and 10 cm depth, the organic matter content remains fairly stable, fluctuating around c. 70% of the dry weight. This upper part of the core (above 210 cm) might be interpreted as having sedimentation conditions similar to the present day, thus implying a minerogenic fen, largely covered by *Phragmites* beds as indicated by the peat rich in reed macrofossils. The LOI indicates that the upper sediments are low in carbonate content (LOI_{950}), which rarely reaches above 5%. Therefore it is unclear if this can be interpreted as carbonate content or if it might, for instance, be evaporation of more difficult to dislodge water molecules in clay minerals (e.g.Dean, 1974, Heiri et al., 2001).

At around 290 cm depth there is a short increase in the MS, which lasted for approximately 100 years according to the Bacon age-depth model. This increase is probably due to increases in ferromagnetic or canted antiferromagnetic components, which is probably due to increased minerogenic matter eroding in from the catchment (Dearing, 1999). This erosion is indicated by the relative reduction in organic matter. This is possibly due to an active palaeochannel, as the sedimentology becomes much coarser, indicative of a higher energy system. In the interval between 285 and 235 cm depth the MS record is stable and low, reflecting the high amount of organic matter and diamagnetic components in the sediment. From c. 235 to c. 210 cm there is a steady increase in the MS, indicating increased erosion rates, which is supported by a lower organic matter content, again possibly due to reactivation of the palaeochannel or catchment erosion. This is followed by an abrupt decrease after 210 cm sediment depth, when the sediments shift to organic rich peats. The MS record is fairly low and stable in the remainder of the core, 210 and 10 cm depth, with the low values probably driven by high amounts of diamagnetic material in the peat. The interval containing the crannog construction and use does not stand out in the MS or LOI records, apart from a few fluctuations around 140 cm.

The XRF data closely follows the sedimentology, with several erosional indicators (Si/kcps, Ti/kcps and Zr/kcps, Croudace et al., 2006, Rothwell et al., 2006) that have higher values at the bottom of the core below 290 cm. The Ca/Si is higher around this time as well, indicating more alkaline sediments, which is supported by the presence of charophyte oospores (also gyrogonites) microfossils and somewhat supported by increases in carbonate content as evident in the LOI. The next sequence (290-240 cm) indicates lower mineralogical indicators, while there is an apparent increase in the Fe/Mn and Fe/Ti ratios, indicating a reduction in oxygen availability in the lake bottom water (Engstrom and Wright Jr., 1984). These sediments indicate a lake with a higher organic matter deposition. Towards the end of the organic layer there is a peak in the Si/Ti ratio, indicating higher biogenic silica accumulation and diatom productivity. Between 240 and 230 cm there is another sandy layer, with increases in the MS, a reduction in the Ca/Si and short peaks in the Si/Ti, probably indicating inwash of allogenic matter, which led to increased planktonic production rates (Boyle, 2001). The geochemistry supports the interpretation of a palaeochannel, as well as deeper water conditions during the deposition of sandy deposits.

Above 210 cm the sedimentology changes to mainly *Phragmites* peat, with a small quantity of silts. This is indicated by low MS values and relatively high OM (c. 70% dry weight). The Fe/Mn and Fe/Ti ratios are generally low, indicating more oxygenated waters. Rapid decreases in the Fe/Mn ratio might indicate inwash from the surrounding mosses, as research has indicated that spring flooding of semi-enclosed basins can release high amounts of manganese into connected streams (Björkvald et al., 2008).Changes in either the productivity or organic matter loading of the lake will influence the Fe/Mn ratio due to increased microbial activity. The K/Rb increases to higher levels, which is indicative of increased detrital content (Rothwell et al., 2006, Croudace et al., 2006). Around 180 cm the Ti/kcps increases, indicating higher erosion rates, which precedes the depth of the crannog. The increased Ti/kcps might indicate that the age-depth model of the core is slightly off, although it can be assumed that catchment disturbances probably precede the construction of the crannog. Around 190 cm the Ti/kcps is generally low, while there are increases in the Fe/Mn and Fe/Ti, indicating a lower amount of clastic sediment washing in, though the Fe/Mn ratio probably represent inwash from the surrounding mosses. Finally at the top of the core the Ti/kcps increases again, indicating higher erosion rates.

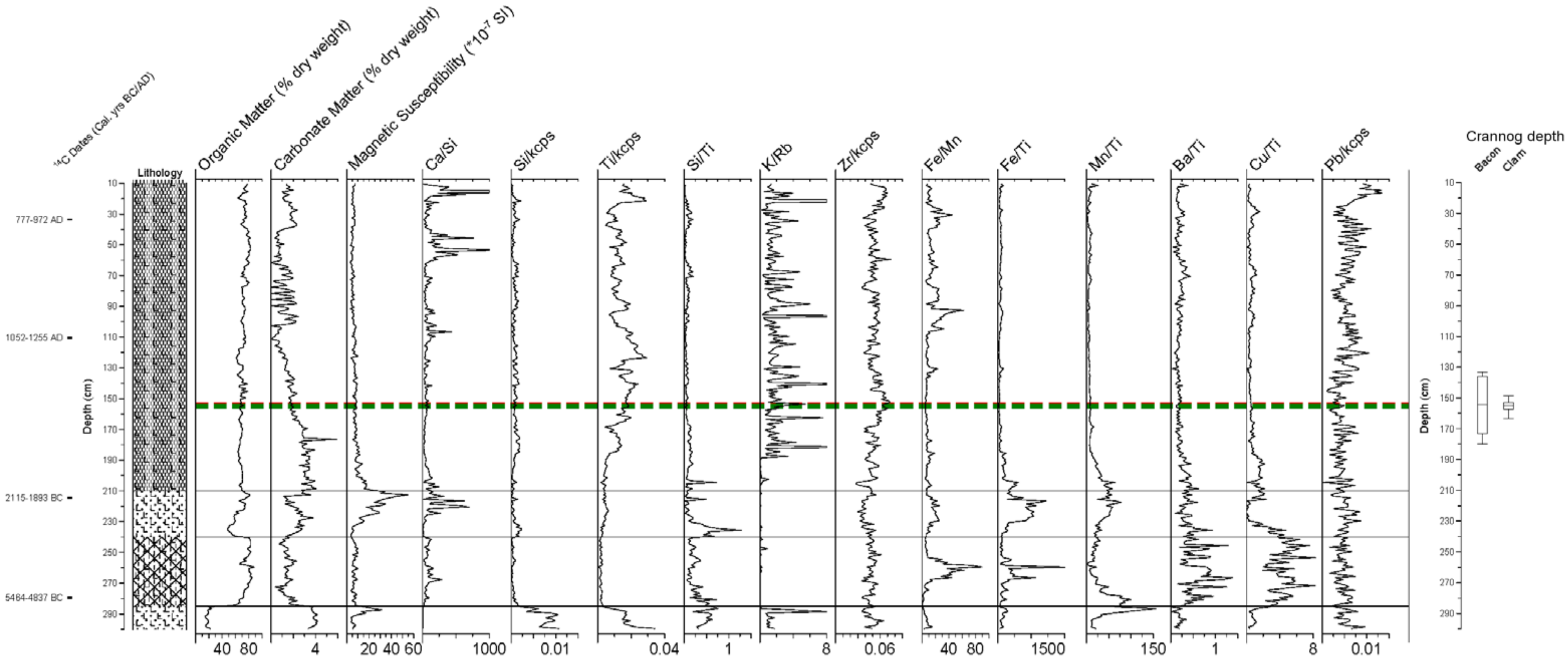


Figure 5.2.3 LOI, MS and selected XRF data from Barhapple Loch core BL04. The dashed lines (red: Bacon, green: Clam) indicates the estimated depth of the crannog, while the solid black lines represent the changes in the sedimentology. The box plots on the far right represent the uncertainty of the crannog radiocarbon age using the two models

Around the time of the crannog (red line in figure 5.2.3) there is a steady but small increase in Zr/kcps, indicating a change in the sediment source and more resistant minerals being deposited. Increased erosion rates are supported by the higher Ti/kcps around this time. An increase in humic components can be inferred from the steady reduction in carbonate matter. The Pb/kcps is higher at the top, probably related to modern fossil fuel emissions, which means that the sediments probably date from the 20th century. There is a distinct peak in the Pb/kcps around 16.5 cm depth, which has been used as a marker of the maximum in lead deposition around 1970 AD (Brännvall et al., 2001, Farmer et al., 1997).

5.2.4 Diatoms

The diatom study at 10 cm resolution reveals a few notable shifts in species abundances (see figure 5.2.4). Overall, the core has high abundances of *Stauroforma exiguiformis*. Other species which are common throughout the core are *Staurosira* cf*. elliptica, Achnanthidium minutissimum, Eunotia incisa*, *E. implicata* and *Frustulia saxonica*. *Stauroforma exiguiformis*, *Frustulia saxonica*, *Brachysira brebissonii*, *Cyclotella meneghiniana* and *Eunotia spp.* are commonly found in acidic and/or dystrophic aquatic systems (Ortiz-Lerín and Cambra, 2007, Jones et al., 1989, Flower et al., 1996).

The CONISS cluster analysis identified five zones (separated by the horizontal lines in figure 5.2.4): 300-280 cm (BL04D1), 280-230 cm (BL04D2), 230-210 cm (BL04D3), 210-100 cm (BL04D4) and 100-10 cm (BL04D5) depth.

<u>Zone BL04D1 (300-280 cm)</u>

The bottom zone shows high abundances of *Frustulia saxonica*, *Eunotia incisa* and some fragilarioid species. This bottom zone contains evidence of Chrysophyte cysts and the epiphytic taxa *Brachysira brebissonii* and *Eunotia* sp., indicating macrophytes were probably abundant. The abundance of *Cyclostephanos dubius* might be related to an increased mixing regime during this interval.

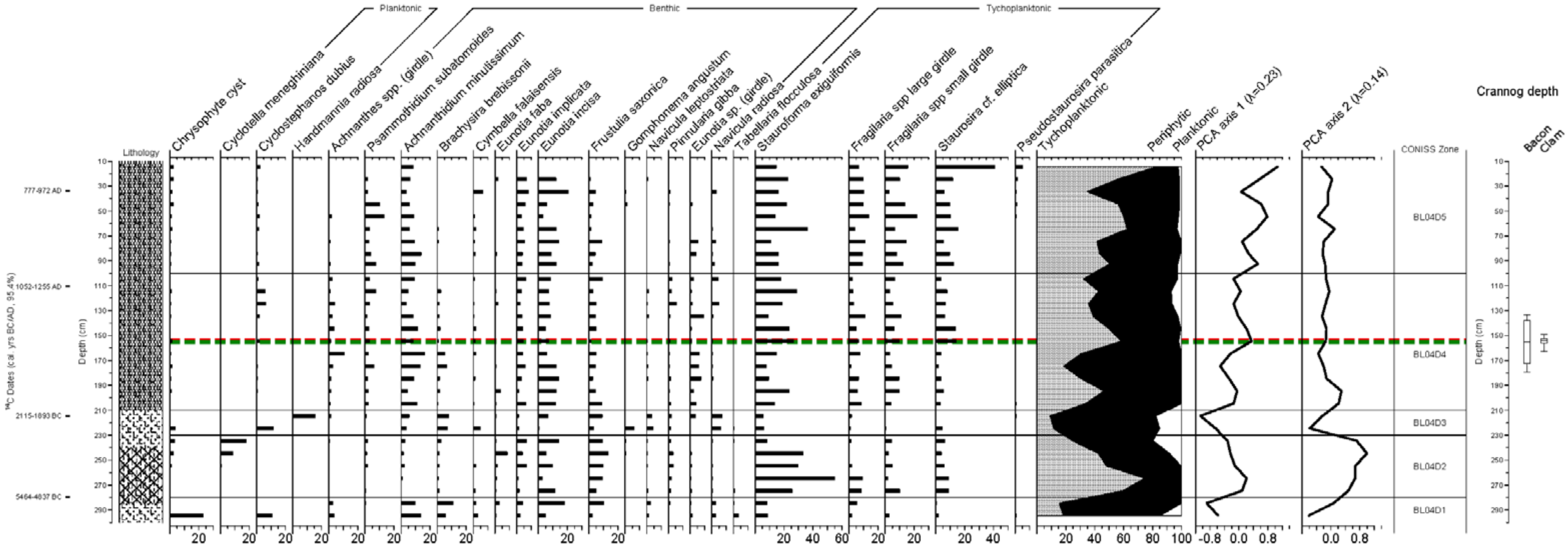


Figure 5.2.4 Diatom taxa occuring at least 5% in BL04 with PCA axes, CONISS zones and the estimated crannog depth (dashed lines)

Zone BL04D2 (280-230 cm)

The next zone shows an increase in fragilarioid diatoms, which can be interpreted as increased mixing and/or shallower water depth. There is a steady increase in the amount of Chrysophyte cysts, possibly indicating increased sedimentation during colder conditions, as Chrysophyceae are common in winter layers in varved sediments (Lotter, 1989). Deposition of these cysts is most likely to occur during autumn. There is a distinct peak in the abundance of *Stauroforma exiguiformis* around 260 cm. When this species starts to decrease, there is a shift from more oligotrophic towards more eutrophic taxa (following Van Dam et al., 1994), mainly driven by increases in centric diatoms, indicating an increase in the trophic status of the lake. The end of the zone is characterised by an increase of planktonic diatoms in the form of *Cyclotella meneghiniana*. *Cyclotella meneghiniana* has been associated with warm summer temperatures in shallow rivers (Mitrovic et al., 2007), possibly indicating an increase in summer temperature above 240 cm depth. As this zone mainly overlaps the more organic phase in the sedimentology, it probably indicates a shallow environment with slow moving water. This could be interpreted as the shutting down of the palaeochannel and reversion to a humic fen. The organic phase is followed by an active water channel with higher nutrients as indicated by the increases in *Cyclostephanos dubius* towards the top of the zone, which is a common diatom in shallow lakes (Sayer et al., 2010).

Zone BL04D3 (230-210 cm)

The second zone is initiated by consecutive short-term increases in the planktonic diatom species *Cyclostephanos dubius* and *Handmannia radiosa*. *Cyclostephanos dubius* appears from c. 225 cm and prefers cooler temperatures compared to *Cyclotella meneghiniana*, indicating a shift to cooler conditions. *Handmannia radiosa* appears at 215 cm which is associated with mesotrophic conditions, implying an increase in nutrient levels in the lake. Overall this zone shows an increased abundance of eutrophic and hypertrophic species (e.g. *Handmannia radiosa and Nitzschia palea*). Furthermore the planktonic species of this zone prefer a more alkaline environment, possibly related to more riverine conditions. There are also increases in a few periphytic taxa, such as *Brachysira brebissonii*, *Gomphonema angustum*, *Nitzschia palea*, *Navicula radiosa and Cymbella falaisensis*. These periphytic species mentioned above appear more commonly throughout the core from this zone onwards.

Zone BL04D4 (210-100 cm)

This zone is characterised by slightly lower values (up to 68% abundance) of the periphytic taxa common throughout the core. The abundance of fragilarioid taxa increases (up to 61%), due to several intervals with a higher abundance of *Staurosira* cf. *elliptica* and *Stauroforma exiguiformis*. A higher abundance of *Staurosira* cf. *elliptica* is probably related to a higher mixing regime and possibly an increased nutrient level (Van Dam et al., 1994), however, the nutrient requirements of araphid diatoms are poorly understood (Sayer, 2001). This zone is characterised by higher abundances of *Psammothidium subatomoides*, which might indicate that diatoms from benthic environments became a larger component in the assemblages (Bukhtiyarova and Round, 1996). Planktonic taxa disappear from the assemblages, implying mainly shallow conditions. Prior to the crannog, around 185 cm depth, *Eunotia incisa* appears to reach a maximum, replacing *Achnanthidium minutissimum and Stauroforma exiguiformis*. The taxon *Eunotia incisa* is a common taxon in oligotrophic minerotrophic fens (Ortiz-Lerín and Cambra, 2007). Around the time of the crannog (c. 155 cm depth), there is a distinct increase in *Stauroforma exiguiformis* and *Staurosira* cf. *elliptica*, replacing *Achnanthidium minutissimum*. *Achnanthidium minutissimum* is a ubiquitous taxon, common in low nutrient and more alkaline environments. It is also a pioneer taxon, often one of the first colonizers of newly formed substrates (Potapova and Hamilton, 2007). This could be interpreted as colonisation of new shallow periphytic habitat created by the construction of the crannog. This is followed by an increase in the planktonic *Cyclostephanos dubius* around 135 cm depth. This interval can be interpreted as the replacement of the pioneer species *Achnanthidium minutissimum* attaching to new substrates, followed by disturbance and wetland indicators *Stauroforma exiguiformis* and *Staurosira* cf. *elliptica*. Finally the arrival of *Cyclostephanos dubius* indicates increased nutrient levels, which might be related to human activities in and around the lake (Bradshaw and Anderson, 2003).

Zone BL04D5 (100-10 cm)

The uppermost zone is characterised by a peak in periphytic taxa, but also a few tychoplanktonic species. *Brachysira brebissonii* is absent from the record, while there is a peak in acidophilic *Eunotia incisa*, *Eunotia implicata* and *Stauroforma exiguiformis*. Given the suppression of planktonic taxa and dominance of more humic lake indicators in the diatom assemblages, it is likely that the lake was predominantly shallow and had a low pH throughout this zone. Similarly to Cults Loch (see section 5.1.3.2) this supports the assumption that the top of the core is probably recent, as acidification took place in many lakes in Scotland after 1970 (Battarbee et al., 1984). At the top of the core there is a distinct peak in *Staurosira* cf. *elliptica* and the occurrence of *Pseudostaurosira parasitica*. When looking at their trophic preferences (Van Dam et al., 1994), these species are common in meso- to eutrophic environments and are tolerant of mild pollution, especially *Pseudostaurosira parasitica*. Given the presence of the Derskilpin farm estate since at least the first revision OS map of the area (1893-1915), the increase in tychoplanktonic diatoms, preferring higher nutrient loadings, could indicate the intensification of cattle or sheep grazing in the immediate vicinity during the last century, which probably led to the increased production rates in the lake, driven by an increased influx of phosphates and silica. This might have caused the lake to switch to a turbid state (Scheffer, 2004).

5.2.4.1 Diatom interpretations

Overall the core is dominated by periphytic taxa (15-85%), followed by fragilarioid taxa (7-82%). There are two short intervals containing an increase in the abundance of planktonic species (c. 260-200 cm, up to c. 20%, and c. 140-90 cm, up to 8%). The ratio between periphytic and planktonic taxa is indicative of the relative water depth (e.g. Wolin and Duthie, 2001, Lotter and Bigler, 2000). The high abundance of periphytic taxa indicates a shallow lake throughout the core. The intervals with an increased abundance of planktonic taxa coincide with sandy intervals in the lower half of the core and might indicate instances where the lake is less shallow. The mid-Holocene climate in Scotland is complicated, though there are several studies mentioning a dry phase in bog records near the Solway Firth (Barber et al., 1994, Tipping, 1995, Birks, 1972), which might be the cause of the more organic interval between 240 and 210 cm depth. This interval is remarkably similar to the upper peaty half of the core, with high amounts of *Stauroforma exiguiformis* and low amounts of planktonic diatoms.

The sandy intervals contain several planktonic taxa: the bottom section contains *Cyclostephanos dubius*, while the upper sandy section also contains *Handmannia radiosa* towards the end. *Handmannia radiosa* indicates more oligotrophic conditions, which might be related to the observed reduction in XRF Si/Ti around 220 cm depth, when the organic matter starts to increase again. It is possible that the increased biogenic silica production rates (Boyle, 2001) in combination with infilling and shallowing of the loch depleted the silica availability and led to a shift in dominant diatoms. The top of the core is indicative of a shallow fen, with high abundances of benthic, periphytic and tychoplanktonic diatoms, while euplanktonic diatoms are absent. Furthermore, increases in humic taxa indicate the lake probably had a reduced pH and was somewhat turbid as indicated by the tychoplanktonic taxa. The increases in very small tychoplanktonic diatoms around the time of the crannog are difficult to interpret, but might be related to a shorter growing season. *Staurosira* cf. *elliptica* is one of the smallest frustule sizes encountered and in lake Tahoe a reduction in *Cyclotella* frustule size has been linked to lake warming (Winder et al., 2009), driven by reduced sinking rates and a lower surface area to volume (Smayda, 1970). The establishment of the crannog could create a physical boundary within the lake that might limit the wind fetch and/or might increase the energy required for fully mixing the lake.

5.2.4.2 5.2.4.2 Diatom PCA analyses

A DCA on taxa occurring at least 1% in a sample indicated that the first axis has a gradient length of 1.94, warranting a PCA analysis to describe the overall changes in the assemblages. This first axis ($\lambda = 0.23$) shows strong fluctuations in diatom zones BL04D1, BL04D2 and BL04D3, reflected by changes in the diatom assemblages (figure 5.2.4 above and 5.2.5). The first PCA axis also indicates lower values throughout the sandy sediments and higher values in the more organic sediments and closely follows *Staurosira* cf. *elliptica* and other tychoplanktonic taxa. As it steadily increases towards the top of the core, it is likely related to the shallowing of the lake over time. The first three diatom zones show the biggest shifts on the second PCA axis, with zones BL04D1 and BL04D3 relatively similar with benthic taxa and zone BL04D2 associated with tychoplanktonic *Stauroforma exiguiformis* and planktonic *Cyclotella meneghiniana*, while it Is negatively affiliated with *Achnanthidium minutissimum* and *Cyclostephanos dubius* (Van Dam et al., 1994). The opposite direction of the planktonic diatoms might be related to alkalinity, as *Cyclostephanos dubius* has a higher pH optimum than *Cyclotella meneghiniana*. This is supported by acidophilous *Eunotia* sp. and *Frustulia saxonica* positively aligned with the second PCA axis.

As the diatoms towards the right of PCA axis 1 are mainly tychoplanktonic with the addition of benthic *Cavinula scutelloides*, it is likely that the uppermost samples represent fluctuating shallow water levels and turbid waters.

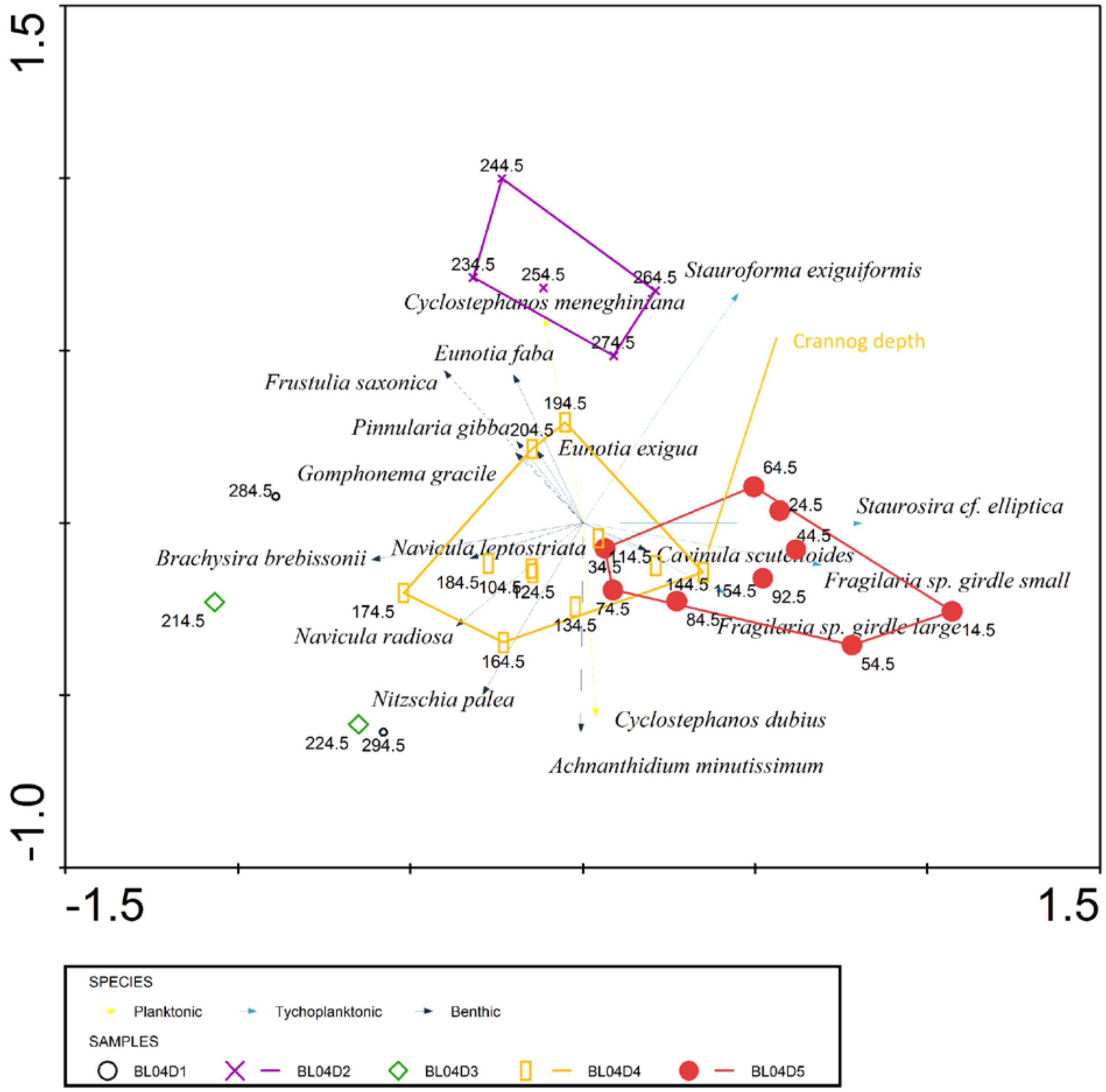


Figure 5.2.5 Diatom biplot from core BL04 with species and samples in relation to the PCA axes (35%). The crannog related sediments are estimated to be around 155 cm, towards the right within their zone

5.2.4.3 Diatom and geochemistry RDA

In an attempt to better understand the relationship between the geochemistry and the diatom assemblages, a RDA was performed (figure 5.2.6). Several geochemical variables were selected that represent some of the major sedimentological changes in the core (see table 5.2.2).

Table 5.2.2 Significance of selected geochemical variables in the RDA analysis of geochemistry and diatoms

Significantly correlated environmental variable (correlation $1^{st}/2^{nd}$ axis)	Multiple regression significance level (full model significance)	Multiple regression coefficient	RDA significance
MS (PCA1: -0.55)	**<0.005**	-0.71	**0.001**
Ca/Si (PCA1: 0.41)	**<0.005**	0.47	**0.001**
Ti/kcps (PCA2: -0.65)	**0.020**	-0.58	**0.001**
OM (PCA1: 0.45)	**0.014**	0.31	Not significant
Ba/Ti (PCA2: 0.66)	**0.015**	0.16	
Zr/kcps (PCA2: -0.38)	Not significant		
K/Rb (PCA2: -0.42)			
Si/Ti (PCA1: 0.64)			
Mn/Ti (PCA1: -0.60)			**0.001**

With the combination of the geochemistry and the diatom assemblages, the CONISS diatom zones remain more or less valid, with the exception of samples 284.5 cm and 204.5 cm. These samples are from the lower part of the core, where the sedimentology indicates sandy sediments and are grouped closely to diatom zone BL04D4, which indicates strong affiliation with a positive loading on the first RDA axis. The first axis is negatively aligned with tychoplanktonic *Staurosira* cf. *elliptica* and small *Fragilaria* girdle sp., while it is positively aligned with Mn/Ti, indicating some relationship with the influx of groundwater from the surrounding peatlands (Björkvald et al., 2008). This is somewhat supported by the alignment with peatland indicators, such as *Brachysira brebissonii* and *Frustulia saxonica*. Interestingly the Mn/Ti was not significant in the multiple regression analysis, though it is strongly negatively correlated to the first diatom PCA axis.

The samples at 294.5 cm, 224.5 cm and 214.5 cm depth are sandy sediments with a high MS and more alkaliphilous and oligotrophic diatoms, such as *Handmannia radiosa* and several periphytic diatoms (e.g. *Navicula leptostriata* and *Brachysira brebissonii*). The second RDA axis has a close alignment with Ti/kcps, indicating that erosion into the lake is another factor driving the diatom assemblages. This is supported by the multiple regression analysis, which indicates Ti/kcps is one of the significant variables influencing the second diatom PCA axis (table 5.2.2). The samples 274.5 – 234.5 cm and 204.5 cm are of peaty sediments with higher OM and are located at the bottom of the graph, with negative loadings on the second RDA axis. Since these samples are opposite to Ti/kcps, they are more likely related to a low minerogenic component (Rothwell et al., 2006, Croudace et al., 2006). There is some secondary response of low pH and macrophytes, as the epiphytic *Eunotia exigua* and *Frustulia saxonica* are aligned with these samples. Between 100 cm and 10 cm sediment depth the diatoms are located on the left of the graph, with a negative loading on the first RDA axis, affiliated with tychoplanktonic diatoms (*Staurosira* cf. *elliptica* and F*ragilaria* sp. girdle small) indicating more mixed and turbid conditions.

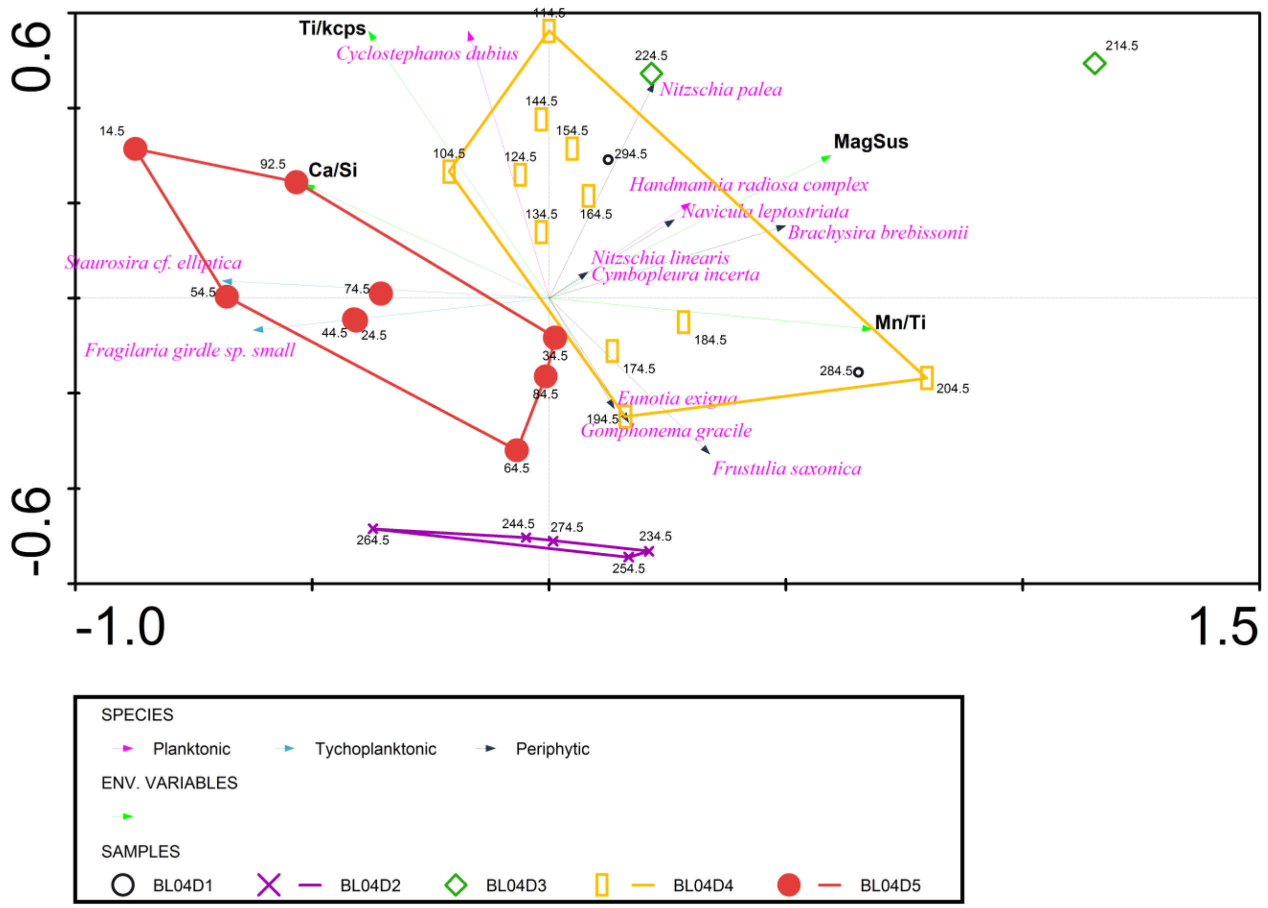


Figure 5.2.6 RDA analysis of diatom assemblages and significant geochemistry of core BL04. The samples are grouped together according to the diatom zonation (figure 5.2.5), while the diatoms were seperated into planktonic, tychoplanktonic and periphytic species

5.2.5 Pollen

The pollen study at 10 cm resolution reveals a few notable shifts in the vegetation (see figure 5.2.7). Overall the core is dominated by arboreal pollen from the taxa *Corylus, Betula, Quercus and Alnus*. At the bottom of the core there is an abrupt decrease in *Isoetes* spores coinciding with a short term increase in oak pollen and gradual increases in Ericaceae (heath) pollen and Corylus. Other grass and herb pollen taxa which appear commonly in the core are Poaceae, Cyperaceae and *Plantago* sp.. In the upper half of the core occasional cereal grains start to appear.

The CONISS cluster analysis identified four zones (separated by the horizontal lines in figure 5.2.7): 295-240 cm (BL04P1), 240-210 cm (BL04P2), 210-170 cm (BL04P3) and 170-0 cm (BL04P4) depth. These zones largely coincide with the PCA axes (section 5.2.5.1) and reflect the long term transition to a more open vegetation in the catchment, punctuated by a few distinct disturbances.

<u>Zone BL04P1 (294-240 cm)</u>

This zone is characterized by high amounts of *Isoetes* spores, as well as arboreal pollen. Few grass and herb pollen were found. A relatively high proportion of *Nymphaea* pollen (c. 5-10%) is found in this zone, indicating shallow to moderately deep water and good to moderate water quality. There is a low amount of pine pollen in this zone, agreeing with established pollen curves from the area (Birks, 1972, Jones et al., 1989), which indicate pine pollen dropping below 10% during the later Holocene (i.e. post 6000 BC). There is a moderate amount of elm pollen present in the sediment, which drops from around 10% - 5% abundance at the top of this zone. As the Bacon age-depth model indicates that the top of this zone is dated to c. 2748 cal. yrs BC, the elm decline in core BL04 is close to the later age range of the elm decline in Scotland (i.e. c. 3500-3000 cal. yrs. BC Parker et al., 2002). It is also close to evidence from more regional vegetation that places it around 2800 cal. yrs BC (Tipping, 1997). The presence of a burnt mound (Moore, 2010) towards the west of Barhapple Loch indicates local human activity during the Bronze Age and deforestation is evident from low abundances of anthropogenic indicators (Behre, 1981) in this zone. The evidence of Bronze Age deforestation has been reported extensively in southern Scotland (e.g. Turner, 1965, Birks, 1972, Jones et al., 1989, Tipping, 1995, Ramsay et al., 2007) and can be described as discontinuous (Tipping, 1997). This zone combines two sedimentological units (sandy gyttja and peaty gyttja) and probably represents a change in local hydrology from an active channel to a shallow lake with standing water, as indicated by the high amounts of aquatic pollen throughout the organic sediments between 285 cm and 230 cm depth. Aquatic pollen are present in this zone (5-10%), indicating submerged macrophytes, indicated mainly by Nymphaea, as well as the high abundance of *Isoetes* spores.

Zone BL04P2 (240-220 cm)

The second pollen zone shows a distinct reduction in *Isoetes* spores, coinciding with increases in oak and heath pollen. Towards the top of this zone S*phagnum* spores and grass pollen start to appear in higher amounts, indicating established peatlands and grasslands nearby. Further evidence of nearby peatlands comes from the occasional *Drosera* pollen grains. The amount of heath pollen almost doubles to around 15%. Together this indicates an increase in the openness of the landscape, with some evidence of cultural activities, as indicated by the low amounts of anthropogenic indicators (<2%). As no *Nymphaea* pollen were identified in this zone, it might indicate increased water depth or a lotic environment (Preston et al., 2002, Stace, 2010), although a higher total count or scanning for specific pollen might be able to detect them. *Ulmus* pollen are nearly absent, largely replaced by increases in *Quercus* pollen. The commonly seen increase in anthropogenic indicators coinciding with the elm decline is not as clear in Barhapple Loch, where in zone BL04P3 it is mainly composed of *Rumex acetosa/acetosella* type, indicative of wet meadows and grazing. There are some increases towards the top of this zone, but not to the extent as in some other studies in the region (Tipping, 1995, Birks, 1972, Ramsay et al., 2007, Jones et al., 1989). The high amount of oak and pine pollen is slightly more difficult to interpret, though it might indicate a re-establishment of mature woodlands. However, it might be that the total accumulation rate of pollen increases in this interval, due to increased erosion rates, leading to an overestimation of the arboreal from the catchment. A decrease of spike spores (*Lycopodium*) relative to the amount of total land pollen counted during this zone indicates that relative to the sediment accumulation, the pollen accumulation rate was likely higher during this zone. Trees have much higher pollen productivity rates than most herbs, so it is likely that increased inwash from the catchment, for instance via the palaeochannel, would have increased the relative amount of tree pollen. A reason for increased erosion rates might be the deforestation itself, as several studies have been able to link erosion rates to deforestation in Scotland (Ballantyne and Dawson, 2003, Edwards and Whittington, 2001). The top of this zone also contains higher amounts of *Sphagnum* spores, indicating bog development.

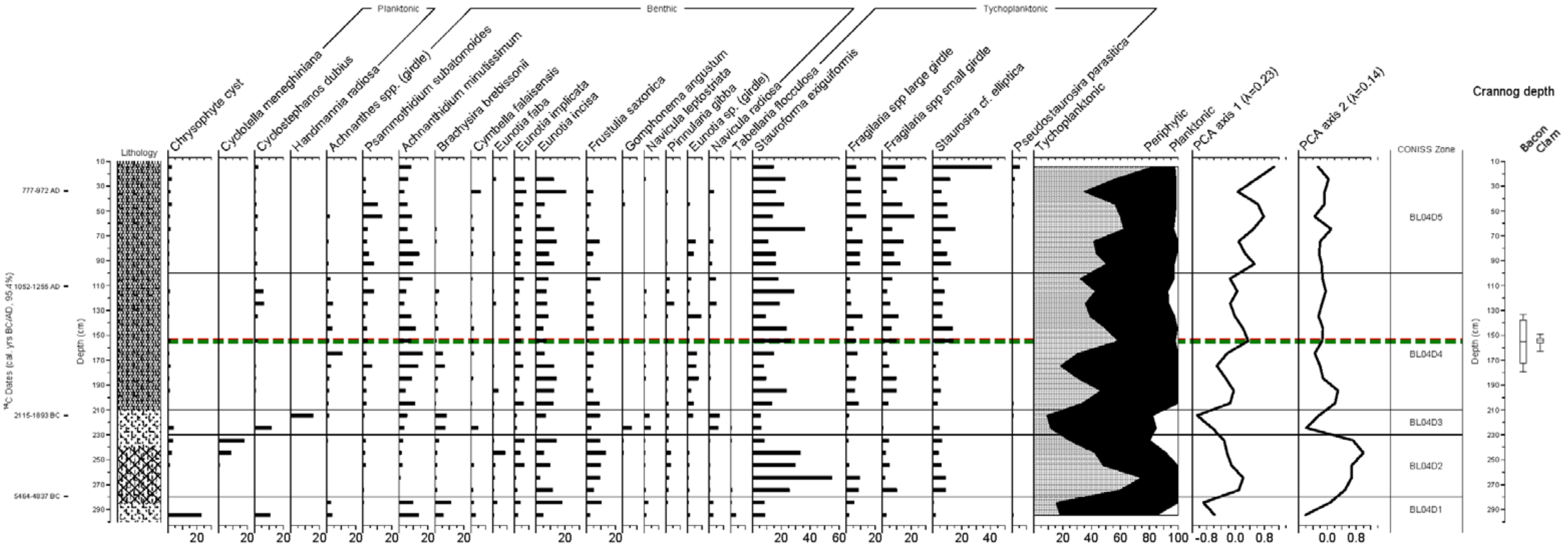


Figure 5.2.7 Selected pollen and spore taxa from core BL04, with pollen PCA axes. The dashed lines indicate the estimated depth of the crannog

Zone BL04P3 (220-160 cm)

This zone signifies a transition in the catchment vegetation, as it indicates a significant drop in the arboreal pollen, which can be interpreted as extensive deforestation. The oak pollen returns to previous values (about 15-20%), similar to the other arboreal pollen taxa. Heath pollen continues its doubling trend (up to c. 30%), indicating increased landscape openness and possibly pastoralism taking place in the catchment, supported by increases in non-arboreal pollen. Evidence of pastoralism in the Galloway Hills has been identified from the Bronze Age (Jones et al., 1989, Tipping, 1997, Tipping, 1994) and is further substantiated by a rapid increase of anthropogenic indicators around c.180 cm depth. Towards the top of this zone the amount of *Isoetes* spores increases again, while the S*phagnum* spores remain relatively stable, indicating an established bog nearby. Currently Tanieroach Moss is to the north-east, while Derskilpin Moss is located towards the south - these mosses are probable sources of the *Sphagnum* spores. Combined with the reappearance of *Nymphaea* pollen this can indicate shallow water and a stable fen during this zone (Preston et al., 2002, Stace, 2010).

Zone BL04P4 (160-10 cm)

This uppermost zone contains over half of the sediment analysed, indicating a fairly stable catchment throughout. There are some changes in the pollen taxa; most pronounced is the appearance of occasional cereal pollen grains, indicating that near the site cereals were processed or stored (Bower, 1992, Robinson and Hubbard, 1977, Edwards and Whittington, 2003). As the initiation of cereal pollen coincides with the supposed depth of the crannog, it is likely that human activity on or near the lake intensified at the same time (O'Brien et al., 2005). There is a dramatic reduction in *Isoetes* at the base of this zone, coinciding more or less with the time of the crannog. As *Isoetes* requires clear water, it is probably related to more turbid conditions and organic matter enrichment (Stace, 2010, Preston et al., 2002, Chappuis et al., 2015). Although a pine rise is not obvious in BL04, pine pollen remains present in low abundance throughout this zone. Even though pine plantations have dramatically altered the region's vegetation since the 1950s (Gilbert and Wright, 1999), the low amounts of pine pollen do not necessarily mean that the core top has been lost, as a pine rise is not always found in south west Scotland (Birks, 1972, Jones et al., 1989). This last zone is interpreted as a similar aquatic setting to the present, which is a shallow reed fen. In the uppermost sample Nymphaea are absent, probably indicating deterioration in the water quality and/or a dramatically reduced water level (Preston et al., 2002, Stace, 2010).

5.2.5.1 Pollen and spores PCA analysis

A PCA analysis on the pollen percentage data (excluding spores and aquatics) was performed to describe the overall changes taking place in the core (figures 5.2.7 and 5.2.8). The pollen assemblages seem to follow a shift from closed forests (*Quercus*, *Pinus (pine)*, *Alnus* and *Ulmus* pollen) towards a more open landscape (grass, plantain and heath taxa), which agrees well with the pollen percentages (eigenvalue of the first axis is 0.69). As the core corresponds to the Late Mesolithic, this transition in dominant pollen taxa from zones BL04P1 to BL04P3 likely reflects both climatic and anthropogenic influences on the catchment vegetation.

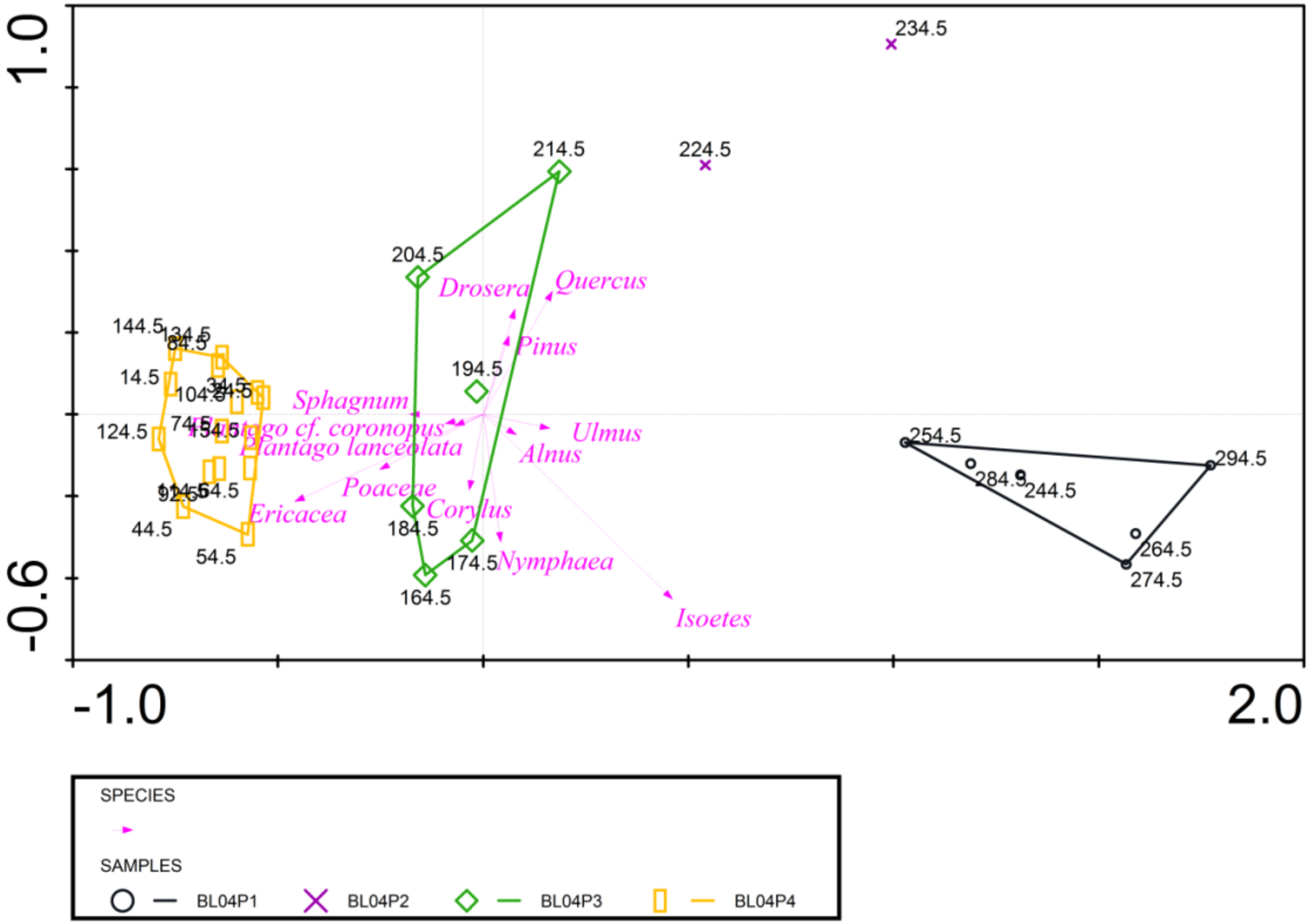


Figure 5.2.8 Pollen PCA axes from core BL04. Dominant species (>40% species weight range) in the assemblages are indicated by the blue arrows, while the pollen zones are indicated by the different colours

5.2.6 Barhapple Loch conclusions

The extensive palaeoecological analyses of core BL04 from Barhapple Loch show the complex interaction of climate and human impact upon the lake ecology. Overall core BL04 shows the potential for using the multiproxy approach to reconstruct the long-term palaeoenvironment of crannogs. There are distinct disturbances in the geochemistry, pollen and diatom analyses related to the crannog (see figure 5.2.9). The radiocarbon dates have to be approached with caution, as there is clear evidence of age-reversal in the top of this core. To produce a more suitable age-depth model, the radiocarbon dates were compared to the other proxies, to allow a more robust age-depth model. The bottom of the core (300-210 cm depth) shows dramatic sedimentological changes, dated around 2250 cal. yr. BC. It is possible that a palaeochannel (Moore, 2010) was connected to Barhapple Loch, which led to the deposition of coarser sediments, as well as specific planktonic and benthic diatoms. It also indicates that this palaeochannel was not continuously active, as the sandy deposit is interrupted by a continuous peaty gyttja layer, with higher amounts of organic matter and more acidophilous and tychoplanktonic diatoms, indicative of a shallow and acidic fen (Sayer et al., 2010, Jones et al., 1989). During this time the pollen assemblages indicate some signs of human disturbance, though low. The relatively high amount of hazel (c. 30%) indicates that the regional vegetation was relatively open.

Towards 210 cm there is a reduction in elm pollen, which appears largely diachronous in the British Isles (Parker et al., 2002) but appears to have occurred around 2800 cal. yrs BC in Southern Scotland (Tipping, 1997). Thus, the pollen assemblages support the radiocarbon dates for the bottom part of the core, which place the elm decline in BL04 at 210 cm depth around 2750 cal. yrs BC.

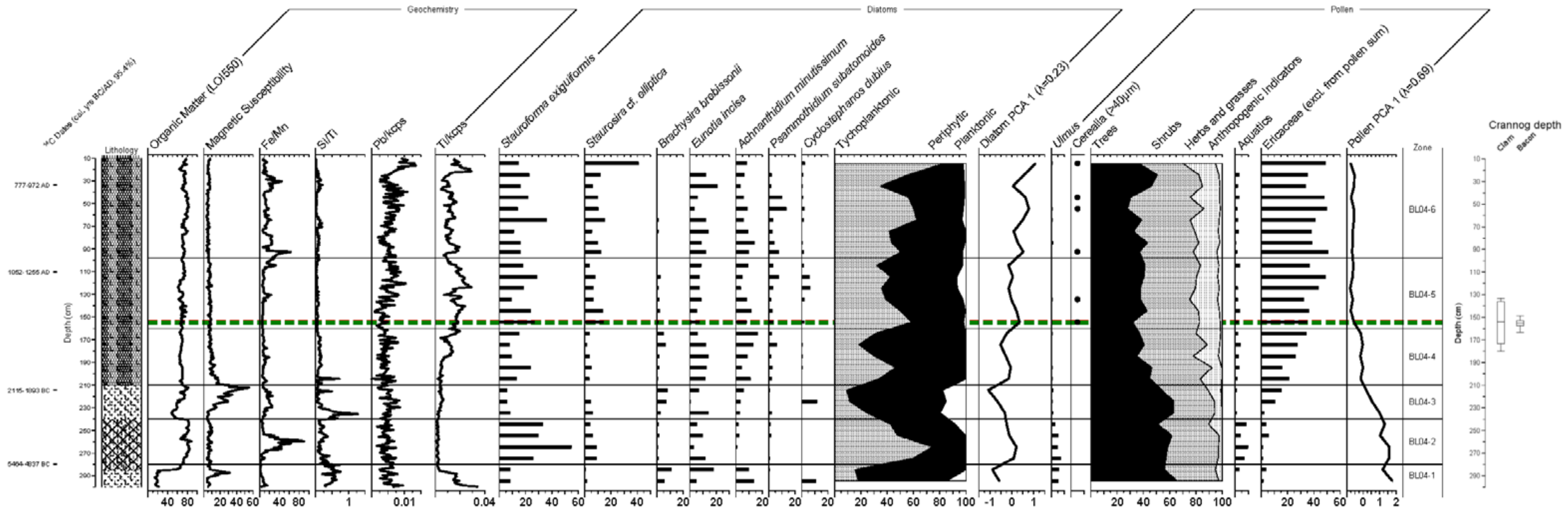


Figure 5.2.9 Summary diagram of sediment core BL04 with selected results from geochemical, pollen and diatom analyses

From 210 cm the sedimentology is stable, indicating peat with high amounts of macrofossils. The pollen assemblages show reduced arboreal pollen (to c. 40%), with some increases in anthropogenic indicators. There is a steady increase in tychoplanktonic diatoms, as indicated by the first diatom PCA axis. Another distinct change in the pollen and diatom assemblages occurs around 160 cm, near to where the age-depth model places the crannog (c. 155 cm). From here, cereal pollen start to occur and the tychoplanktonic diatoms become a more stable dominant component. Anthropogenic indicators occur at slightly higher levels and there are increases in erosional indicators Ti/kcps and Zr/kcps. Although there is little support for an active palaeochannel at this time, it is likely that the adjacent mosses were still very wet. As shallow logboats (<0.5 m deep) have been described from Barhapple Loch (Wilson, 1882) and nearby Dernaglar Loch (Wilson, 1885), the mosses and fens might have been traversed from the crannog. This could be explored further by assessing the hydrology of the region in greater detail. Most of the catchment vegetation had already been altered by the time the crannog was constructed, though it might indicate a stable time when little disturbance to the communities took place. There is some evidence of eutrophication in the lake, with increases in the planktonic diatom *Cyclostephanos dubius* around the crannog, but also later, around 120 cm depth. This might be related to a secondary occupation phase or increased cattle grazing in the region. Without a more extensive excavation of the crannog it is difficult to interpret the occupation history with confidence.

Towards the top of the core the lake appears relatively unchanged for long periods of time, although there are increasing amounts of tychoplanktonic *Stauroforma exiguiformis* and *Staurosira* cf. *elliptica.* At the very top there are increases in Pb/kcps and Ti/kcps, indicative of the acceleration of post-Industrial erosion rates (Rose et al., 2011) and lead deposition (Brännvall et al., 2001), which have been used to validate the age-depth model.

5.3 Black Loch of Myrton palaeoecology

5.3.1 Chronology

No radiocarbon dates have yet been submitted for this core, as this core was a late addition to the project. As no radiocarbon dates were initially part of the PhD, there was not enough time to submit a proposal or attempt additional analyses such as SCP's or ^{210}Pb dating. An estimate of the age of the sediments is attempted by assessing the sediments in the core.

Around 1800 AD drainage took place, which has probably altered the upper sediments. This might be related to the reduction in organic matter towards the top of the core. The sediments are probably also disturbed by the trees, nettles and reeds currently growing on and around the site, as well as the reduction in the groundwater table, which has impacted the stratigraphy (Holden et al., 2006, Holden et al., 2004, Armstrong et al., 2009). As core BLM01 was collected about 10 metres from the excavation site (Crone and Cavers, 2013, see appendix A.3), it is possible to estimate at which depth sediments related to the settlement can be found. At the edges of the excavation cross-section, the deposits relating to the settlement are between c. 35 and 50 cm depth (appendix A.3), so it is probable that sediments related to the settlement are located at a depth of up to 35 cm in core BLM01. This depth is indicated by a dashed red line in the figures, as it indicates the upper limit of the settlement deposits.

5.3.2 Geochemistry

The upper 30 cm of the core was not sampled for loss-on-ignition and magnetic susceptibility, as it had cemented and crumbled apart when trying to separate into 1 cm samples. The organic matter (OM) content of the core (figure 5.3.1) is generally high, with values around 60% for most of the core. The lower part of the core, below 50 cm depth, has a relatively stable OM of between 55 and 60%. Above 50 cm depth there is a minor increase and the OM stabilises at around 60-70% OM. Around 35 cm there is a dramatic, though short-lived, reduction in organic matter, probably related to a higher minerogenic component which could be linked to the occupation of the settlement.

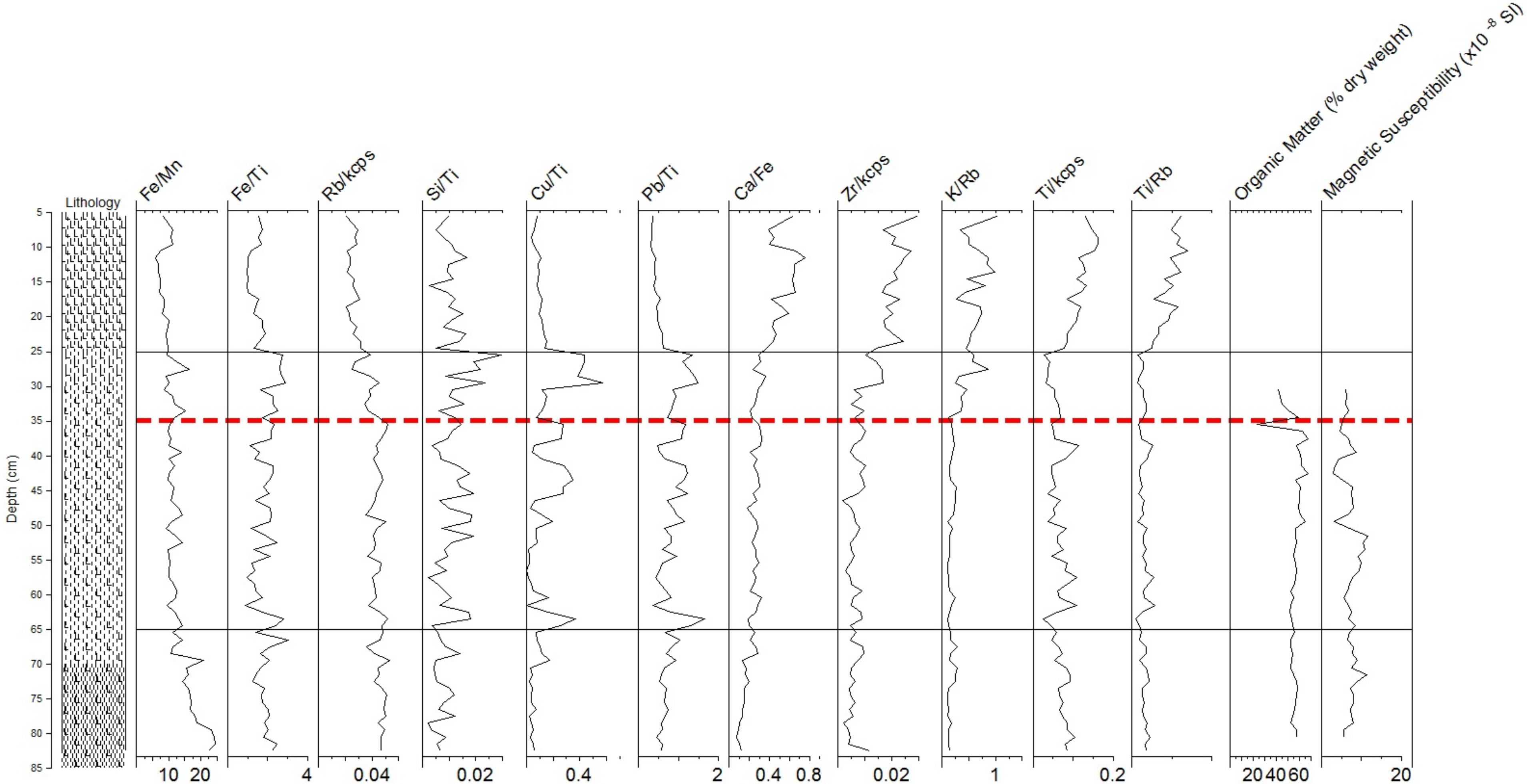


Figure 5.3.1 Selected XRF, LOI and MS analyses from core BLM01

The Magnetic Susceptibility (MS) of the core (figure 5.3.1) is below 10^{-7} SI for most of the core, indicating the sediments are mostly composed of diagenetic components. The lower half of the core (below 50 cm depth) has a slightly higher MS, indicating that ferromagnetic or canted antiferromagnetic components are present in the sediments (Dearing, 1999). There is a small peak around 71 cm depth, possibly indicating a small erosion event, as well as around 50 cm depth. Between 55 and 35 cm depth there are several increases and decreases in the MS, probably related to changes in the deposition regime, which coincides with the estimated settlement deposit depth. As the excavation yielded an extensive timber foundation with several large hearthstone slabs (Crone and Cavers, 2013), it is probable that there were dramatic changes in the local hydrology, leading to changes in the deposition regime. From c. 35 cm depth the MS appears to stabilize similar to 50 cm depth.

The U-channel was successfully filled with sediments and has been analysed for its chemical elements using the XRF scanner (figure 5.3.1). At the bottom section of the core the erosional indicators are relatively stable, though the Fe/Mn and Fe/Ti appear to increase around 70 cm depth, indicating hypoxic conditions (Engstrom and Wright Jr., 1984, Boyle, 2001). This is followed by increases in minerogenic indicators such as Rb/kcps, Ti/kcps and Zr/kcps (Croudace et al., 2006, Rothwell et al., 2006) around 67 cm depth, indicating increased erosion rates, after which these indicators appear to stabilize. The Fe/Mn and Fe/Ti indicate some reductions in the oxygen availability, possibly related to stagnant water (Wetzel, 2001). As the excavation hints at the possibility of a compact reed layer underlying the settlement deposits (Crone and Cavers, 2013), it might lead to compaction of the peat and reduced oxygen permeability from 35 cm depth. Several erosional indicators increase from 35 cm depth, which is probably related to changes in the sediment deposition from this period. This supports the reduction in organic matter as evident from the LOI analysis. Between 30 and 25 cm depth there are reductions in minerogenic indicators Rb/kcps and Ti/kcps, while there is a minor increase in Zr/kcps and a distinct peak in the K/Rb. This might be related to a short term increase in more resistant minerals. As it coincides with an increase in the Cu/Ti, which can indicate more diagenetic conditions (Rothwell et al., 2006, Croudace et al., 2006), it might be related to the drainage, which would have led to increased aeration of the sediments. The Pb/Ti appears to increase between 30-25 cm, before it decreases in the upper sediments, where it appears to stay relatively stable. An explanation of this might be that the increase is due to secondary enrichment leading to an accumulation horizon (Preiss et al., 1996), which is supported by the close proximity of the water table around this depth.

5.3.3 Diatoms

The diatom assemblages (figure 5.3.2) are dominated by tychoplanktonic taxa, with high amounts of periphytic taxa with a high degree of diversity, while planktonic taxa are absent from most of the core with occurrences <1%. This supports the interpretation that the core was never submerged, although as the core was taken from between the raised mounts it might have been prone to flooding. The main tychoplanktonic taxa are *Staurosira construens* var. *venter*, *Staurosira* cf. *elliptica*, *Stauroforma exiguiformis* and *Pseudostaurosira brevistriata*. These are relatively small fragilarioid taxa, often indicative of turbid waters in shallow lakes (Sayer et al., 2010). The main periphytic taxa are *Achnanthidium minutissimum* and *Gomphonema angustum,* while towards the top of the core *Planothidium* sp. increases.

As the periphytic diatoms appear to have a high level of variability, it was decided to separate the taxa into attachment groups, rather than habitats, as the literature suggests periphytic diatoms are unselective in their substrate (Winter and Duthie, 2000). Stalked attachment taxa in this study are principally *Gomphonema sp., Eunotia sp.* and *Achnanthidium minutissimum.* Most of the motile taxa fall within the genera *Pinnularia* sp., *Navicula* sp. and *Sellaphora* sp. To assess changes in the water level, diatom taxa were categorized according to their moisture preference (Van Dam et al., 1994). Overall aerophilous taxa are low (<5%), which indicates that the sediments are relatively wet for most of the year. A CONISS analysis was performed to cluster the samples, which identified three main zones and roughly follows the changes in the sedimentology.

<u>BLM01D1 (85-68 cm)</u>

This zone is dominated by *Staurosira construens* var. *venter* and *Staurosira* cf. *elliptica. Pseudostaurosira brevistriata* appears to decrease towards the top of the zone, while *Achnanthidium minutissimum* is increasing; *Gomphonema angustum* occurs irregularly at higher abundances (c.10%). Towards the bottom of the zone there are a few *Aulacoseira distans* frustules (<0.5%) and planktonic *Cyclostephanos dubius*, indicating that the site had occasional input from water bodies (Van Dam et al., 1994). *Stauroforma exiguiformis* increases towards the top of the zone, together with increases in *Achnanthidium minutissimum* and *Gomphonema sp.*, which is indicative of a higher macrophyte presence in the environment. Aerophilous taxa are present in low amounts (<2%), indicating relatively wet conditions. *Staurosira construens* sp. and *Pseudostaurosira brevistriata* decrease together with other tychoplanktonic diatoms, probably related to clearer water, which could be interpreted as a minerogenic fen.

BLM01D2 (68-20 cm)

The second zone shows further increases of tychoplanktonic diatoms, with occasional occurrences of *Aulacoseira distans* in the lower half of the zone. *Achnanthidium minutissimum* decreases, while *Gomphonema angustum* is less abundant in the lower half of the core. Around this time mesotrophic tychoplanktonic *Staurosirella pinnata* increases slightly, together with increases in prostrate diatoms. Aerophilous diatoms are higher in the bottom part of this zone, where they increase somewhat around c. 40 cm. The excavation indicates that it is probable that sediments relating to the settlement can be found up to 35 cm depth (red dashed line in figure 5.3.2). At the same time there are reductions in *Pseudostaurosira brevistriata* and *Stauroforma exiguiformis*, while *Achnanthidium minutissimum* increases, representative of a reduction in tychoplanktonic diatoms and increasing periphytic diatoms. This trend is probably related to a reduction in the water table, though there are rare occurrences of *Cyclotella distinguenda* and *Fragilaria crotonensis* at the top of the core, coinciding with the start of more clay in the sediments (c. 30 cm).It probably represents a flooding surface. *Fragilaria crotonensis* is indicative of higher nitrogen loading (Saros et al., 2005), indicating that cattle were probably kept on or around the settlement (Shahack-Gross et al., 2007).

BLM01D3 (20-5 cm)

The uppermost zone shows a large reduction in all tychoplanktonic taxa, with increases in both attached diatom groups, represented by increases mainly in *Gomphonema angustum* and *G. subtile* as well as *Planothidium frequentissimum* and *P. lanceolatum*, while motile diatoms remain more or less stable. This is likely related to a shallower environment and increased macrophytes, supporting the geochemistry and sediments in probably indicating the lake drainage. Drainage is supported by increases of broken/dissolved frustules in the uppermost samples to c. 4%, together with increases in aerophilous taxa, indicating a lower moisture content in the sediments (Johansen, 2010).

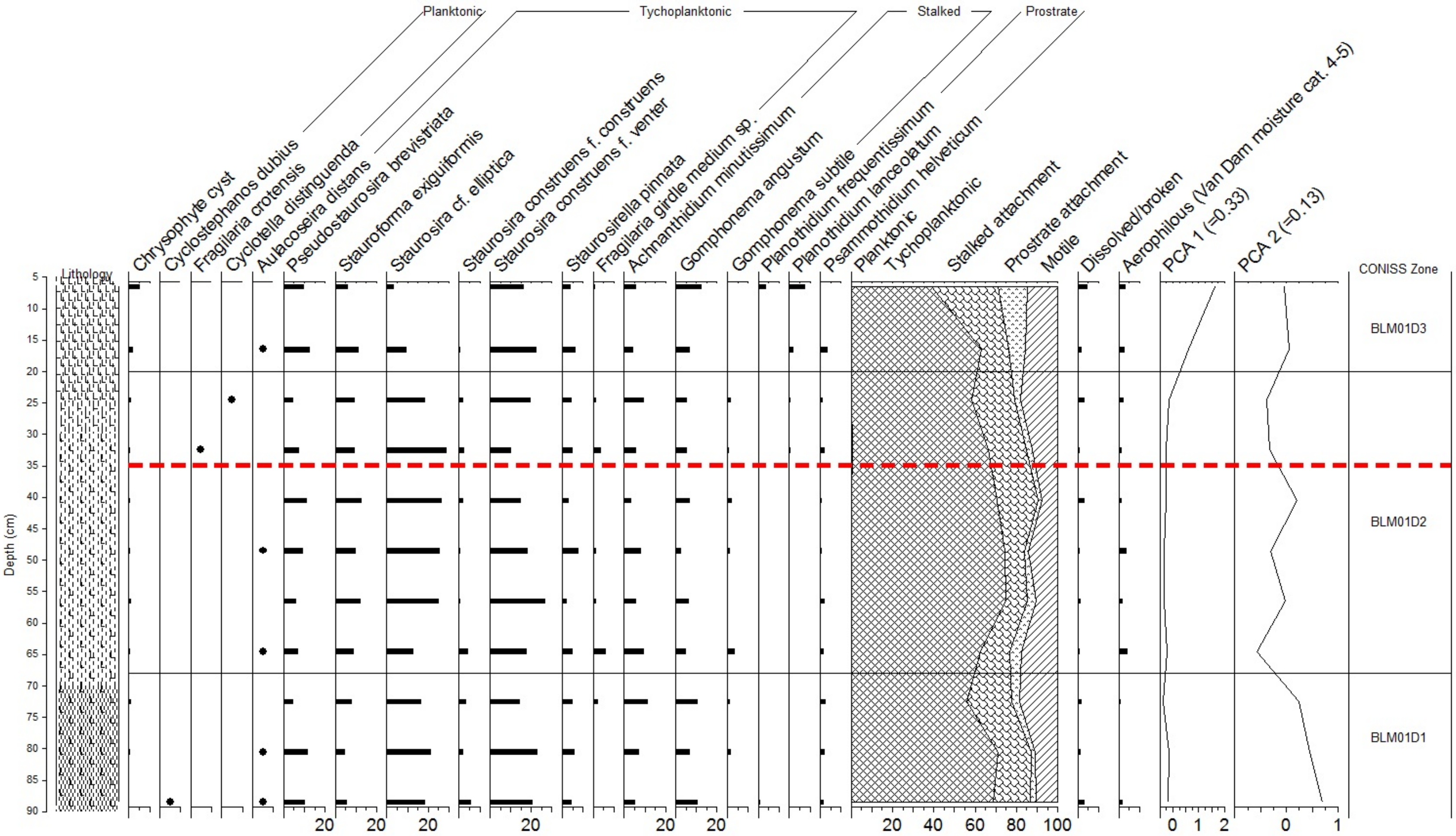


Figure 5.3.2 BLM01 selected diatom taxa (>3%) with attachement groups, PCA axes and CONISS zones

5.3.3.1 Diatom PCA analyses

As a DCA on the taxa occurring at least 1 percent in the assemblages indicated a gradient length of 1.33, a PCA analysis was warranted (Ter Braak and Prentice, 2004, Ammann, 2000). The first PCA axis (λ=0.33) mainly separates the upper two samples and the rest of the core (figure 5.3.2 and figure 5.3.3), where the uppermost sample in particular is strongly related to the first PCA axis. Positively aligned with the first PCA axis are mainly prostrate diatoms, such as *Planothidium frequentissimum* and *P. lanceolatum*, which are common in benthic environments (Round et al., 2007), as well as motile diatoms. Negatively aligned to this axis are mainly tychoplanktonic diatoms, with *Staurosira construens* var. *construens* and *Staurosira* cf. *elliptica* indicative of more turbid water below 30 cm. The second PCA axis appears negatively affiliated to the presence of motile diatoms, for example, *Pinnularia* sp. and *Navicula* sp., which might indicate a higher sediment component (Smol and Stoermer, 2010). As diatom zones BLM01D1 and BLM01D2 are separated principally by the second PCA axis, it might indicate that the bottom zone was deposited during wetter conditions, compared to the middle zone.

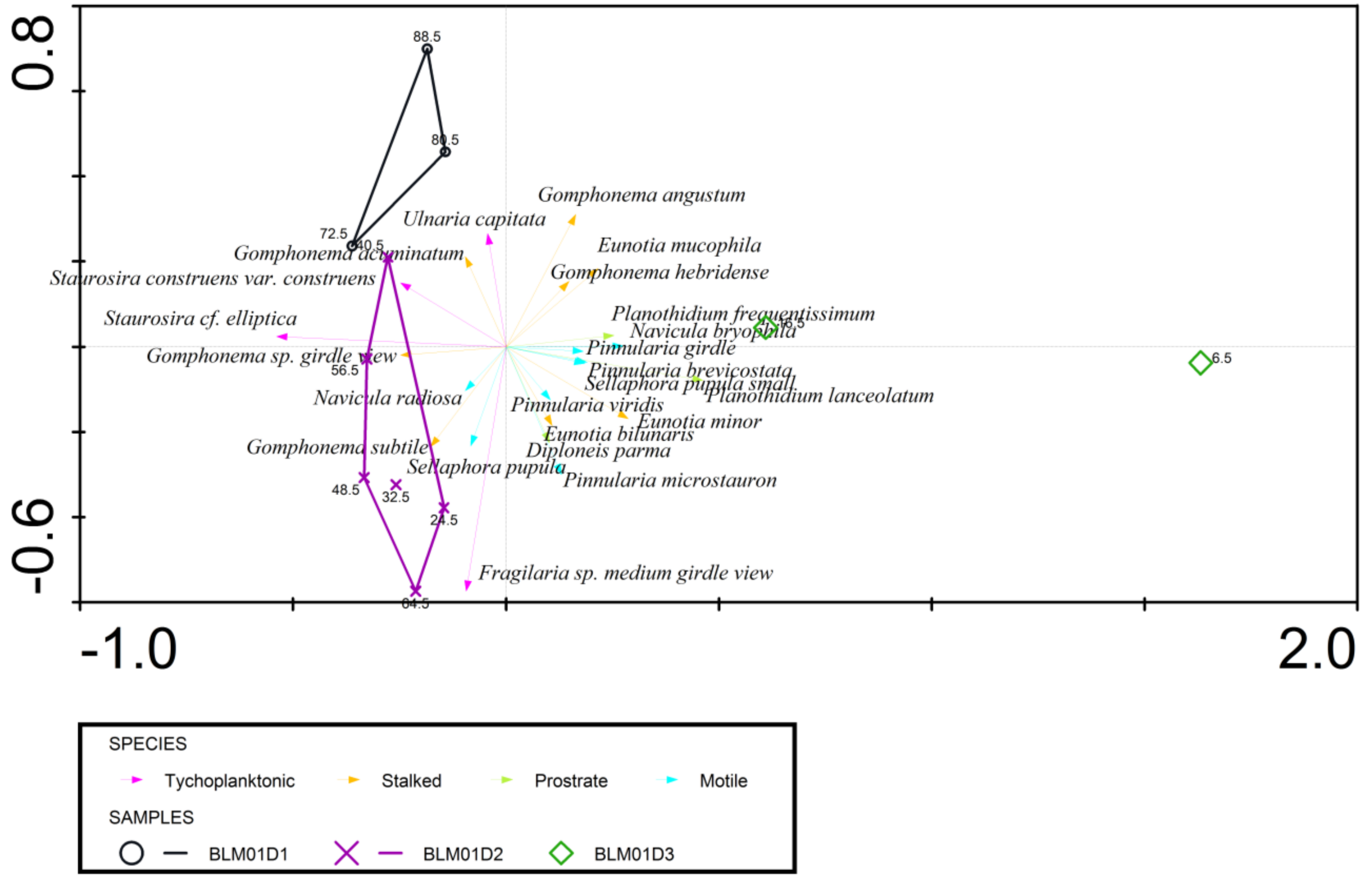


Figure 5.3.3 BLM01 Diatom PCA axes 1 and 2 with taxa (40% fit inclusion) and samples zones

5.3.3.2 Diatom conclusions

The diatom assemblages have been able to identify some key episodes in the core. Overall the core is dominated by periphytic and tychoplanktonic taxa, indicating a very shallow wetland environment, but not a lake. There are rare occurrences of centric genera *Aulacoseira* and *Cyclotella*, which are probably related to floods. The periphytic diatom taxa have been separated into prostrate, stalked and motile diatoms, which allowed closer examination of the assemblages. The bottom zone is probably related to wetter conditions with higher amounts of tychoplanktonic diatoms, while there are more motile diatoms throughout the middle zone, which are indicative of a higher sediment component in the diatom assemblages. However, the most pronounced changes occur at the very top of the core, supported by increases in the first PCA axis, when prostrate taxa increase.

5.3.3.3 Diatom and geochemistry RDA

To assess the relationship between the geochemistry and the diatom assemblages, an RDA was performed as well as a multiple regression. The correlation indicated that several geochemical variables were significantly ($p<0.05$) correlated to the first two diatom PCA axes (table 5.3.2). The correlated geochemical variables are indicative (Rothwell et al., 2006, Croudace et al., 2006) of more resistant sediments (Fe/Rb, Ti/Rb, Ti/kcps and Zr/kcps) or changes in the oxygen availability (Fe/Rb and Mn/Ti). The correlation between changes in sediment components and the first diatom PCA axis (DPCA1) is to be expected, as PCA1 mainly reflects the change in sedimentology in the uppermost part of the core. The second diatom PCA axis (DPCA2) is only significantly correlated to Mn/Ti, indicating that either it is related to increases in oxygen availability, or is possibly a secondary effect of clastic input.

To investigate these relationships further, an RDA analysis was performed using all the significantly correlated geochemical variables to extract patterns from the explained variation (direct gradient analysis). The use of an RDA is justified as the diatom assemblages indicated a linear rather than a unimodal relationship (see previous section).

Table 5.3.1 BLM01 statistics of multiple regression and RDA analysis of geochemistry and diatoms

Significantly correlated environmental variable (correlation $1^{st}/2^{nd}$ axis)	Multiple regression significance level (full model significance)	Multiple regression coefficient	RDA significance
Fe/Rb (DPCA1: 0.93)	<0.001	0.24	Not significant
Mn/Ti (DPCA2: -0.80)	0.006	-0.31	
Ti/kcps (DPCA1: 0.82)	Not significant		
Ti/Rb (DPCA1: 0.92)			
Zr/kcps (DPCA1: 0.78)			0.002

The RDA indicated that only Zr/kcps was significantly influencing the diatom assemblages (table 5.3.1). It shows a strong relationship with the uppermost sample in the core, which is probably a response to a reduced organic component in the sediments (figure 5.3.4). Overall the diatom assemblages show a similar response to the PCA analysis, with the RDA first axis positively associated with prostrate diatoms and negatively with tychoplanktonic taxa. However, the second RDA axis does not separate the bottom two diatom zones, with the bottom zone in a narrow zone towards the left of the axis origin, while samples from zone BLM01D2 are in a similar location, but with a higher degree of variance in its RDA axis scores. The PCA analysis was able to separate these two zones to a much greater degree. This is probably related to the addition of the geochemical variables, which show a lot less variability below 20 cm depth.

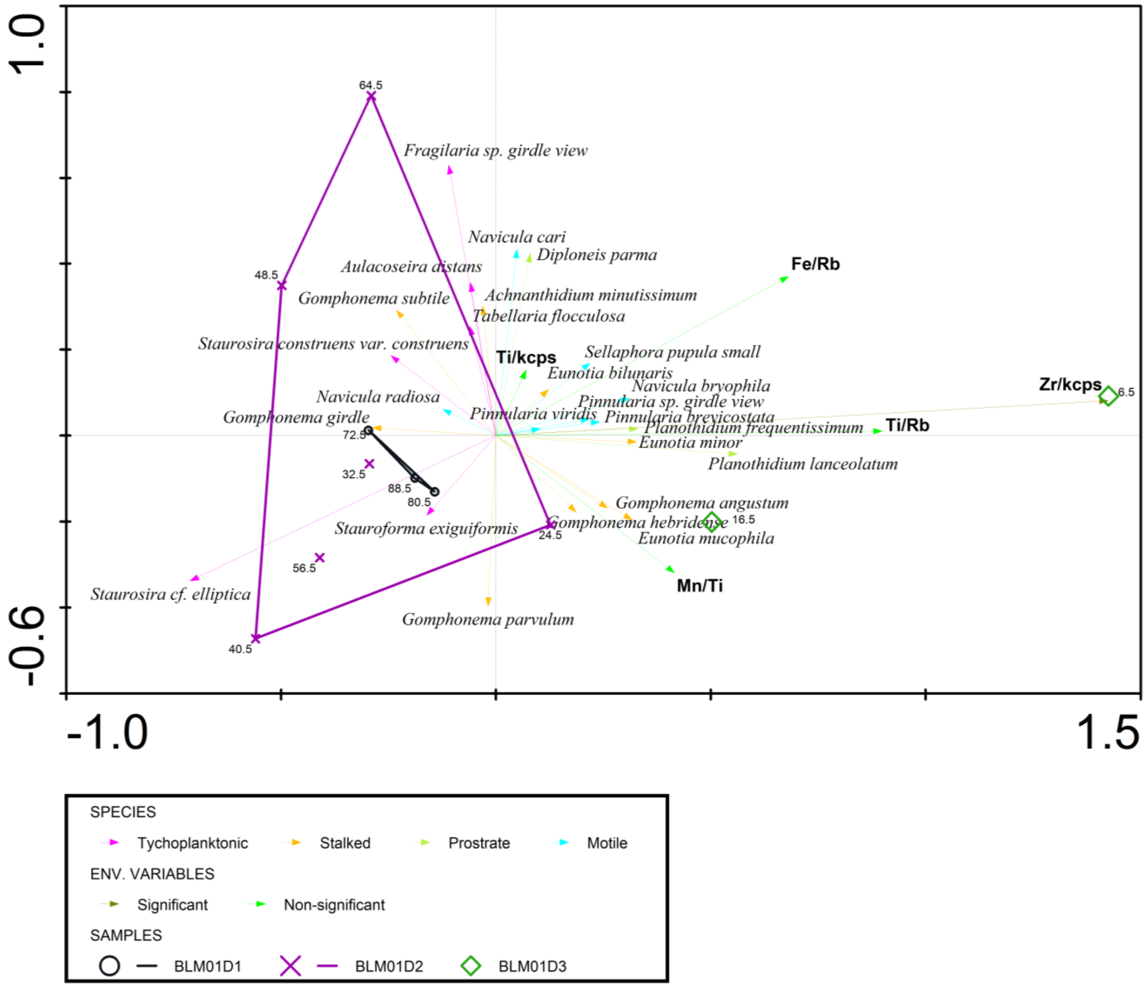


Figure 5.3.4 BLM01 RDA analysis indicating the relationships between the geochemistry and diatom assemblages. The diatom samples are clustered by diatom zone

5.3.4 Pollen

To identify changes in the catchment vegetation, the pollen assemblages of core BLM01 were analysed (figure 5.3.5). Overall the core is rich in non-arboreal pollen, generally below 50%, while the arboreal pollen is composed mainly of shrubs, indicating low woodland cover for most of the period analysed. The dominant taxa are Poaceae and Cyperaceae as well as *Corylus* and *Filipendula* (meadowsweet), which are all common in wet meadows, wet heath or even bogs. The amount of *Quercus* in the core is very low, which is surprising as the excavation indicated that oak was an important part of the timbers used in the construction (Crone and Cavers, 2013) and might indicate either the selective felling of oak trees, or collection of the material from further away. The pollen assemblages are probably from a very local source as it is dominated by wetland vegetation (Prentice, 1985), so it is difficult to estimate where the oak dominated woodlands would have been. Anthropogenic indicators are present throughout the core in low amounts (5-10%) indicating meadows nearby (Behre, 1981) throughout the analysed depths. Given the extensive range of *circa* Iron Age archaeology from the region (e.g. hill fort Fell of Barhullion (Feachem, 1965), standing stones and cists around Blairbuy), as well as the nearby crannog in the White Loch of Myrton (Henderson et al., 2003, Henderson et al., 2006), it is probable that human occupation was fairly widespread in the region. A CONISS cluster analysis was used to establish the three pollen zones.

<u>BLM01P1 (90-36 cm)</u>

The bottom zone encompasses a large period of time and overlaps the sedimentological change around 70 cm depth. The lower samples indicate a decrease in willow pollen, coinciding with a short lived increase in alder around 81 cm depth. The samples in this zone are rich in *Corylus*, Cyperaceae, *Filipendula* and Poaceae. This indicates that the vegetation was probably relatively open, with wet meadows nearby. There is a maximum in *Corylus* pollen around 65 cm depth, after which it slowly decreases. From 81 cm upwards the non-arboreal pollen start to increase towards the top of the zone, driven by increases in sedges and anthropogenic indicators. Heath and willow pollen are relatively stable in the upper part of the zone, though there is a fluctuation around 50 cm depth in the heath pollen. Around 55 cm depth there is a peak in anthropogenic indicators, together with a rare appearance of a *Hordeum* type pollen grain, while at the top of the zone (c. 40 cm depth) there are two more *Hordeum* type grains. Although this precedes the estimated depth of the settlement deposits (35 cm), the increases in NAP are probably related to the processing or storage of cereal grains within the settlement (O'Brien et al., 2005) and/or to zoo-transport of pollen into the settlement, as floor profiles of reconstructed settlements have indicated elevated levels of cultivated and arable pollen types (Macphail et al., 2004). If it is assumed that the cereal pollen more likely represents occupation deposits, settlement deposits would be located around 55-40 cm depth. Apiaceae occur in very low amounts (<3%) in this zone and might be related to the natural vegetation in response to elevated nutrients. *Sphagnum* increases towards the top of this zone, indicating bog development in the catchment. The presence of *Epipactis* (<5%) is difficult to interpret, as the pollen might be marsh helleborine (*Epipactis helleborine*), which is rare in the region (Preston et al., 2002, Hill et al., 2004) although it can occur in disturbed areas.

<u>BLM01P2 (36-20 cm)</u>

This zone shows a recovery of arboreal pollen, with increases in *Alnus*, *Betula* and a few *Pinus* and *Ulmus* pollen. Hazel and heath remain more or less stable, while willow is reduced. There are increases of Poaceae and *Filipendula*, which might be related to establishment of a wet meadow directly near the core, while anthropogenic indicators remain present in low numbers (<5%). This zone is probably indicative of abandonment of the settlement, with the establishment of alder trees and wet meadow species. *Sphagnum* spores decrease at the top of the zone, indicating a reduction in the influx of bog material, which might be related to the drainage activities. Interpretation of this zone is limited, as it probably has been disturbed by drainage activities.

<u>BLM01P3 (20-5 cm)</u>

The uppermost samples are rich in *Alnus*, with a minor increase in Ericaceae. *Filipendula* and Poaceae decrease, while low occurrences of *Pinus* and Ulmus (<3%) remain stable. *Sphagnum* spores decreases further. Although there is a general reduction in non-arboreal pollen, *Humulus*/*Cannabis* type and Apiaceae pollen increase. The presence of hemlock and cow's parsley was identified during the excavation (Crone and Cavers, 2013), so it is likely that the Apiaceae pollen represent these taxa. Furthermore, the settlement will probably have added additional nutrients into the sediments and the presence of Apiaceae is likely related to this (Preston et al., 2002, Hill et al., 2004).

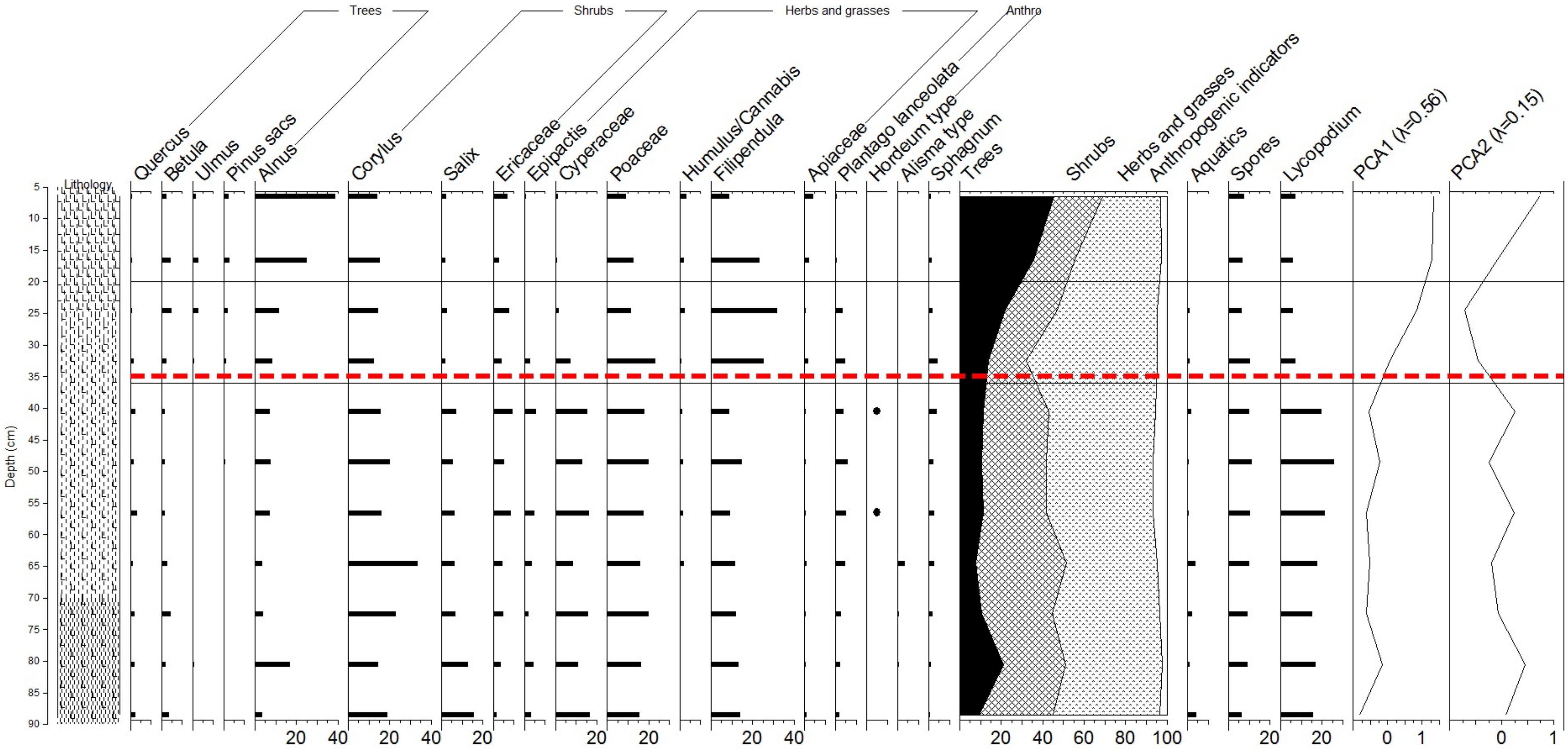


Figure 5.3.5 Pollen assemblages of core BLM01, with CONISS zones and first two PCA axes

5.3.4.1 Pollen and spores PCA analysis

As a DCA analysis on the pollen assemblages indicated a short gradient length (0.87), a linear relationship was more probable and a PCA analysis was used to explore the relationship between the samples and the pollen taxa (figure 5.3.5 and 5.3.6). The major changes in the vegetation, as indicated by the first PCA axis, are probably related to human presence in the region and subsequent abandonment. This first PCA axis (λ=0.56) separates the initial vegetation (Cyperaceae and Salix) indicating an open wetland, while the recent vegetation (*Alnus*, *Pinus*, *Ulmus* and Apiaceae) is on the right of the graph, indicating a more forested environment. The second PCA axis (λ=0.15) is negatively affiliated with *Filipendula* and to a lesser extent *Plantago lanceolata* type and positively with *Sanguisorba minor* and *Epipactis*, as such it is probably related to marshier rather than dryer meadows. As the zone moves from the left of the graph to the lower part and finally the right and upper quadrants, it represents a shift from a mix of woodland and meadows, to more open wet meadows, towards woodlands with some herbs.

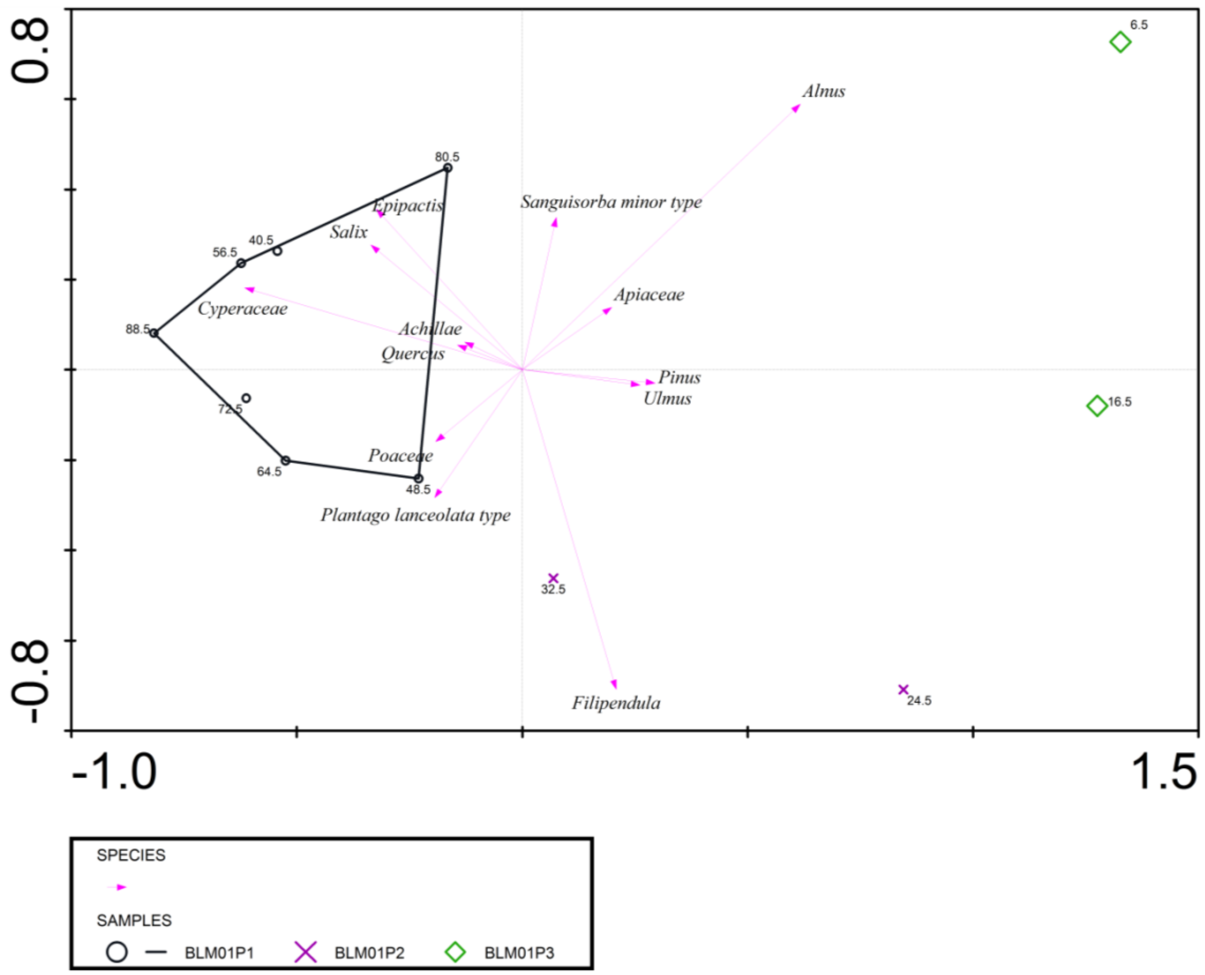


Figure 5.3.6 BLM01 pollen PCA axes with species (>40% fit) and samples grouped per CONISS zonation

5.3.5 Black Loch of Myrton conclusions

The wide range of palaeoecological analyses applied on core BLM01 was able to reconstruct some of the changes on and around the lochside settlement of the Black Loch of Myrton (figure 5.3.7). The sedimentology of BLM01 indicates a steady increase in minerogenic matter, which is in line with most of the pronounced changes in the analyses. The diatom assemblages indicate an occasionally flooded littoral wetland, as indicated by the absence of planktonic diatoms and the dominance of tychoplanktonic and periphytic taxa. This is supported by high amounts of Cyperaceae and *Filipendula* in the pollen assemblages, indicating wet meadows.

The geochemistry at the bottom of the core indicates that sediments are richer in OM, related to low oxygen availability as indicated by the higher Fe/Mn ratio. The diatom assemblages in the lower sediments are rich in tychoplanktonic, stalked and motile taxa, though virtually absent of planktonic diatoms (<0.5%), indicative of subaerial, low conductivity wetland (Round et al., 2007, Gaiser and Rühland, 2010, Johansen, 2010). The core has very high amounts of non-arboreal pollen (c. 40-50%), indicating an open vegetation surrounding the site, though this is probably influenced by a very local signal in the pollen assemblages (Prentice, 1985) and was probably a fen for most of the period analysed. *Corylus* and *Salix* are the main components of the initial arboreal vegetation, though around 80 cm depth there is a limited increase in *Alnus* (c. 16%). As neither *Quercus* nor *Betula* increase at this time, increases in arboreal pollen might be driven by local expansion of alder carr woodland. This is somewhat supported by the occasional occurrence of planktonic diatoms, so it is possibly related to flooding phases, rather than continuous inundation. As aquatic pollen are more common (c. 3%) in the bottom part of the core, a higher water table at this time is probable.

The Fe/Mn ratio decreases towards 70 cm, around the depth minerogenic indicators (Ti/kcps and Zr/kcps) appear to fluctuate, coinciding with increases in *Corylus/Myrica*. The tychoplanktonic diatoms have a maximum around 55 cm depth, after which they decrease. This coincides with increases in motile and stalked taxa above 50 cm depth, which might indicate a higher macrophyte and sediment component in the assemblages, indicative of a wetland or shallow fen environment.

Around the 50 cm depth, there are occurrences of *Hordeum*-type pollen, indicating it is probable that settlement deposits are between c. 55 cm and 40 cm depth. This coincides with reductions in the Fe/Mn and MS, while the OM increases. These fluctuations might be related to the settlement, for instance due to peat compaction or additional organic matter deposition. Aquatic pollen are nearly absent (<0.5%), supporting dryer conditions when these sediments were deposited, which would be favourable for crannog construction. From 50 cm upwards the more resistant minerals increase (Ti/kcps and Zr/kcps), with reductions in the OM. This is probably related to increased decomposition rates, which is probably driven by a lower water table limiting organic matter accumulation (Armstrong et al., 2009, Holden et al., 2004). The diatom assemblages indicate stalked taxa and to a lesser extent motile taxa are increasing, likely related to increased macrophytes. The pollen assemblages indicate a steady increase in non-arboreal pollen and a reduction in aquatic pollen, while shrubs decrease in favour of herbs and grasses. A probable range of settlement deposits would be between 58 and 35 cm depth (indicated by the red screen in figure 5.3.7), based on all the proxies analysed in this study, though the drainage activities on the site have probably influenced the decomposition processes within the sediments. As this zone is followed by occurrences of planktonic diatoms, it might indicate that the site was abandoned following a series of flooding events, which could be explored in the archaeological remains.

Around 25 cm the increases in erosional indicators (Zr/kcps and Ti/kcps) are more dramatic, which is supported by the sedimentology, which has a higher silt component. The diatom assemblages indicate increases in stalked and prostrate diatoms, probably related to a lower moisture content of the sediments. This is supported by a further reduction of tychoplanktonic diatoms, absence of planktonic diatoms and increases in dissolved/broken diatom frustules. A probable explanation is that the sediments above 25 cm depth are heavily influenced by the lake drainage that took place around 1900 AD (Munro, 1885), which supports the initial interpretation that the upper 25 cm of sediment were deposited after 1900 AD. These upper sediments are distinctly different from the rest of the core in all proxies, indicating that recent disturbances have dramatically altered the local ecology, even when compared to previous settlement on the site.

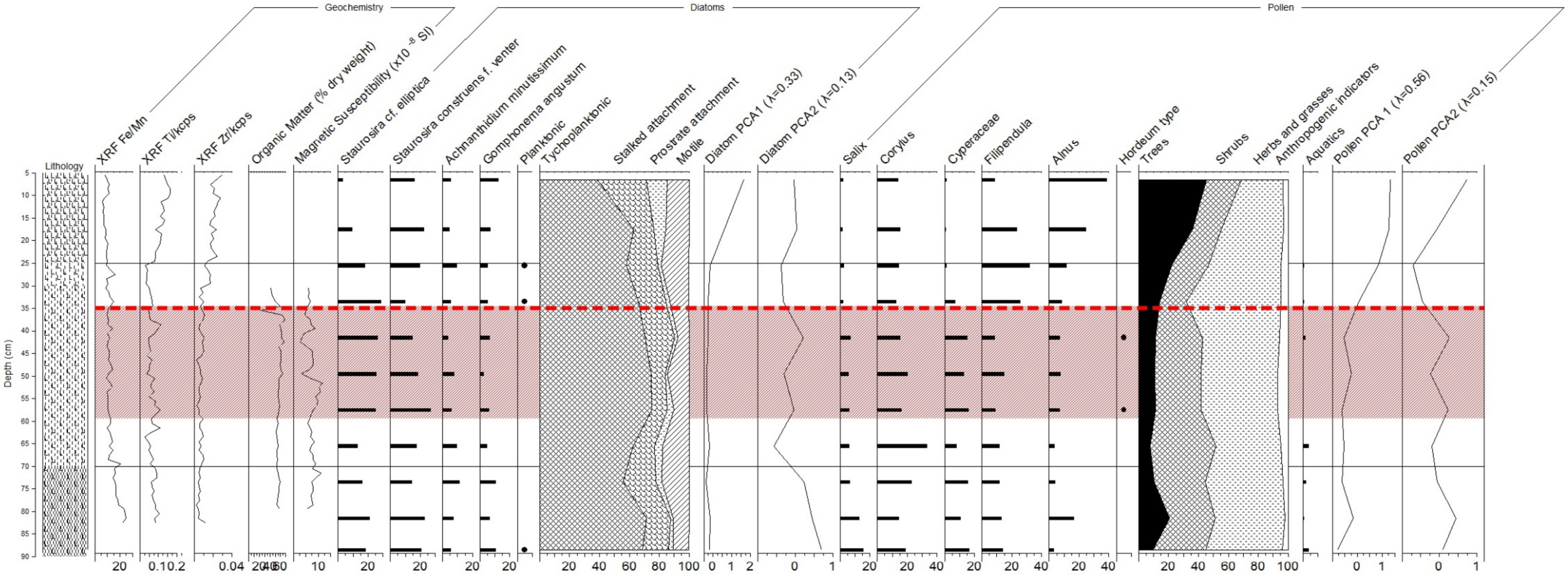


Figure 5.3.7 Summary diagram of the main changes in the geochemistry and pollen and diatom assemblages of BLM01. The red screen highlights the depths with the greatest evidence of crannog related disturbances, while the red dashed line is the upper depth of the archaeological trench nearby

Chapter 6: Results and Discussion – crannogs in Co. Fermanagh

6.1 Derryhowlaght Lough palaeoecology

6.1.1 Chronology

Initially the upper three core sections were analysed. However, four terrestrial plant macrofossil samples submitted to ORAU returned dates younger than the crannog, while one sample did not yield sufficient carbon for analysis and failed to return a radiocarbon date (see table 6.1.1 and figure 6.1.1). This indicated that it was probable that the crannog is located below 196 cm depth which is why a 4th section (DL01S4) was sampled to further the analysis. A problem arises as two ^{14}C dates are nearly identical (1064 ± 28 and 1060 ± 26 ^{14}C yr. BP), indicating possibly very rapid accumulation of sediments and/or mixing of old organic particles with younger sediments for a sustained period. A possible explanation could be that during this interval there was a lot of inwash from old sediments outside of the lake. This might indicate that erosion rates have probably not been constant, but as there is no other chronological markers it will be assumed the radiocarbon dates give the best estimate of the age of the sediments. The pollen assemblages might give an independent estimate of the age-depth. Another issue is that the uppermost sample gave a modern date (22-23 cm, 1.16 BP ± 0), but it is uncertain if samples further down might return modern radiocarbon dates, due to the issues of ^{14}C dating modern material. The Bacon and Clam age-depth models (Blaauw and Christen, 2011, Blaauw, 2010) produced ages at 1 cm intervals. These model estimated that sediments at **236** cm (Bacon) and **239** cm (Clam) had a mean age closest to the median age of the timber from the crannog (1213 cal. Yrs BP). These depths are indicated by the dashed lines (red: Bacon, green: Clam) in the figures describing the palaeoecology of Derryhowlaght Lough.

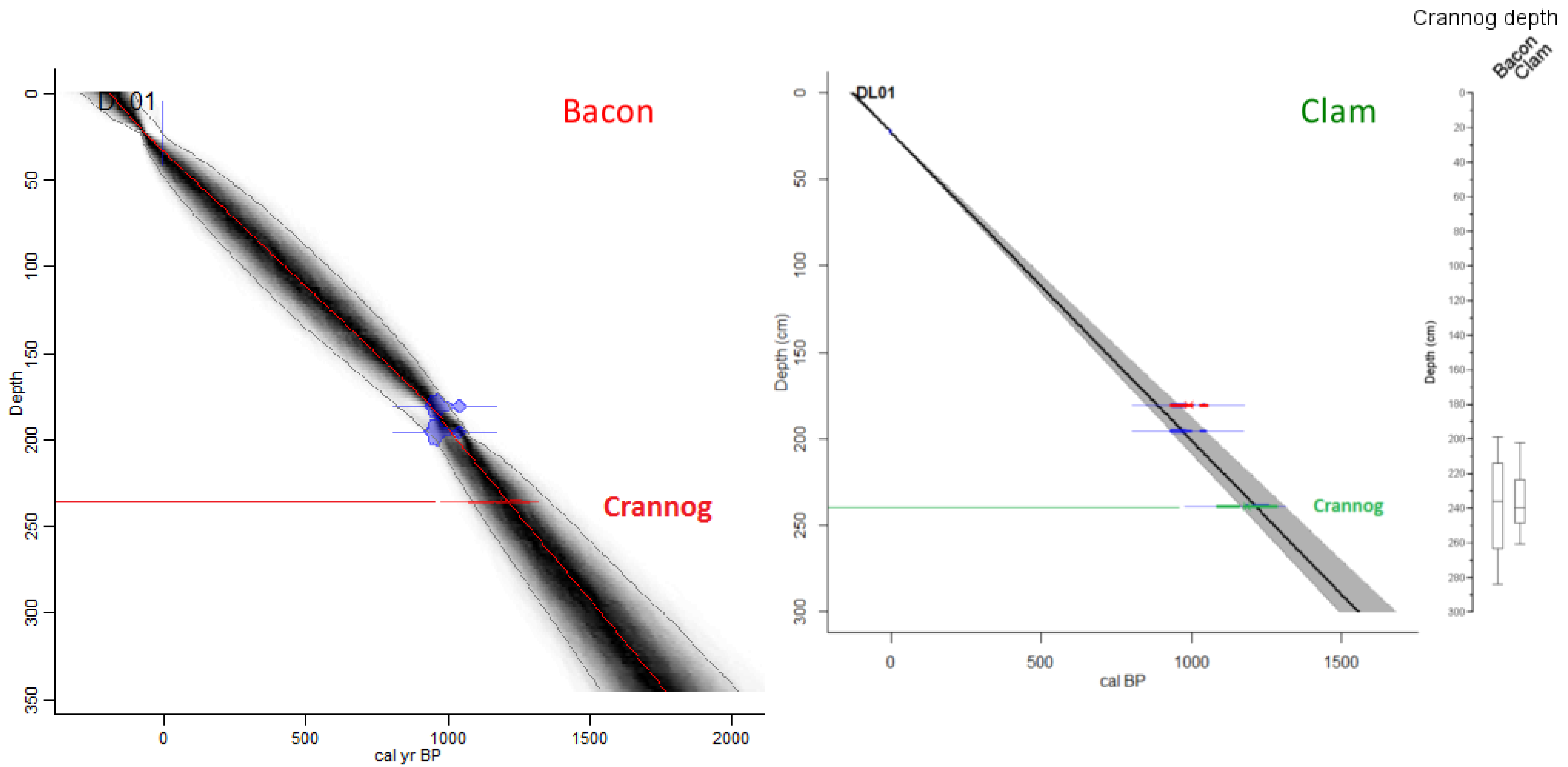


Figure 6.1.1 Radiocarbon age-depth of samples from DL01 using the Bacon age-depth model (right), where the red line indicates the most probable depths of the crannog. The middle graph represents the Clam age-depth model, with the green line the Clam based crannog depth estimate. The right boxplots represent the uncertainty of the age models and the crannog radiocarbon dates. The tails (or whiskers) indicate the full range of sediments which might be dated to the crannog (α=0.0025), while the boxes indicate sediments that might be dated to the median age of the crannog (α=0.05). The horizontal lines near the middle of each of the boxes represent the samples with a mean age closest to the median age of the radiocarbon date of the crannog

Table 6.1.1 Radiocarbon dates from Derryhowlaght Lough

Sample name and depth	Material	Radiocarbon date yrs. BP ($\delta^{13}C$)	Calibrated age range, 95% (median)
Derryhowlaght Lough Crannog (Q8803)	alder	1262 ± 38 (-30.177)	667-867 AD (767 AD)
DL01 22-23 cm (OxA 34537)	Leaf matter	1.16199 ± 0.00326 (-29.2)	1952-1955 AD (1953)
DL01 80-81 cm (OxA 34538)	Leaf matter	Failed, low yield	
DL01 180-181 cm (OxA 34539)	Leaf matter	1064 ± 28 (-32.0)	898-944 AD (921 AD)
DL01 195-196 cm (OxA 35552)	Roundwood	1060 ± 26 (-2604)	900-1023 AD (962 AD)

6.1.2 Geochemistry

The results from the loss-on-ignition, magnetic susceptibility and X-ray Fluorescence analyses are summarized in figure 6.1.2. Apart from the upper part of the core and a section around 135 cm depth, the core is moderately high in Organic Matter content (OM, >40%) as indicated by the LOI_{550}, which is related to the preservation of the OM, as well as increases in minerogenic content (Dean, 1974). The carbonate content (LOI_{950}) is consistently low (<8%) throughout the core, probably related to the high amount of organic matter and humic/acidic material in the core. Increases in the carbonate content are most likely coinciding with reduced organic matter content and slightly higher sediment pH. Below 210 cm depth, the core appears to have had a stable OM of about 50%. The estimated crannog phase (red dashed line at 231.5 cm depth) coincides with a slight reduction in the OM, possibly driven by increased erosion of minerogenic matter from the site. However, between 210 and 139 cm depth, the core seems to fluctuate between 35% and 80% OM. If the crannog was occupied during this period, it is more likely that erosion rates increased, possibly coinciding with increased disturbances in the catchment, reducing the organic matter content. There is a distinct interval between 139 and 133 cm depth where the OM content drops to below 35%. Above this interval the OM increases again and appears more stable, fluctuating around 45-65%. From c. 46 cm depth the OM decreases, though it is still fluctuating. The upper 10 cm of the core has distinctly lower OM than the rest of the core, around 25-30%, indicating increases in minerogenic matter.

The MS record indicates that the core has a very low MS, though there are fluctuations, related to increases in ferromagnetic and canted antiferromagnetic sediment (Dearing, 1999). Below 250 cm depth the MS appears to decrease, though it fluctuates slightly with a short-lived stable phase around 240 cm depth, with slightly lower MS values, coinciding with a minor increase in the OM. These sediments are near the depth where the age-depth model estimates crannog associated with the crannog are located, but are difficult to interpret. After a short term increase around 220 cm, the MS record decreases further up to 198 cm. This is followed by an interval of distinct fluctuations (c. 163-185 cm depth). The majority of the core above 163 cm depth is characterised by a low MS, with a particularly stable and low interval between 131 and 115 cm depth, followed by a distinct peak between 115 and 100 cm depth. Finally the top of the core shows a steady increase in MS, from around 12 cm depth. As the organic matter content decreases, coinciding with increases in the MS, it is likely that this is driven by increased erosion rates, which is a common feature of modern sediments in many lakes.

The XRF record (figure 6.1.2) indicates both fluctuating sedimentation regimes as indicated by the Ti/kcps, K/Rb (Croudace et al., 2006, Rothwell et al., 2006), as well as periods with a high influx of water from semi-enclosed basins, such as peatlands (Björkvald et al., 2008), as indicated by increases in the Mn/Ti. The lower part of the core (up to c. 210 cm depth) appears to have a higher Cu/kcps counts compared to the rest of the core, indicating it has been subjected to diagenetic reactions (Rothwell et al., 2006, Croudace et al., 2006), so care has to be taken in the interpretation of this section. At these depths the ratio of calcium and minerogenic matter (Ca/Fe) is higher than higher up in the core, indicating its sedimentology is different from higher parts of the core and indicating more alkaline conditions (Croudace et al., 2006, Rothwell et al., 2006). The K/Rb indicates changes within the clay composition, with K more common in detrital clays. Between 245 and 235 cm there is a marked decrease in the K/Rb ratio.

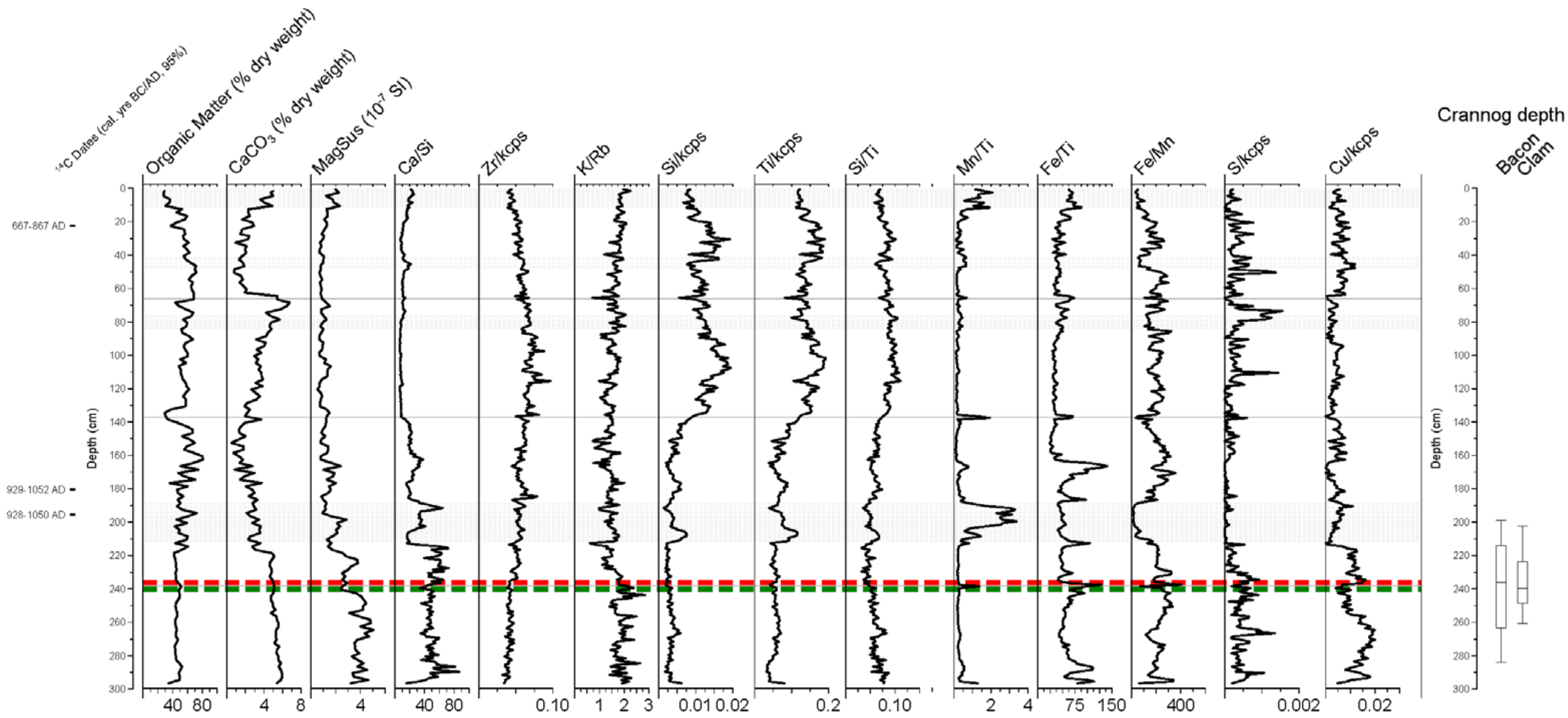


Figure 6.1.2 Geochemical data of core DL01, with the estimated crannog depth indicated by the dashed lines. The greyed lines and areas indicate periods with a low Fe/Mn. On the far right the box plots represent the maximum extend of the crannog radiocarbon dates

Around 240, 140, 70 and 45 cm depth and between 210 and 190 cm depth, there are marked increases in the Fe/Mn ratios (dark red line in 6.1.2), mainly driven by increases in Mn (Mn/Ti). This is probably not related to changes in the oxygen saturation, as shallow lakes are continuously circulated (Scheffer, 2004). This is supported by water chemistry measurements, which indicated 100% oxygen saturation. Rather, increases in manganese are probably related to the increased influx from peatlands. The increases in manganese in the lake might be related to the build-up of manganese in peatlands during winter, before it is released into streams and lakes during spring flooding (Björkvald et al., 2008). When looking at all the geochemical records, around 140 cm depth there is a major change in the sediments, while between 260 and 140 cm there are erratic fluctuations. Above 140 cm sediment depth the Si/Ti ratio increases, together with Ti/kcps as well as a reduction in Ca/Fe. This indicates an increase in more resistant minerals, thus it can be inferred that the erosion rates must have increased as well. An interpretation could be that disturbances to the record started at a depth of c. 260 cm, preceding the crannog, with disturbances leading to fluctuations in the sediment record until about 140 cm, where the record appears to stabilize.

6.1.3 Diatoms assemblages and CONISS zonation

Diatom assemblages were analysed for the main taxa and their habitat groups, to analyse changes in predominant diatom habitat type (figure 6.1.3). Taxa occurring in high abundances (>15%) are *Staurosira cf. elliptica, Staurosira construens f. venter, Aulacoseira ambigua, Cyclostephanos dubius, Handmannia radiosa* and *Stephanodiscus* cf. *minutulus/parvus*. The genera *Pseudostaurosira* and *Staurosira* belong to the group that previously encompassed the genus *Fragilaria* (Krammer and Lange-Bertalot, 2000), which is predominantly tychoplanktonic. The taxon *Staurosira cf*. *elliptica* is an amalgamation of small morphotypes (<5 µm) of several fragilarioid taxa, as these proved too difficult to separate underneath the light microscope. Only clear examples of small *Pseudostaurosira brevistriata* and *Staurosirella pinnata* were excluded from these counts.

The genus *Aulacoseira* is also considered tychoplanktonic. Tychoplanktonic taxa are periphytic but easily detached when disturbed, which is when they will be planktonic. These tychoplanktonic taxa are often indicators of turbid waters or changes in lake circulation, but can occur in a range of trophic levels. *Aulacoseira alpigena* is oligotrophic, while *Aulacoseira granulata* is more often found in mesotrophic-eutrophic systems.

Cyclostephanos dubius and *Handmannia radiosa* complex are euplanktonic taxa, which can be found in the water column. Several taxa can indicate higher nutrients in the lake. The genus *Handmannia* (Khursevich and Kociolek, 2012) is separated from the main *Cyclotella* genus, though initially incorrectly named *Puncticulata (Häkansson, 2002)*, based on the areolate central area consisting of areolae and valve face fultoportulae as well as marginal striae and interstriae of different length and thickness. Due to taxonomic difficulties separating the taxa of the *Handmannia* genus under the light microscope (e.g. *H. radiosa*, *H. comta* and *H. balatonis)* these taxa were grouped in the *H. radiosa* complex (Genkal, 2013), as these taxa have relatively similar ecological preferences (i.e. oligo- to mesotrophic nutrient preferences, winter/spring bloom).

Finally the main diatom species can be investigated with regards to nutrients in the lake. For example, *Fragilaria capucina*, *Cyclostephanos dubius*, *Handmannia radiosa* and *Stephanodiscus minutulus/parvus* are mesotrophic with regards to phosphorous loading (Hall et al., 1999, Bradshaw and Anderson, 2003), while *Fragilaria crotonensis* is indicative of higher nitrogen concentrations in the lake (Interlandi and Kilham, 1998, Saros et al., 2005). Increases in these mesotrophic taxa indicate eutrophication might have taken place in the lake, especially in the upper samples. This will be discussed further, following the zonation based on a CONISS cluster analysis. This indicated that the samples might be split into five zones. A PCA analysis was also performed to interpret general changes in the diatom assemblages throughout the core.

<u>Zone DL01D1 (290-262 cm)</u>

This zone is characterised by initially high amounts of *Handmannia radiosa* complex, together with small abundances of fragilarioid taxa (*Staurosirella pinnata*, *Pseudostaurosira brevistriata*, *Staurosira* cf. *elliptica* and *Staurosira construens* f. *venter*) as well as low abundances of achnanthoid taxa (*Achnanthidium exiguum*, *Achnanthidium minutissimum* and *Planothidium frequentissimum*). This phase has mesotrophic nutrient loading as inferred from *Handmannia radiosa*. There appears to be a reduction of planktonic taxa in favour of tychoplanktonic taxa towards the top of the zone. There is a low abundance of Chrysophyte cysts, indicating some macrophytes nearby and possibly cooler conditions (e.g. Lotter, 1989).

Zone DL01D2 (262-200 cm)

These samples have most probably been deposited around the time of the crannog (c. 236 or 239 cm depth, dashed lines in figure 6.1.3), based on the age model estimates. These samples show a continuation of the reduction of the taxon *Handmannia radiosa* complex, being replaced by tychoplanktonic taxa *Staurosira* cf. *elliptica* as well as *Staurosira construens var. venter.* There appears to be a maximum in *Staurosirella pinnata*, which has a slightly higher nutrient loading than other small fragilarioid taxa and is commonly found attached to sand grains, possibly indicating an influx of coarser sediments. This zone is probably influenced by the same disturbances picked up in the sediment, as they show a decrease in OM and an increase in MS, indicating an interval with increased erosion rates. If the increased erosion rates are driven by higher land run-off, it probably led to increased water column mixing, explaining the increases in *Staurosira* cf. *elliptica*. There are moderate increases in the abundance of Chrysophyte cysts. The increases in tychoplanktonic taxa and Chrysophyte cysts during this zone might also be interpreted as a shallowing phase, which could thus be related to the crannog construction/occupation phases.

Zone DL01D3 (200-182 cm)

This zone consists of only one sample with is distinctly different from the lower samples. *Handmannia radiosa* has more or less disappeared, being replaced by *Cyclostephanos dubius,* which has a higher nutrient optimum (e.g. Håkansson et al., 1998). The achnanthoid taxa have been replaced by other periphytic species: *Gomphonema minutum* and *Eunotia* sp., which are predominantly epiphytic taxa. The small tychoplanktonic fragilarioid taxa have more or less been replaced by *Fragilaria capucina* and *Aulacoseira* sp. (*A. ambigua* and *A. alpigena*). This zone could be interpreted as a higher human impact phase, with increased macrophytes and nutrient loading as indicated by *Fragilaria capucina*. However, the radiocarbon dates indicate that these depths are probably c. 200-300 years after the construction of the crannog. These sediments will be explored further via the pollen assemblages to determine if this diatom zone has increased human activity in the catchment or was driven by activities associated with the crannog.

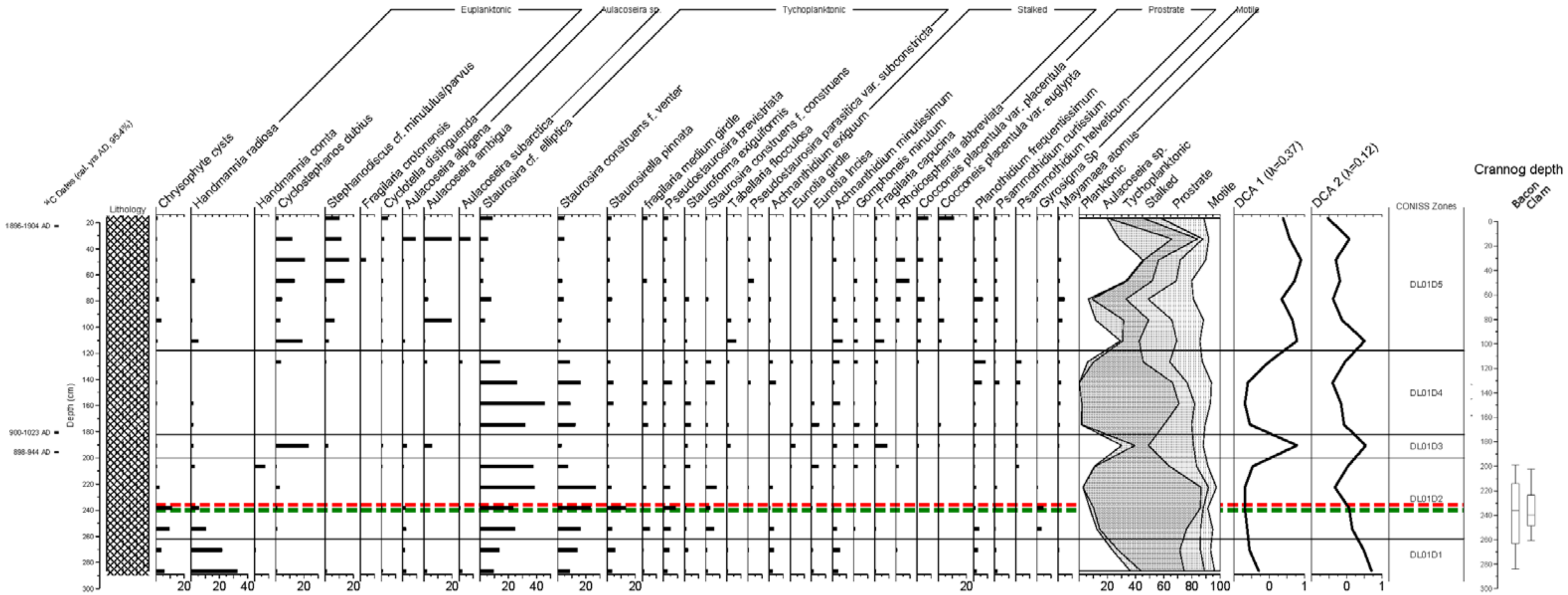


Figure 6.1.3 Diatom assemblages, PCA axes and CONISS zonation from core DL01. The red dashed line indicates the estimated depth of crannog-related sediments

Zone DL01D4 (182-118 cm)

This zone shows a distinct increase in *Staurosira* cf*. elliptica*, together with other fragilarioid taxa. This interval is characterised by the almost complete absence of planktonic taxa. At the same time this zone shows short-term increase in the abundance of *Staurosira* cf*. elliptica*, which peaks around 158 cm, after which it decreases. Following the decrease of the small *Staurosira* cf. *elliptica*, other slightly larger tychoplanktonic taxa appear in higher abundances (i.e. *Staurosira construens var. venter*, *Staurosira construens var. construens* and *Pseudostaurosira brevistriata*). Towards the top of this zone, the tychoplanktonic abundances decrease rapidly, while the other lifeform types increase (figure 6.1.3). Specifically, there are increases in *Eunotia* sp., *Psammothidium curtissimum*, *Psammothidium helveticum, Planothidium frequentissimum, Achnanthidium minutissimum* and *Achnanthidium exiguum*. The increase in epipelic diatoms is not solely driven by a few dominant taxa, but additionally by many taxa occurring less than 1%. In particular, this zone contains small amounts of *Navicula lanceolata*-type taxa, which in this core consist of *Navicula lanceolata*, *N. leptostriata, N. capitatoradiata*, *N. cryptocephala*, *N phyllepta* and *N. angusta*. These *Navicula* taxa are common in benthic environments and are generally mesotrophic to eutrophic and are often capable of surviving high organic matter content in the sediments.

Zone DL01D5 (118-10 cm)

The upper part of the core is characterised by a continuing trend of reduced tychoplanktonic diatoms, while at the same time there are increases in planktonic taxa and a continued increase in periphytic taxa for most of the core. However, there are several distinct shifts in planktonic taxa instead of a continuous increase. The zone starts with an increase in *Cyclostephanos dubius* frustules, coinciding with increases in *Cyclotella radiosa*, *Tabellaria flocculosa*, *Fragilaria capucina* and *Achnanthidium minutissimum*. This is followed by a short interval with increases of *Aulacoseira ambigua* and *Stephanodiscus minutulus*, indicating increased nutrient levels and more turbid waters. Around 64 cm depth there is a distinct increase in *Rhoicosphenia abbreviata*, a periphytic taxon common on both *Cladophora* filaments and epilithic in streams (Levkov et al., 2010, Lange-Bertalot, 1980). This coincides with increases in eutrophic and mesotrophic *Stephanodiscus minutulus* (Kilham and Kilham, 1978) and *Cyclostephanos dubius*, which remain dominant until around 32 cm depth. The top of the core indicates reductions in meso- to eutrophic planktonic taxa, while *Aulacoseira* sp. taxa increase in abundance. At the very top these planktonic taxa are reduced in abundance, coinciding with increases in *Cocconeis placentula* sp., a benthic diatom that is often related to lotic ecosystems (Anyam, 1990). These upper samples might indicate a shallowing phase with increased periphytic taxa.

6.1.3.1 Diatom PCA analyses

The PCA results are presented in figure 6.1.4. As the initial DCA analysis indicated a gradient length of the first axis of 1.7, it was chosen to perform a PCA analysis. The PCA analysis indicates that the first axis, though only explaining a small amount of the variance (λ=0.37), is separating samples with either predominantly tychoplanktonic or planktonic taxa, such as *Cyclostephanos dubius* and *Stephanodiscus minutulus/parvus*. Whether this axis represent changes in turbidity or a mainly planktonic algal phase is not clear, as there is some overlap and the eigenvalue is quite low. The second axis (λ= 0.12) appears to separate tychoplanktonic taxa (i.e. *Aulacoseira* sp. and *Tabellaria quadriseptata*) and periphytic taxa (i.e. *Cocconeis placentula* sp. and *Planothidium lanceolatum*).

When looking how the CONISS zones are represented on the axis it is evident that the bottom zone (DL01D1) has a strong relation with the *Handmannia radiosa* complex and the bottom zone has high loadings on the second PCA axis and moderate negative loadings on the second axis. The second zone shifts towards the right of graph with high negative loadings on the first axis. The third zone (sample 190.5 cm depth) indicates a singular sample which is surprisingly similar to the sample at 110.5 cm depth. The fourth zone shift from near the second zone towards the right, indicating a shift towards more meso- to eutrophic diatoms. The top zone is located on the far right of the graph and has a strong relationship with the various meso- to eutrophic diatoms (i.e. *Cyclostephanos dubius* and *Stephanodiscus minutulus/parvus*). From this interpretation it can be inferred that the diatom assemblages are mainly driven by changes in turbidity and nutrients in the lake. The sample at 190.5 cm depth is peculiar as it appears similar to the first sample of the upper zone (110.5 cm). The samples closest to the crannog (238.5 and 222.5 cm) are on the far left of the graph, indicating they are heavily impacted by local turbidity.

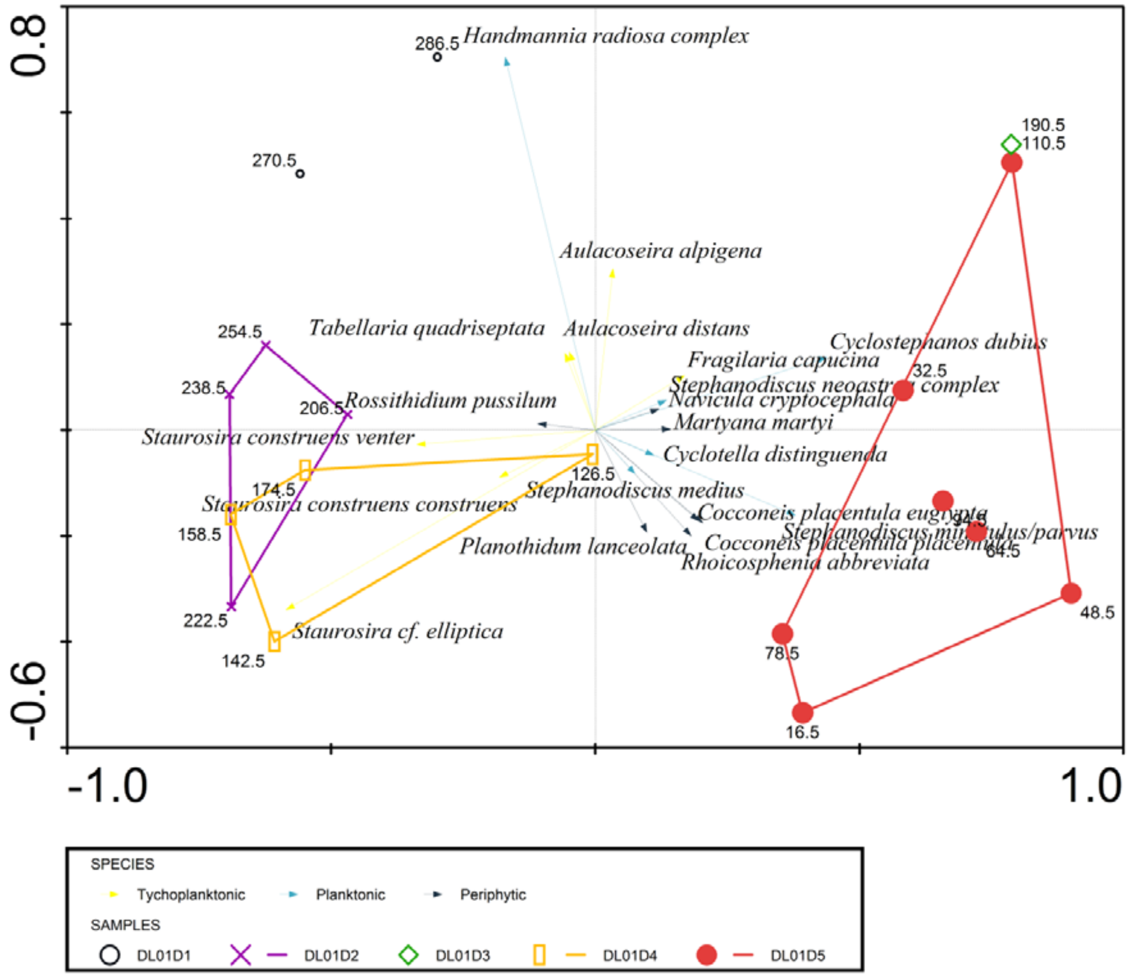


Figure 6.1.4 A biplot of PCA axes from the diatom assemblages of core DL01, indicating both species (>45% species weight) and samples. The samples are labelled according to their zone

6.1.3.2 Diatom interpretations

The diatom assemblages in core DL01 shows distinct shifts between planktonic, tychoplanktonic and benthic taxa. The bottom of the core (zones DL01D1-DL01D2, figure 6.1.3 and figure 6.1.4) shows a reduction in planktonic taxa, which is probably due to reduced water levels and increased turbidity. This part of the core probably is due to changes in the catchment as well as the construction of the crannog. This led to increased erosion rates as well as local shallowing, which appears visible in the core with the reduction in *Handmannia radiosa* complex, coinciding with increases in tychoplanktonic *Staurosira* cf. *elliptica*. As the core was taken less than 5m from the crannog, it is highly likely influenced by local disturbances. The middle part of the core was subject to shifting ecological pressures, which led to a brief interval with a high abundance of planktonic diatoms. However, the majority of the lower section of the core is dominated by tychoplanktonic and benthic taxa. This section of the core is dominated by *Staurosira* cf*. elliptica*, which is a small fragilarioid diatom. As previously discussed by Sayer (Sayer, 2001), this taxon has a wide range of nutrient preferences and is common in oligotrophic lakes, during the Late-Glacial (Haworth, 1975, Marciniak, 1986), but also eutrophic lakes eutrophic (Moss, 1988, Bennion, 1994) which means it is difficult to interpret changes in the trophic status of the lake (Fritz et al., 1993, Hall et al., 1997).

Sayer (2001) notes that small fragilarioid taxa have been described as both periphytic and tychoplanktonic (Lowe, 1974, Barker et al., 1994b), but based on his own research suggests that they are “bottom-dwelling forms which are loosely attached to stable sediment surfaces and the bases of emergent macrophytes” (Sayer, 2001). Difficulties with the taxonomy under the light microscope means that this taxon probably encompasses multiple diatom taxa (Morales et al., 2010). Lakes with a high amounts of araphid diatoms are often shallow, low-to-medium alkalinity lakes with a large amount of overlap in the assemblages (Bennion et al., 2004a).

Towards the upper part of the core there is a distinct reduction in *Staurosira* cf*. elliptica* in favour of planktonic taxa. This is probably related to increasing nutrient input into the lake, as the centric taxa that start occurring at the top (*Cyclostephanos dubius* and *Stephanodiscus minutulus*), are mesotrophic to eutrophic. However, at the very top of the core these planktonic taxa decrease and are replaced by less the eutrophic *Aulacoseira* sp. and finally benthic *Cocconeis placentula* varieties, with both taxa common in fluvial environments. *Cocconeis placentula* is mainly an epiphytic taxon, common in freshwater stream, thus a possible explanation for the reduction in planktonic taxa might be an apparently lower water level. This is slightly strengthened by increases in benthic and tychoplanktonic taxa. At present the top of the core is not accurately dated, so whether the top sediments are related to increased flooding and shallowing of the lake during the 20th century is uncertain. As the river Erne has been subjected to water management since the 19th Century, it is likely that the hydrology of the lake has also been influenced. This could be a potential reason for increases in *Cocconeis placentula* sp. as it is normally common in benthic environments and attached to plants. A lower water level would likely lead to a relative increase in shallow environment.

6.1.3.3 Diatom and geochemistry RDA

To better understand the relationship between the geochemistry and the diatom assemblages in Derryhowlaght Lough, correlations and a multiple regression was run using backward elimination. This identified Si/kcps as the main significant variable influencing the diatom PCA (see table 6.1.2). This can be achieved by running a RDA analysis, using the geochemistry as environmental variables and the diatom assemblages as species variables. An RDA was applied as the species data DCA had a gradient length of less than 2, warranting a linear gradient analysis. Some of the results of the multiple regression are shown in figure 6.1.5 and table 6.1.2. It indicates some interesting relationships between the XRF data and specific diatom groups.

Four of the variables had a significant relationship to the first diatom PCA axis, which are: MS, Si/Ti, Si/kcps, Ti/kcps and Zr/kcps. However, when backward elimination was performed until only significant variables remained, only Si/kcps was left, indicating it is probably the main driver of diatom variance. When looking at the second diatom PCA axis, only one variable is significantly correlated: Ca/Si. This variable would appear to be mainly a secondary effect of the inverse of erosional indicators Ti, Rb and Si, with some minor influence of calcium in the sediments.

Table 6.1.2 Statistics on geochemical variables used in the RDA and multiple regression

Significantly correlated environmental variable (correlation 1st/2nd axis)	**Multiple regression significance level (full model significance)**	**Multiple regression coefficient**	**RDA significance**
Si/Ti (PCA1: 0.6)	*Not significant*		
Ti/kcps (PCA1: 0.67)			
Ca/Si (PCA2: 0.55)	0.0187	0.197	
MS (PCA1: -0.64)	*Not significant*		*0.001*
Zr/kcps (PCA1: 0.52)	*Not significant*		0.046
Si/kcps (PCA1: 0.69)	0.0017	0.432	0.001

In the diatom RDA, all the significantly correlating variables were used to determine the relationship between these and the diatom assemblages. The graph shows that all these variables are mainly aligned with the first diatom PCA axis. However, the most significant variables aligned to the first PCA axis are MS, Zr/kcps and Si/kcps.

At the right of the graph, there are several other erosional indicators, with increases in XRF Si/kcps and Ti/kcps related to increases in several small planktonic diatom taxa (e.g. *Cyclostephanos dubius* and *Stephanodiscus minutulus*/*parvus*), as well as several benthic taxa (e.g. *Cocconeis placentula*) in these uppermost samples. As the planktonic taxa (right of the graph, diatom zone DL01D5) differ in their axis score from the planktonic taxa in the bottom of the core (upper left of the graph, diatom zone DL01D1), it is probable that they are separated by different nutrient requirements. This is probably related to different pH (as indicated by the Ca/Si ratio) and different levels of eutrophication (e.g. *Handmannia radiosa* complex is oligotrophic to mesotrophic, while *Stephanodiscus minutulus*/*parvus* is mesotrophic to eutrophic).

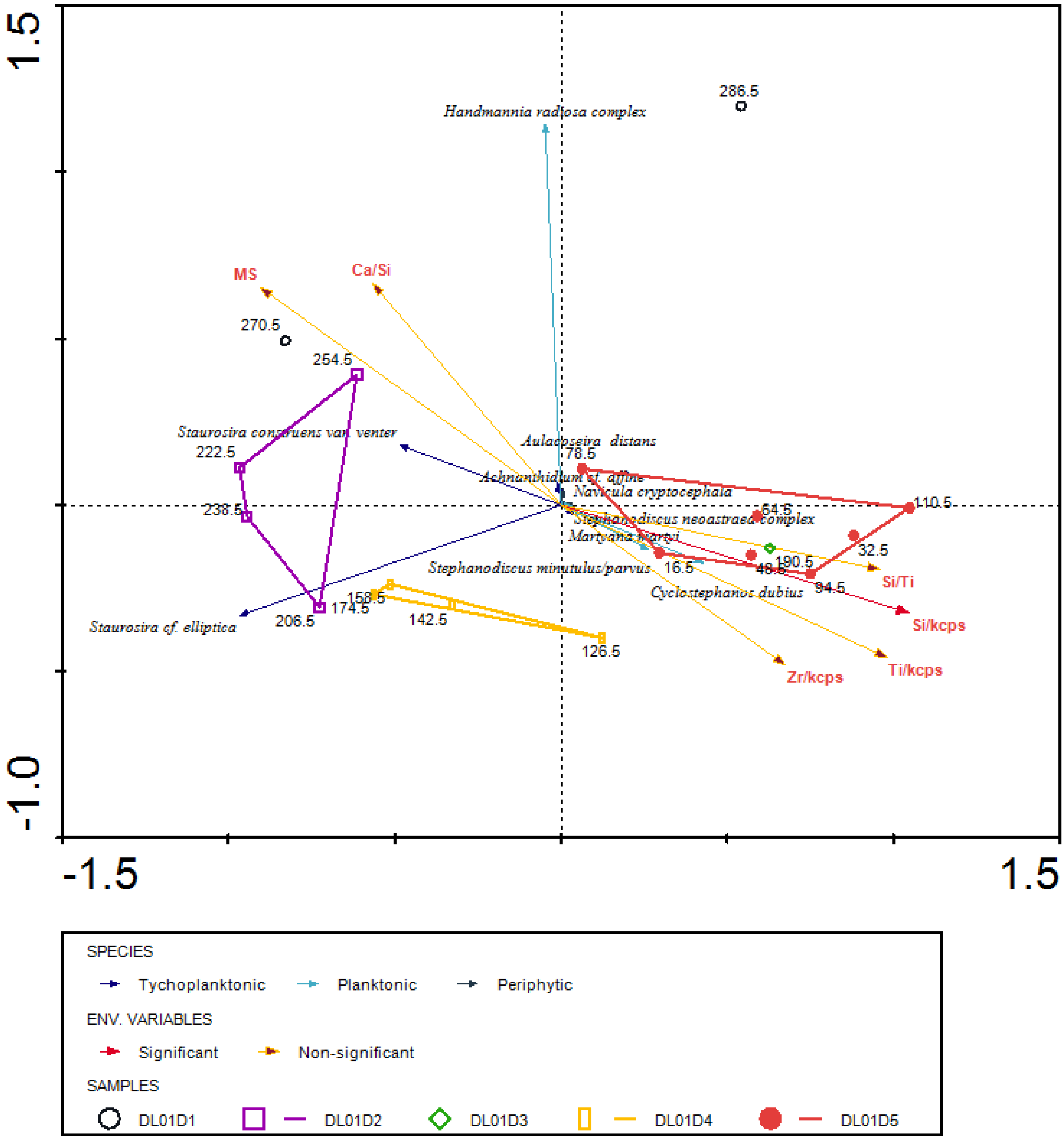


Figure 6.1.5 RDA of the diatom assemblages and the geochemical data. The samples are clustered based on the diatom CONISS zones, while diatom taxa are split by lifeform

6.1.4 Pollen

The pollen assemblages from Derryhowlaght Lough show major disturbances in the vegetation (figure 6.1.6). To assess changes in the vegetation openness, the taxa were grouped according to vegetation type and summed accordingly. The pollen assemblages contains several anthropogenic indicator taxa: Cereal type, *Matricaria* type, Cichorioideae, Chenopodiaceae, *Humulus*/*Cannabis* type, *Plantago lanceolata*, *Polygonum* (knotweed), Ranunculaceae (buttercup), Rubiaceae (e.g. bedstraw), *Rumex acetosa/acetosella* and Urticaceae. The most abundant taxa in the record are *Alnus, Quercus, Corylus,* Cyperaceae and Poaceae. Other taxa that are occurring in the core are *Betula*, *Pinus*, Ericaceae, *Filipendula* and *Plantago lanceolata* (ribwort plantain). Cereal type pollen are present (<1%) throughout the core in very low numbers. Willow and alder pollen were separated from the tree and shrubs pollen sum, to better reflect catchment vegetation, as these taxa are more likely to occur around the lake edge. At the basal part of the core, tree taxa are more abundant (c. 60%), while in the middle and top, grasses and herbs become more abundant. This change towards more meadow pollen is most pronounced from around 190 cm depth. To investigate these changes, a CONISS cluster analysis has been performed, to identify whether these changes led to distinct sample clusters, which identified three distinct zones.

<u>Zone DL01P1 (290-214 cm)</u>

The bottom zone is the most forested, with high amounts (>90%) of arboreal pollen (trees and shrubs), mainly oak, alder and hazel. However, due to much higher production rates of arboreal pollen the forest component is probably overestimated. As herb and grass pollen make up 5-10% of the assemblage at the lowermost sample, the vegetation was probably moderately closed, with some meadows nearby. A single occurrence of a cereal pollen grain around 240 cm might be related to the crannog. However, as cereal pollen appear continuous throughout most of the core, there is evidence that cereal cultivation took place in the catchment at most times. There is a substantial reduction in oak pollen, while alder and willow pollen increase together with non-arboreal pollen. Even though this is the bottom zone analysed, the radiocarbon dates indicate that the deposits were probably laid down during the Early Christian period, when human impact on the landscape was widespread. In nearby Tattenamona bog a substantial reduction in oak pollen took place, occurring with increases in *Plantago lanceolata* (Mitchell, 1956). In this bog, at the same depth, several Bronze Age spearheads dated to 1400-1200 BC were found, providing evidence that opening up of the woodlands took place at least 1000 years prior to the sediments analysed at Derryhowlaght Lough in this study.

Zone DL01P2 (214-168 cm)

The next zone indicates a continuously high amount of arboreal pollen, mainly alder, oak and hazel. Towards the top of this zone, there is a clear reduction in arboreal pollen while the grasses and herbs (including anthropogenic indicators) increase to up to 20%, indicating that more of the surrounding lands were being turned into pastures and arable fields. The low abundance of aquatic pollen in the top of the zone could be interpreted as an increase in shallow lake vegetation, possibly related to lower lake levels.

Zone DL01P3 (166-86 cm)

The third zone starts with a drastic increase in the abundances of grasses, herbs and anthropogenic indicators (up to 60%), while arboreal taxa decrease. Very low abundances of pine pollen start to appear in the sediment samples. The main taxa increasing in this interval is grasses, sedges and meadowsweet. This zone indicates a further opening of the landscape. The abundance of up to 10% of Ericaceae might indicate poor and dry soils nearby. Slightly wetter conditions might be inferred from the increase in meadowsweet in the middle to upper part of this zone. As more *Lycopodium* spores were counted per pollen grains, this indicates reduced pollen accumulation during this zone, driven by the lower pollen production rates of herbs compared to trees. The top of the zone has between 5 and 10% abundance of narrow plantain, which is often used as an indicator of meadows, indicating that the opening of the landscape was probably driven by humans and not a response to climate change.

Zone DL01P4 (86-10 cm)

This zone shows a further expansion of herbs and grasses, maily coinciding with a reduction in anthropogenic indicators. Shrubs initialy continue to decline, but recover towards the top of the core. *Pinus* increases to up to 5% of the pollen assemblages. Although Scots Pine is native to Ireland, it had largely dissappeared during the medieval period. It is complicated to asses whether the increase in *Pinus* in this zone is related pine plantations (i.e. 18th Century), as the post-medieval rise in *Pinus* pollen does not appear contant throughout Ireland and has occurred as early as the 13th Century (Hall, 2003), but appears absent from Tattenamona bog (Mitchell, 1956).

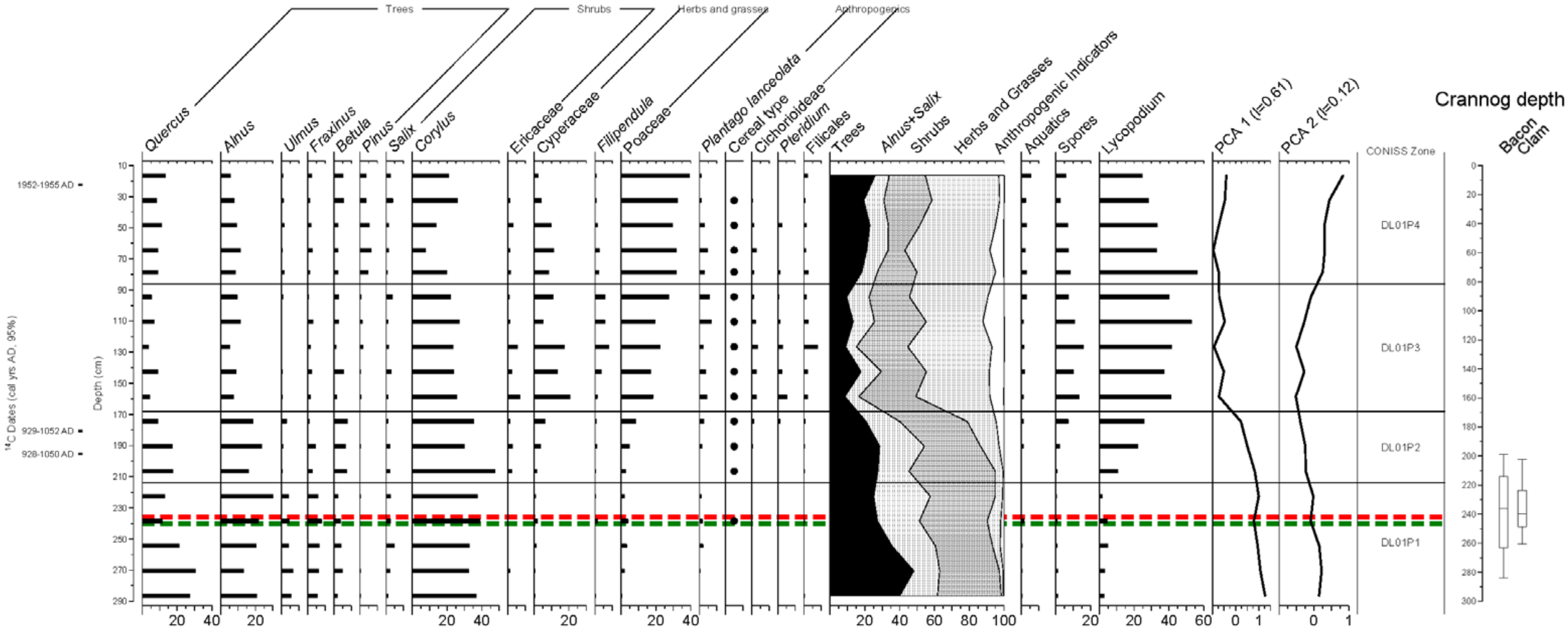


Figure 6.1.6 Dominant pollen taxa (>3%) in core DL01, with PCA axes and CONISS zonation

6.1.4.1 Pollen PCA analyses

As a DCA analysis revealed that the first axis had a gradient length of 1.2, thus warranting a PCA analysis. The first axis (λ=0.37), has a similar pattern to the arboreal pollen (AP, trees and shrubs, see figure 6.1.6). This indicates that vegetation openness can be used to mainly describe the pollen assemblages. Assuming the radiocarbon dates are correct, the core encompasses around 1600 years. This means that the changes in the vegetation are predominantly driven by human needs, with the creation of pastures for grazing throughout most of the core and the reestablishment of woodlands in the very top of the core. The second PCA axis (λ=0.12) appears to be driven by several taxa and it is unclear whether this relates to distinct changes in vegetation openness.

To explore the relationship between the PCA axes and the species further, a PCA biplot of species and samples (figure 6.1.7) was created. Most of the arboreal taxa (except *Pinus*) have positive loadings on the first PCA axis, while the majority of the grass and herb taxa (i.e. Poaceae, Asteraceae, *Plantago lanceolata*, Cyperaceae and Cichorioideae) have negative loadings. The second PCA axis has less distinct patterns, but rather appears to reflect the dominant taxa at different phases in the core.

The biplot clearly separates the four zones on the first two PCA axes and the zones can be traced across the axes in a clockwise fashion (right-bottom, right-bottom, left-top and left). The lowermost pollen zone is located on the far right of the graph and appears closely related to *Quercus*, *Ulmus* and *Fraxinus*. Especially *Quercus* and U*lmus* are mature deciduous woodland species, related to an established deciduous forest dominating the catchment. The second pollen zone (DL01P2) has slightly lower PCA axis 1 scores and these samples are mainly correlated with *Alnus* and *Corylus*, indicating a shift to a more open landscape with more small trees, reflecting a grazed landscape. Pollen zone DL01P3 shows a distinct shift towards lower scores on both of the PCA axes, indicating less arboreal taxa and more herbs and grasses, mainly *Plantago lanceolata*, Cyperaceae and Cichorioideae. These herb taxa are anthropogenic indicators, indicating that disturbed meadows were a dominant part of the landscape surrounding the lake. This is supported by the occurrence of cereal grains in the samples. Finally, the uppermost pollen zone (DL01P4) shifts towards positive loadings on the second PCA axis. The samples appear to correlate mainly with *Pinus*, Poaceae and Asteraceae. As the samples continue to have negative scores on the first PCA axis, the vegetation surrounding the lake probably remains predominantly herbaceous.

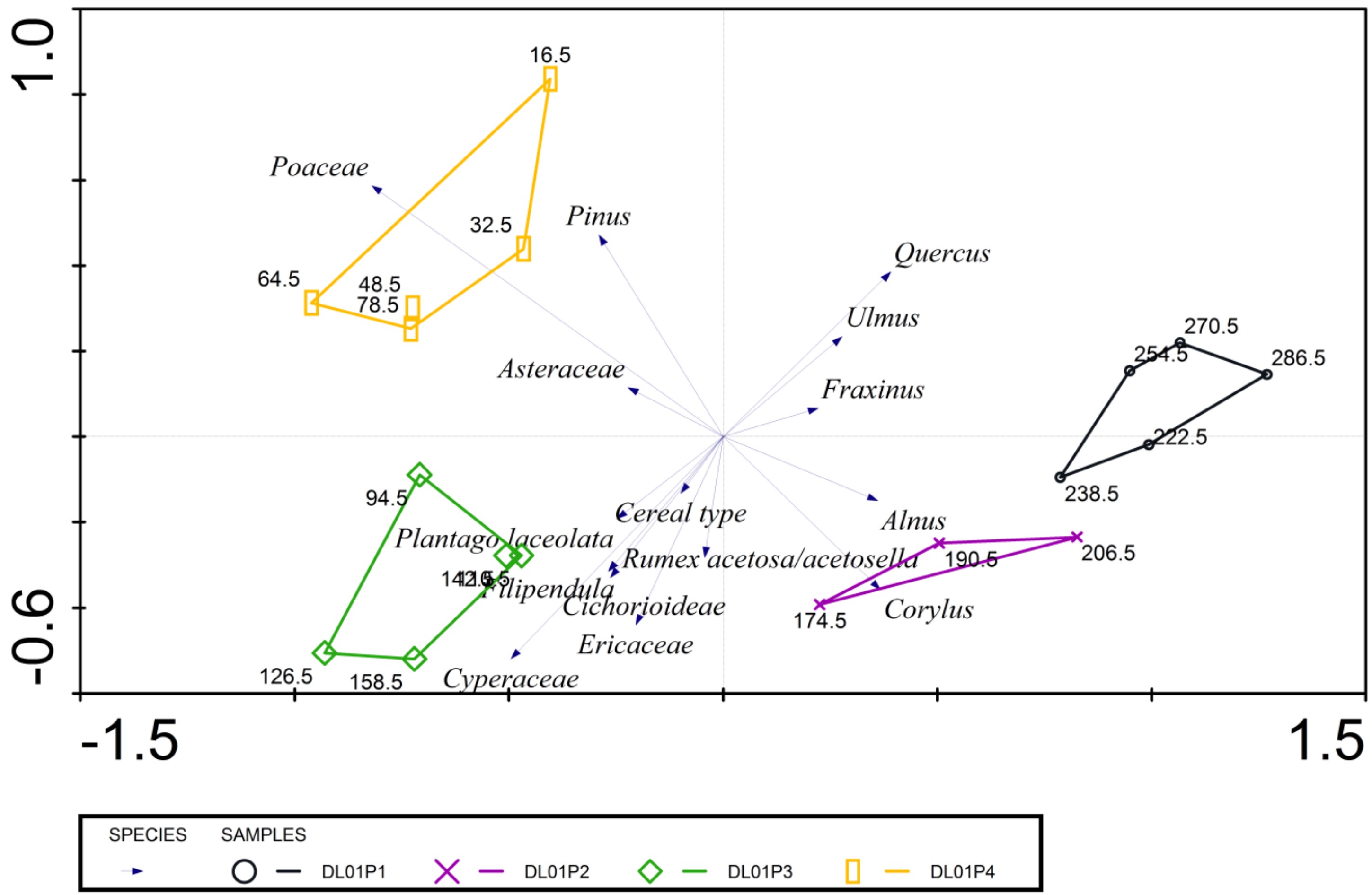


Figure 6.1.7 A biplot of PCA axes from the pollen assemblages of core DL01

6.1.4.2 Pollen Conclusions

The pollen assemblages are mainly driven by changes in vegetation openness. Dominant arboreal pollen taxa (e.g. *Ulmus*, *Quercus*, *Alnus* and *Corylus*) in the basal part of the core are being replaced by herb and grass taxa (e.g. Poaceae, Cyperaceae and *Plantago lanceolata*). The PCA analysis shows a distinct shift from woodlands, to more open vegetation and finally the establishment of pine forests.

As both anthropogenic indicators (e.g. *Plantago lanceolata* and Cichorioideae) and herb and grass taxa increase together, the shift is probably related to the creation of meadows. Together with low amounts cereal pollen present throughout the core, there is clear evidence of cereal cultivation, processing or storage near and/or on the lake, similar to evidence from Lough Kinale (O'Brien et al., 2005). As the core encompasses the last c. 1200 years, it reflects the increasing pressure of humans on the landscape.

There are a few other pollen records in Co. Fermanagh (see appendix A, figure A.4.3) to which this site might be compared (Mitchell et al., 2013). A short Bronze Age record exists from Glen West (Plunkett, 2008), as well an early historic record from Gortaturk bog (Hall, 2003), while the most complete published record originates from Tattenamona bog (Mitchell, 1956, see figure A.4.4). These sites show similar patterns to the core from Derryhowlaght Lough, with evidence of late prehistoric deforestation. Furthermore, there is distinct evidence that deforestation accelerated during the Early Medieval period, when large section of mature woodlands disappeared. However, it should be noted that the bog record tends to overestimate local vegetation (Jacobson and Bradshaw, 1981) and often grasses and heath have not been excluded from the pollen sum, confounding changes in AP:NAP ratios and changes in woodland cover.

Deforestation has accelerated since the Bronze Age, particularly in the Early Medieval and Hiberno-Norse periods, which are known to have had a dramatic effect on the Irish forests. The top of the core seems to indicate a reestablishment of woodlands and might be related to post-1700 AD pine plantations. However, given the chronological uncertainty of post-medieval pine woodlands in Ireland, this remains uncertain (Hall, 2003). The high amount of grass pollen in the top of the core reflects the dairy farming, requiring meadows, that is currently taking place in the nearby farm.

6.1.5 Derryhowlaght Lough conclusions

When comparing all the records (figure 6.1.8), it becomes evident that the lake system and the surrounding landscape have been disturbed repeatedly during the last c. 1600 years. Below 214 cm depth the sediments are characterised by a steady reduction in planktonic diatoms replaced by tychoplanktonic diatoms, relatively high MS and stable OM, relatively high arboreal pollen and higher XRF K/Rb. Towards 214 cm, the MS appears to decrease substantially. However, this is not a stable decrease and there are several increases. Based on the radiocarbon dates, the top of this zone would be around the time of the construction of the crannog, indicating that the local environment was heavily disturbed during the construction and occupation of the site. The pollen assemblages indicate that the catchment is still more or less forested, which would mean that the crannog was built prior to a major deforestation. However, the diatom records indicate a reduction in planktonic diatoms in favour of tychoplanktonic taxa, which probably also led to more turbid waters. By looking up the mean age of the sediment that coincides with the median age of the radiocarbon date of the crannog, it is most likely that sediments associated with crannog disturbances are located at a depth of c. 236 or 239 cm depth, depending on which model is preferred, which would coincide with a distinct peak in the MS record and a minimum in planktonic diatoms. The erosion around this time might be related to the construction of the crannog, while the reduction in planktonic diatoms is probably similarly related to the crannog, with a shallowing phase and more turbid water.

Between 214 and 182 cm, there are major disturbances in the catchment and the lake. The pollen assemblages indicate the start of deforestation with a reduction in arboreal pollen and increases in herbs and grasses, as well as increases in a few anthropogenic indicator pollen. This coincides with fluctuating organic matter content and a short-lived increase in planktonic diatoms, possibly related to higher nutrient levels. This interval indicates how woodland clearing leads to higher erosion rates, a higher Ti/kcps, higher Mn/Ti, an increased MS during a decreasing MS trend, as well as a short interval with a higher abundance of the mesotrophic diatom *Cyclostephanos dubius*. The MS has higher values around the same time as the tree taxa start to decrease, indicating that local erosion is a likely driver of the changes in the sediment record. There are slightly more periphytic diatoms, which might indicate a larger amount of macrophytes. Put together the sediments between 214 and 182 cm depth have strong evidence of disturbance from the crannog, possibly indicating a period of renewed or intensified activity. Interestingly this takes place prior to the period when activity increases on

Lough Kinale, where large amounts of cereal pollen (>50%) were found from the mid-12th Century AD (O'Brien et al., 2005).

Between 182 and 134 cm depth the sediments indicate a relatively stable MS record, with fluctuating OM. These sediments have the largest shift in the pollen assemblages, indicating a major deforestation phase. Increases in grasses and sedges, as well as anthropogenic indicator species, indicate that pastures have been created in large parts of the catchment. This coincides with a steady increase in the Ti/kcps indicating higher erosion rates. The diatoms respond with a shift to tychoplanktonic diatoms and the disappearance of planktonic diatoms.

Above 134 cm the sediments have a relatively stable sedimentology apart from the uppermost samples. It reflects that the catchment has been relatively stable. However, the diatom assemblages show substantial changes, with dramatic increases and decreases in planktonic and benthic taxa. The tychoplanktonic taxa appear to have a relatively constant abundance and following a decrease at the start at the zone, have a continuously low abundance. These sediments encompass a maximum in anthropogenic indicator pollen, indicating the importance of meadows in the catchment. Overall the vegetation changes little, but towards the top of the core there are increases in arboreal pollen, indicating some regeneration of the woodlands. Around 30 cm there is a distinct peak in planktonic diatoms, identifying another more eutrophic interval. The very top of the core is characterised by a reduction in OM and an increase in the MS, which can be interpreted as increased erosion rates from the catchment. However, as the pollen assemblages are fairly stable at this time, this is not probably due to major changes in the landscape vegetation. Rather, local disturbances such as land drainage or water level management of the River Erne were influencing this around this time. The diatoms indicate a shift towards epipelic species in the uppermost samples. The modern assemblages were probably influenced by additional sediment loading into the lake, as indicated by increased erosion rates. It might indicate that this is a different phase in the lake ecosystem, where the silting up process has led to dominance of sediment dwelling diatoms over planktonic eutrophic taxa. An alternate explanation is that the meso-eutrophic planktonic diatoms are replaced by other algae, such as blue-green algae, which are stronger competitors under high nutrient loading regimes. However, without a more established age-depth model for the upper part of the core, it is difficult to assess this fully.

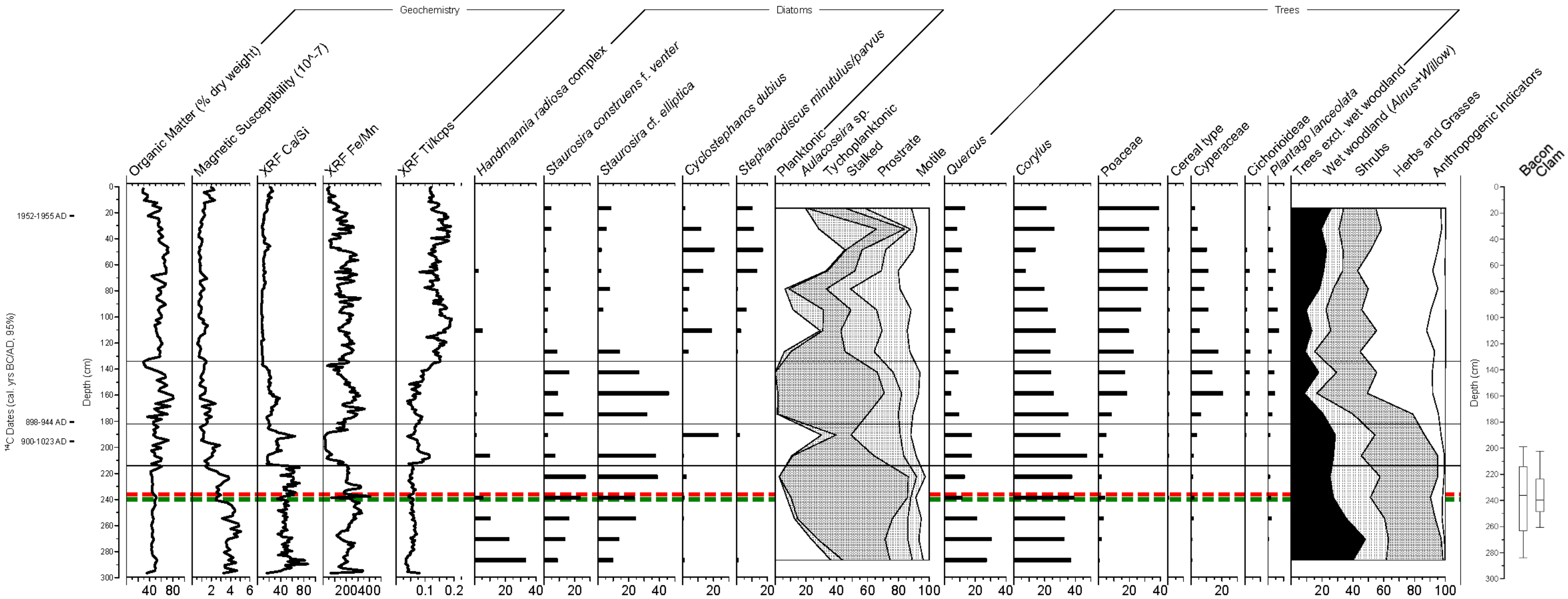


Figure 6.1.8 Summary diagram of Derryhowlaght Lough, indicating the data from the geochemistry, pollen and diatoms

The palaeoenvironmental analysis of core DL01 from Derryhowlaght Lough indicates that the lake has been influenced by dramatic changes to the lake ecology and the catchment, driven mainly by human impact upon the landscape surrounding the lake. There are examples of deforestation, increasing erosion rates and eutrophication. The crannog appears to be a factor of lake ecosystem disturbances, with some evidence of local shallowing and eutrophication. These short-term disturbances in the lake can be related to the crannog, but these changes appeared reversible.

There are at least two phases with increased erosion rates. The first of which is probably driven by deforestation around the 10th Century AD. This woodland reduction took place c. 200 years after the crannog was constructed and might be a phase of increased activity on the site. As this phase succeeds the crannog, it indicates that the crannog was built when farming practices were still expanding and the ecclesial period had not yet reached its maximum. As this site has not undergone more than an explorative excavation, it is unknown how long the site was occupied or was reinforced. However, the palaeoenvironmental analyses indicate that activity increased on and around the lake following its construction around the 7th Century AD. It is likely that the dramatic reduction in arboreal pollen around 260 and 160 cm is related to intensification of land-use in the catchment.

6.2 Ross Lough palaeoecology

6.2.1 Chronology

No radiocarbon dates have been collected for this core, due to funding limitations and the poor quality of the samples, which were barren of plant macrofossils. Furthermore, most of the core had a very low diatom accumulation, limiting the interpretation of the lake ecology, thus it was chosen to focus the awarded radiocarbon dates on the other sites. The accumulation rates of large (>50 ha) and shallow (<5m) lakes (Rose et al., 2011) were compared to determine the age of the upper sediments of Ross Lough. However, it was hoped that the pollen assemblages might be able to identify some chronological markers in the core (section 6.2.5). The core from Ross Lough might be compared to Tattenamona bog (Mitchell, 1956) and Gortaturk bog (Hall, 2003), which are raised bogs with overlapping pollen records from Co. Fermanagh (see appendix A, figure A.4.3).

6.2.2 Geochemistry

To assess changes in the lake geochemistry LOI, MS and XRF were performed on the core (figure 6.2.1). The organic matter content of the core indicated that overall the core had an OM of c.15-30%. At the bottom of the core, below 230 cm, the OM was highest (c.30%), indicating relatively high organic matter accumulation. From 230 cm to 30 cm it is stable at around 25% OM. However, there are several reductions, noticeably around 180 cm and around 60 cm. Above 10 cm the OM decreases to just below 15%, indicating a high minerogenic content. The carbonate content of the core is very low (<4%) and will not be interpreted further. However, there are a few increases in the core, probably related to changes in the pH. From the bottom of the core towards 190 cm, the carbonate content is relatively stable, though there is a short reduction around 230 cm. Between 190 and 130 cm the CM decreases, though there is a short lived increase around 180 cm, coinciding with a reduction in OM. From 130 cm to 60 cm the CM increases and remains relatively stable around 3.5%, after which it decreases to c.3% towards the top of the core. There are distinct reductions around 50 and 10 cm, coinciding with reductions in the OM, indicating that these sediments are probably influenced by increases in clastic matter.

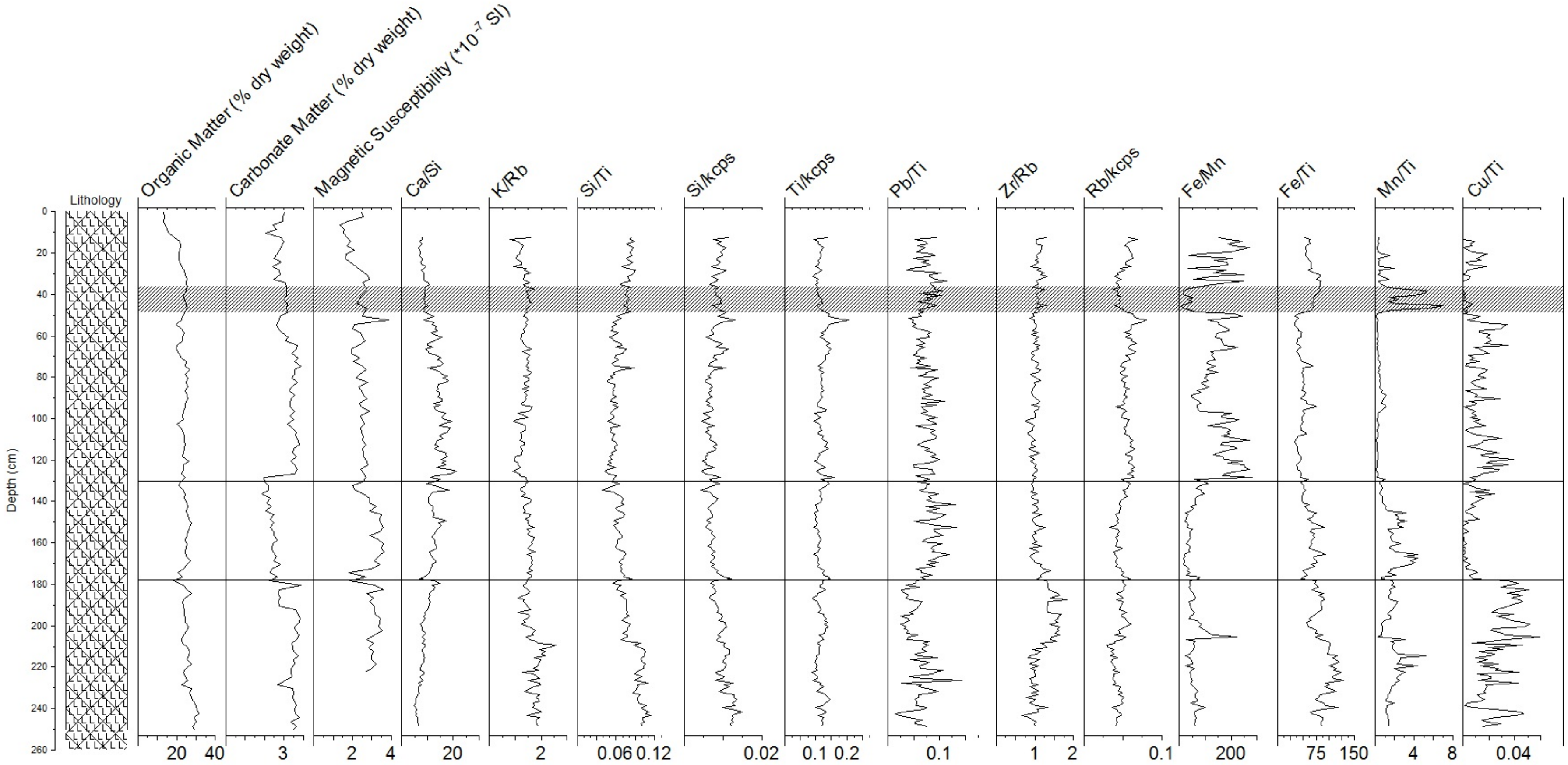


Figure 6.2.1 Selected XRF, LOI and MS analyses from core RL01. The shaded area indicates a zone with a low Fe/Mn ratio

The MS is quite low throughout the core, indicating the sediments are rich in diamagnetic matter (Dearing, 1999). Around 180 cm there is a reduction in the MS, indicating a higher diamagnetic content. However, as this coincides with a reduction in OM, while the CM increases, this could be driven by a higher pH and/or an influx of carbonate matter, which is a component of the bedrock in the catchment (Tyrone Group, Brandon, 1977). Changes in the pH might be explored further by comparing the CM with results from the XRF and diatom analyses.

The XRF analysis indicated that overall the core was relatively stable in its chemical components. Up to 210 cm more resistant clays (K/Rb) are indicative of higher erosion rates (Croudace et al., 2006, Rothwell et al., 2006). Between 210 and 170 cm there is evidence of resistant minerals entering the lake (Zr/Rb), which can be interpreted as a change in sediment provenance (Croudace et al., 2006, Rothwell et al., 2006). Above 170 cm the core appears relatively stable in these erosional indicators, though there is a distinct peak in the Si/kcps, Ti/kcps and R/kcps around 50 cm depth, which probably indicates an erosion event (Croudace et al., 2006, Rothwell et al., 2006), though it is followed by lower amounts of Ti/kcps and Rb/kcps in the sediments.

The most pronounced changes in the XRF analyses are represented changes in the oxygen availability (Fe/Mn, Fe/Ti and Mn/Ti) and diagenesis (Cu/Ti) in the lake (Croudace et al., 2006, Rothwell et al., 2006). A high Fe/Mn with a high Fe/Ti can be used to infer hypolimnic dysoxia (Engstrom and Wright Jr., 1984) , but as shallow lakes are highly mixed, it probably represents inwash from semi-enclosed basins such as peatlands (Björkvald et al., 2008). Below 130 cm the Fe/Mn is relatively stable and consistently low, apart from a rapid increase around 205 cm depth, though this appears mainly driven by reductions in the Mn/Ti, rather than the Fe/Ti, as both appear to be decreasing at these depths. Between 130 cm and 50 cm depth the Fe/Mn is relatively high, indicating that for these sediments were probably deposited during hypoxia. However, there is reduction around 90 cm depth, indicating increased oxygen availability. Between 50 and 35 cm depth the Fe/Mn is rapidly reduced, after which it increases again. As hypoxia can be caused by changes in the circulation, as well as very high productivity in the lake, it is useful to compare the Fe/Mn to the Si/Ti, which has been used as to infer biogenic silica and lake productivity (Boyle, 2001, Croudace et al., 2006, Rothwell et al., 2006). The Si/Ti is higher at the bottom of the core, from where it decreases substantially around 230 cm depth. Following this event, it gradually decreases until around 130 cm depth, after which it remains relatively stable. There is a distinct increase from c. 45 cm depth, followed by a more gradual increase. Below 180 cm depth the Cu/Ti is relatively high, indicating some diagenetic reactions have taken place in the core (Croudace et al., 2006, Rothwell et al., 2006), so care has to be taken with the interpretation of these sediments. Similarly, between 130 and 50 cm depth the Cu/Ti is relatively high, indicating a higher amount of diagenetic reactions.

6.2.3 Diatoms

In order to better understand changes in the lake ecology, the diatom assemblages of core RL01 were analysed. Below 130 cm and between 50 and 30 cm depth (shaded areas in figure 6.2.2), which is over half of the core, the diatom frustules had a very low concentration (<50 frustules in 2 slides), with high amounts of partially dissolved and broken frustules. The partial frustules are composed of central areas of the centric and naviculoid taxa, which are the most silicified parts, indicating it likely that less silicified taxa have probably already dissolved (Ryves et al., 2006, Ryves, 1994).

Overall the assemblages are dominated by tychoplanktonic and periphytic diatoms. The tychoplanktonic diatoms are composed of several small fragilarioid taxa, predominantly *Staurosira construens var. venter* and *Pseudostaurosira brevistriata*. Furthermore, there are reduced occurrences of *Staurosira* cf. *elliptica*, *Staurosirella pinnata* and *Stauroforma exiguiformis*. *Staurosira* cf. *elliptica* is a compilation of very small elliptic fragilarioids (Sayer et al., 2010, Morales et al., 2010), which proved too difficult to separate under the light microscope. The dominant periphytic taxa were *Achnanthidium minutissimum*, *Amphora pediculus* and *Cavinula scutelloides*. Towards the top of the core there is a distinct reduction in tychoplanktonic diatoms, while motile taxa increased dramatically. As planktonic diatoms are almost absent throughout the core, it can be inferred that the lake was shallow for most of the period analysed or had limited diatom productivity in the epilimnion. The high amount of prostrate and stalked taxa indicates a reasonable amount of substrates, such as rocks and macrophytes. However, given the evidence of dissolution (shaded areas in figure 6.2.2) in the core and the fact that the more finely silicified planktonic diatoms are more likely to dissolve, the interpretation will have to be tentative and assumes that the sections that did have a reasonable amount of frustules did not have the assemblages altered by dissolution. A CONISS cluster analysis was performed to help establish the diatom zonation, identifying three main zones.

<u>(240-130 cm)</u>

The diatom counts are very low in this part of the core, less than 50 frustules in 2 slides. Furthermore the samples are dominated by central areas of more heavily silicified naviculoid frustules, which are more resistant to dissolution (Ryves et al., 2006, Ryves, 1994, Barker et al., 1994a). For an extensive discussion on factors influencing diatom dissolution see section 5.1.4 on a diatom dissolution phase in the Cults Loch core TCL1.

Interestingly, both Ross Lough and Cults Loch appear to have elevated levels of Mn/Ti and a low Fe/Mn during the dissolution phase, indicative of the inwash of water from semi-enclosed basins, such as peatlands, during spring flooding (Björkvald et al., 2008), rather than the usual interpretation of oxygen availability (Engstrom and Wright Jr., 1984), as the water masses of shallow lakes can be assumed to be fully oxygenated (Scheffer, 2004). As spring and autumn circulation are periods for diatom blooms, it might be related to nutrient elevation and increased nutrient demands. This is somewhat supported by slightly increased levels in the Si/Ti in the core from Ross Lough, indicative of increased biogenic silica accumulation. Without a robust chronology it is difficult to estimate whether the accumulation rates changed in these sediments, though the pollen spike accumulation rates might help to provide an estimate (section 6.2.5).

RL01D1 (130-64 cm)

The amount of fragmented diatoms is relatively high at the bottom of the zone (over 30%) so interpretation of the lowermost diatom sample has to be cautious as the sample might have been influenced by dissolution. The assemblages indicate high amounts of tychoplanktonic diatoms, with a relatively stable amount of prostrate frustules (c. 20%). The dominant taxa are *Staurosira construens* var. *venter*, *Pseudostaurosira brevistriata*, while at the bottom of this zone *Staurosira* cf. *elliptica* is occurring more than in the rest of the zone. There are some stalked and motile diatoms in this zone, mainly composed of *Achnanthidium minutissimum*, *Martyana martyi*, *Cocconeis neodiminuta* and *Amphora pediculus*. These taxa are probably living attached to macrophytes, therefore the increase in stalked taxa around 130 cm might be related to expansion of macrophyte habitat. The motile diatoms are mainly composed of *Cavinula* sp., which are epipelic taxa.

RL01D2 (64-32 cm)

These samples have increased abundances of stalked and motile taxa, while tychoplanktonic taxa decrease. The stalked taxa are mainly composed of *Achnanthidium* sp., which are common pioneer taxa (Potapova and Hamilton, 2007, Ponader and Potapova, 2007). Increases in stalked taxa are probably related to habitat expansion and/or increased macrophytes, which might be a consequence of local shallowing. Planktonic taxa and *Aulacoseira* sp. are occurring in higher amounts (2-5%) and might be a response to increased nutrient concentrations. However, in the uppermost sample of this zone there are very high amounts of fragmented frustules (>30%), which indicates some dissolution in the zone, while the amount of frustules is very low (<50 in two slides).

RL01D3 (32-0 cm)

Although initially reduced, motile taxa increase dramatically in this zone, mainly driven by *Cavinula scutelloides,* while planktonic and tychoplanktonic taxa decrease. The amount of fragmented frustules decreases. *Cavinula scutelloides* has been described in oligotrophic lakes as well as moist subaerial habitats (Krammer and Lange-Bertalot, 1999a) and probably related to a reduction in epilimnic diatom productivity, as these motile diatoms are mainly epipelic (Round et al., 2007). However, the XRF Si/Ti does not indicate changes in the biogenic silica, so it is uncertain what is driving the change in the diatom assemblages.

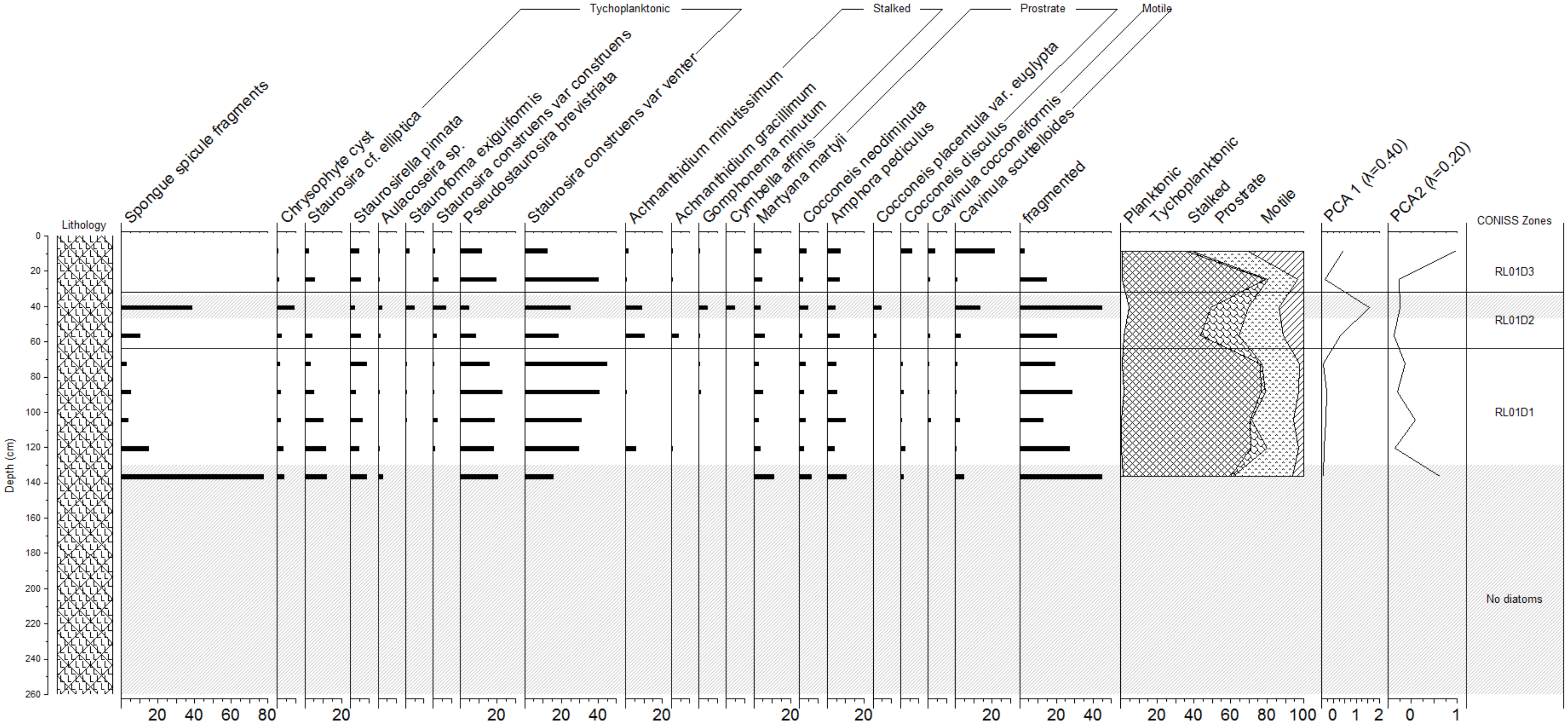


Figure 6.2.2 Selected diatom taxa (>3%) from core RL01 with attachment groups, PCA axes and CONISS zones. The shaded area indicates depths with a reduced Fe/Mn ratio

6.2.3.1 Diatom PCA analysis

To further explore the diatom assemblages and larger shifts in taxa, a DCA analyses was performed (see figure 6.2.3), which indicated a short gradient length (1.17), warranting the use of a PCA (Ammann, 2000, Ter Braak and Prentice, 2004). The PCA analysis was able to explain a large portion of the data, with the first axis (λ=0.40) separating stalked and planktonic taxa and some of the abundant tychoplanktonic taxa (e.g. *Staurosira construens* sp.) towards the right and some other highly occurring tychoplanktonic taxa (*Pseudostaurosira brevistriata*, *Staurosira* cf. *elliptica* and *Staurosirella pinnata*) towards the left of the graph. This indicates that the dominant change in the assemblages reflect a shift towards a higher macrophyte community (Round et al., 2007), with the few planktonic taxa indicating oligotrophic to mesotrophic nutrient concentrations (Scheffler and Morabito, 2003). The split between *Staurosira construens f. construens* and other small fragilarioid taxa is interesting, as this taxon is quite a bit larger. This might indicate that it is more adapted to planktonic conditions. The second PCA axis (λ=0.20) is positively aligned with motile taxa, while weakly negative with stalked and planktonic taxa. This indicates the second most important change in the assemblages is a shift from tychoplanktonic taxa towards motile diatoms. As the bottom zone (RL01D1) is located on the left of the graph, it reflects the high amounts of small tychoplanktonic diatoms in this zone. The second zone (RL01D2) is located towards the lower right of the graph, indicating the higher amounts of stalked and planktonic taxa in this zone. Finally the uppermost zone is spread apart towards the left as well as the upper part of the graph. This reflects a rapidly changing environment with rapid increases in motile diatoms in the upper part of the zone.

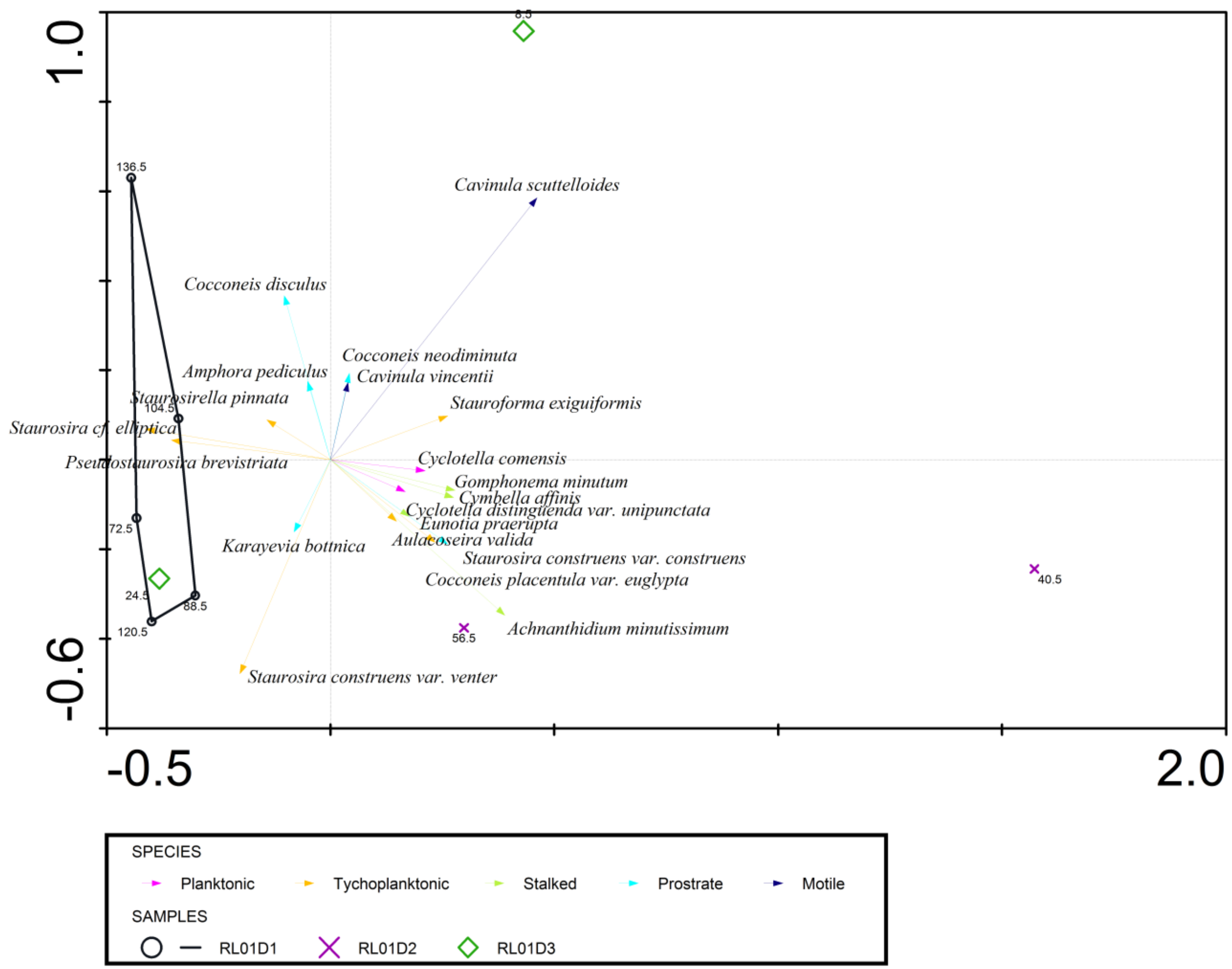


Figure 6.2.3 RL01 diatom PCA axes indicating sample zones and taxa (>40% weight)

6.2.3.2 Diatom and geochemistry

To investigate relationships between the diatom assemblages and the geochemistry, a multiple regression was performed. This indicates that the only significantly variable in the analysis is Mn/Ti (table 6.2.1), although Fe/Rb was significantly correlated to the first PCA axis. Increases in Fe/Rb are thought to be related to mainly oxygen availability, although it might also represent changes in clastic material (Croudace et al., 2006, Rothwell et al., 2006). There is a correlation trend ($p<0.1$) between the carbonate matter content (CM) and the second PCA axis, which might infer either changes in the pH or conductivity being a minor influence on the diatom assemblages. Both of these are known to be a major factor in diatom dissolution (Ryves, 1994, Ryves et al., 2006).

Table 6.2.1 Statistics from multiple regression and RDA RL01 diatoms and geochemistry

Significantly correlated environmental variable (correlation 1st/2nd axis)	Multiple regression significance level (full model significance)	Multiple regression coefficient	RDA significance
Fe/Rb (D-PCA1: 0.72)	<0.001	0.55	Not significant
Mn/Ti (D-PCA1: 0.9)	Not significant		
CM (D-PCA2: -0.65) Not significant			
Ti/kcps			Not significant (p=0.14)
MS			0.001

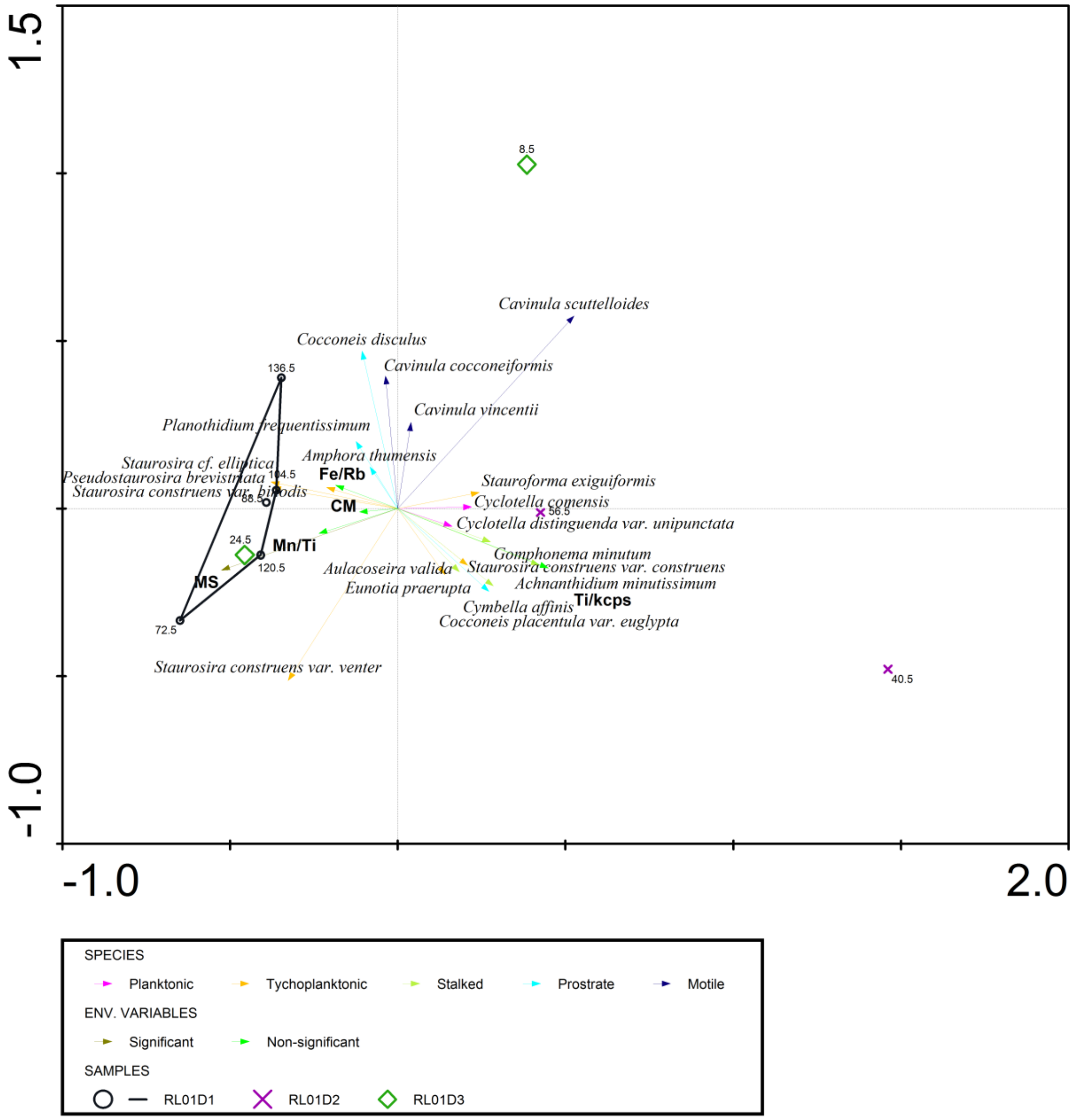


Figure 6.2.4 RDA analysis of core RL01 with geochemistry and diatom assemblages. The diatoms are classified by attachment type RDA analysis of core RL01 with geochemistry and diatom assemblages. The diatoms are classified by attachment type

To explore this further a RDA was performed using these three variables (table 6.2.1 and figure 6.2.4). Interestingly, none of the significantly correlated variables were significantly influencing the RDA, however, the MS was significant (table 6.2.1). Furthermore, most of the variables that were identified as significant so far on either the multiple regression or the RDA (Mn/Ti, CM and MS) are aligned on the same axis. Thus it was decided to add the next most significant variable in the RDA analysis, which was the Ti/kcps. This was aligned perpendicular to the MS and opposite the Fe/Rb, indicating that erosion was indeed an important factor for the diatom assemblages. As the erosional indicator is positively aligned with the first RDA axis, it is a major influence on the diatom assemblages. The centric taxa as well as a few mesotrophic taxa (*Gomphonema minutum*, *Cocconeis placentula* var. *euglypta*) are positively aligned with the first RDA axis, so it might be inferred that some small scale eutrophication did take place, especially in the samples in zone RL01D2.

6.2.3.3 Diatom conclusions

The diatom assemblages of core RL01 are complicated by distinct depths with high diatom fragmentation, located below 128 cm depth and between 48 and 32 cm depth. However, these samples have a higher periphytic component as opposed to the high amounts of tychoplanktonic diatoms. Furthermore the sample around 40 cm depth has a distinct increase in planktonic diatoms, together with increases in mesotrophic diatoms (Van Dam et al., 1994). This was explored further by statistical analyses of the relationship between the geochemical data and the diatom assemblages. The RDA and multiple regression discovered that the sample at 40 cm depth had a higher Ti/kcps. Titanium is more common in heavy resistant minerals and probably indicative of higher erosion rates (Croudace et al., 2006, Rothwell et al., 2006). Probably the higher erosion rates added nutrients to the lake, which caused blooms in the epilimnion. The low Fe/Mn ratio is probably related to increased lake circulation, which would increase the amount of nutrients available in the epilimnion as well (Wetzel, 2001). Higher amounts of stalked diatoms between 64 and 32 cm depth are indicative of a low energy environment and a higher amount of macrophytes. The combination of increased erosion rates and higher amounts of macrophytes might be indicative of the crannog construction and occupation periods, so a tentative depth would be between these intervals, based on the geochemistry and the diatoms.

6.2.4 Pollen

Overall the pollen assemblages of core RL01 (figure 6.2.5) are dominated by arboreal pollen (AP), specifically *Corylus*, *Quercus* and *Alnus* pollen. There is a low amount of non-arboreal pollen (NAP), mainly Poaceae and Cyperaceae, indicative of a small amount of wet meadows nearby. Cereal type pollen are rare in the lower part, as well as the upper part of the core, but absent in the middle, which is probably related to separate occupation phases on and/or around the lake. Most of the catchment of the lake was probably forested for the length of the interval analysed, though towards the top of the core there is a rapid increase in NAP, indicating clearance activities, further evident from higher amounts of anthropogenic indicator taxa (Behre, 1981). The pollen assemblages were zoned using a CONISS cluster analysis, which indicated three zones. The pollen assemblages of Ross Lough have been compared to Tattenamona bog (Mitchell, 1956), which is the longest continuous pollen record in Co. Fermanagh (Mitchell et al., 2013).

Tattenamona bog has a very long record (Mitchell, 1956), with evidence of the early Holocene (or Post-Boreal) as indicated by an alder rise at c. 400 cm. An elm decline was described at 345 cm coinciding with increases in *Plantago lanceolata* and the author attributes this to human interference. Between 300 and 250 cm there is a steady increase in oak pollen, while hazel decreases, indicating a regeneration phase. At 195 cm some Bronze spear heads were found, coinciding with a reduction in oak pollen, while hazel increases. Following these fluctuations *Plantago lanceolata* increases, supporting the interpretation of increased human impact around this depth. Around 50 cm there is a recurrence surface, preceded by reductions in oak and hazel pollen, while alder and birch increases. A similar phase occurred in Derryhowlaght Lough, where arboreal pollen were heavily reduced towards the end of the Early Medieval period (see section 6.1.4). To assist in the interpretation of the pollen assemblages in Ross Lough, a copy of the pollen diagram from Tattenamona Bog is included (appendix A.4.5).

RL01P1 (250-208 cm)

The lowest part of the core is dominated by arboreal taxa (oak, hazel), with moderate amounts of carr-type trees (alder and birch). *Ulmus* occurs reaches around 6% during these depths, indicating that these sediments were deposited before the elm decline (Parker et al., 2002, Mitchell, 1956) or prior to c. 5500 yrs BP. The presence of low amounts of pine pollen (<5%) supports a mid-Holocene interpretation of these samples (Mitchell, 1956). An early Holocene core from the shores of Carran Lough, which flows via a stream to Ross Lough, indicates that hazel was a dominant component since c. 8000yrs BP, while pine never reaches more than 10% abundance (Tisdall, 1996).

RL01P2 (208-64 cm)

The second zone shows a slight reduction in elm pollen, while alder decreases more substantially. However, around the middle part of the zone elm increases to originals levels again. At the same time there is a gradual increase in NAP and some short term increases in anthropogenic indicators, as well as hazel. Near the bottom of this zone some cereal type pollen were found, indicating local cereal cultivation or processing/storage. This is supported by a minor increase in anthropogenic indicators. The cereal type pollen might indicate settlement in the catchment and as there is substantial evidence of Neolithic to Bronze Age lake settlement in Ireland (O'Sullivan, 1998, Fredengren, 2002); it might even indicate occupation on or around the lake shore prior to the Early Christian period, as cereal pollen decreases dramatically at locations distal from the settlement (Behre, 1981). Continuous human activity around the lake since the post-glacial has been described previously, with evidence of worked animal bones, a Bann flake, a bronze dagger and an iron spearhead, as well as a bronze zoomorphic penannular brooch, tentatively dated to either the 3^{rd}-5^{th} or 6^{th}-7^{th} Centuries (Carrol, 1992). Towards the top of the zone (from c. 120 cm) the elm pollen decrease again, so it might coincide with a secondary elm decline, which has been described in Tattenamona bog (Mitchell, 1956), where it coincides with increases in P*lantago lanceolata* pollen, dated to somewhere around the late Bronze Age. Increases in Ericaceae might be from expansion of heathlands on the south western uplands (Big Dog Forest). Increases in aquatic pollen might reflect a more littoral vegetation. So it could indicate a reduction in lake level, though without a more robust chronology it is difficult to tie such changes into specific climatic or anthropogenic events. The exotic *Lycopodium* count increases in this zone, indicating reduced pollen accumulation rates (Stockmarr, 1971).

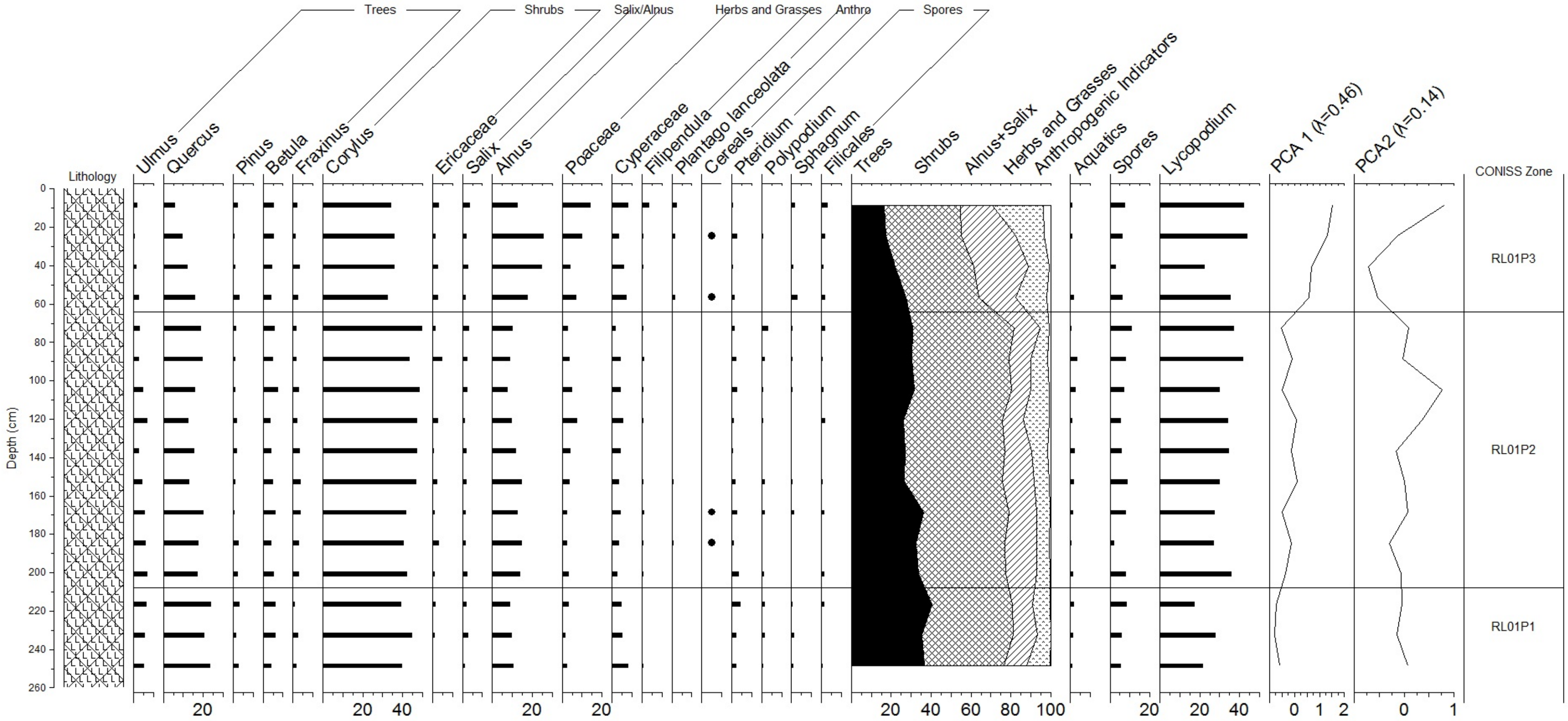


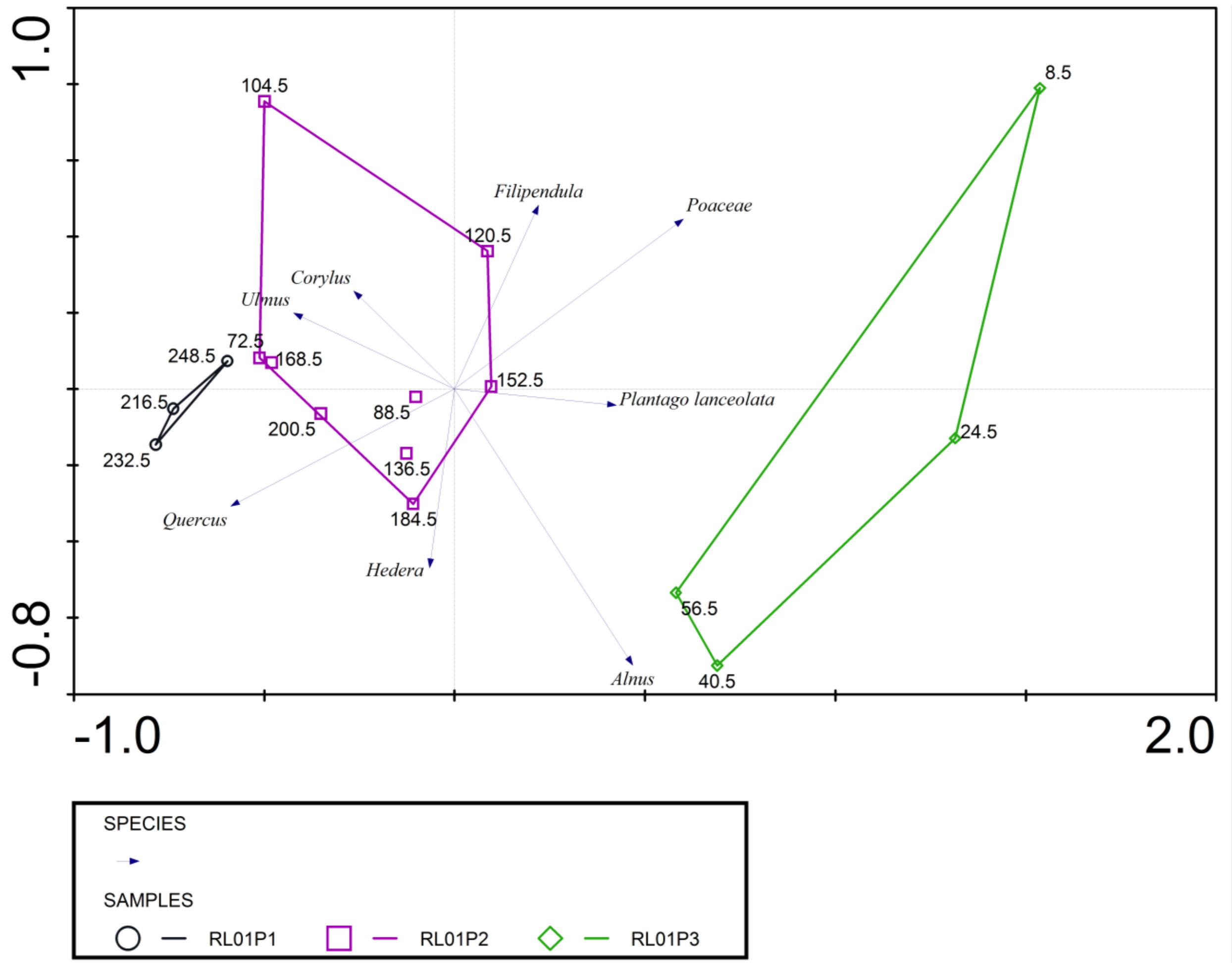
Figure 6.2.5 Pollen assemblages of core RL01, with CONISS zones and first two PCA axes

RL01P3 (65-4 cm)

This zone has a lower amount of hazel and oak pollen, while NAP increases, which reflects the intensification of woodland clearance phases. From other records it is evident that deforestation was extensive in Ireland during the late Early Christian period (Mitchell, 1956), so this upper part of the core probably reflects c. 500-900 AD. As herbs have lower production rates, the littoral arboreal pollen (*Salix* and *Alnus*) makes up a large part of the pollen assemblages. The increases in littoral arboreal pollen probably do not reflect increases in these types but rather an inflation in the representation of established trees. This is supported by higher exotic *Lycopodium* counts, indicating lower overall pollen accumulation rates. The presence of rare cereal type pollen probably reflects local cereal cultivation and processing/storage and might be derived from the crannog, as high amount of cereal-type pollen have been found in a core from Lough Kinale (Brown et al., 2005, O'Brien et al., 2005). It is uncertain if the very top of the core was preserved, as there is not a straightforward increase in *Pinus* pollen and currently Co. Fermanagh has a high amount of pine plantations, with over half of the Co. Fermanagh woodlands classified as conifer (Northern Ireland Forest Service, 2013). However, pine pollen might have occurred locally since c. 1000 years ago (Hall, 2003), so presence in this zone might be derived from local pine woodlands.

6.2.4.1 Pollen and spores PCA analysis

To explore the major changes in the pollen assemblages, a DCA was performed (see figure 6.2.6), which indicated a very short gradient length (0.67), warranting the use of a linear analysis (Ter Braak and Prentice, 2004, Ammann, 2000). The first PCA axis (λ=0.46) indicates the change towards the modern meadow and littoral vegetation (grasses, plantain and alder), as the uppermost zone is located on the far right in the graph. The original woodlands are indicated by oak, elm and hazel, with the bottom two zones on the left of the graph. The second PCA axis (λ=0.14) probably reflects a secondary clearance responses in the uppermost zone, as it is closely aligned with increases in meadowsweet, grasses and hazel, while ivy and alder are at the opposite side of the graph. Hazel and meadowsweet would be more common in wet meadows, while alder might reflect expansion of littoral trees between around 56 and 40 cm depth.



RL01 Pollen PCA axes with species (>40% fit) and samples grouped per CONISS zonation

6.2.5 Ross Lough palaeoenvironmental Conclusions

The core from Ross Lough reflects a long-term palaeoecological record (figure 6.2.7) of a shallow medium sized lake within the Lough Erne/Sillees river system. It appears influenced by changes in the lake hydrology, as evident from increases in the Fe/Mn and diatom dissolution (Ryves, 1994, Ryves et al., 2006). The dissolution is difficult to interpret, but the most pronounced shifts in the proxies is the reduction in Fe/Mn and increases in Mn/Ti, which is probably caused by increased inwash from semi-enclosed basins like peatlands (Björkvald et al., 2008). Furthermore, there is evidence of human impact upon the lake ecology, as the diatoms indicate some eutrophication phases near the same depths of occurrences of cereal pollen. The catchment vegetation indicates long term reductions of oak woodlands, with increases of wet meadows and littoral woodlands towards the top of the core. The interaction between catchment vegetation and lake sediments is evident from the reduction in tree pollen above 208 cm depth, coinciding with increases in erosional indicator Zr/kcps.

The strongest evidence of human impact on the lake precedes the upper dissolution phase (between 48 and 35 cm) in the core, as increases in planktonic diatoms indicate some eutrophication (Van Dam et al., 1994) and the presence of cereal pollen indicates local cereal processing/storage (Behre, 1981). Around the same depth (c. 60 cm) there are increases in erosional indicators (e.g. Ti/kcps and Zr/kcps), indicating increased catchment disturbances and/or a secondary crannog construction phase. Based on the multiproxy analysis, the estimated time construction would be around 64 cm depth, while the site might have been abandoned around 16 cm depth.

An earlier human impact phase might be inferred from the presence of cereal pollen at between 170 and 190 cm depth. As this coincides with decreases in oak pollen and minor increases in *Plantago lanceolata*, it probably reflects prehistoric human activity in the catchment. As the crannog on Lough Ross was never fully excavated, it is uncertain whether it had a Bronze Age occupation phase. A human presence near Ross Lough has been described from a large suite of finds near the Sillees river (Carrol, 1992), indicating Mesolithic burnt bones and implements as well as Bronze Age, Iron Age and Early Christian metal artefacts. However, a detailed age-depth model of core RL01 is essential before prehistoric occupation of the lake can be claimed with confidence.

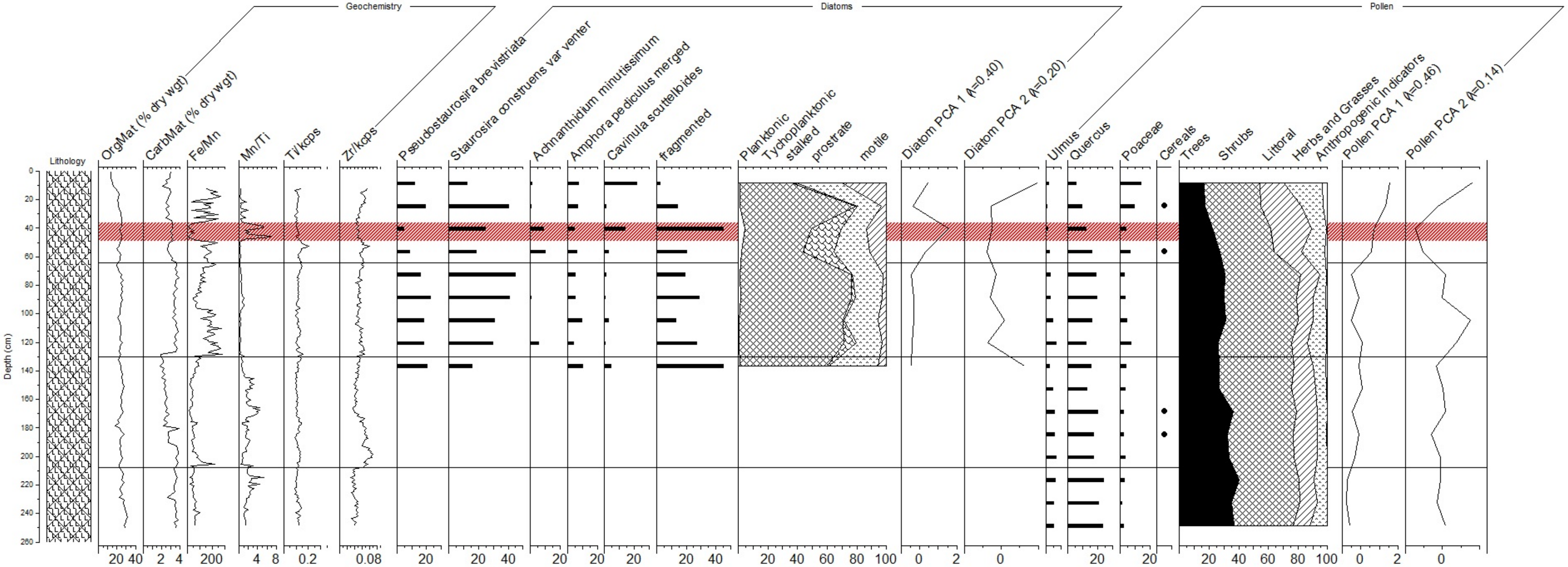


Figure 6.2.6 Summary diagram of the main changes in the geochemistry and pollen and diatom assemblages of RL01, with the main disturbance phase indicated by the red screen

Chapter 7: Discussion

7.1 Evaluation of the palaeoecology of crannogs

This thesis analysed key biostratigraphic proxies in order to establish changes in the lake ecosystem functioning in response to crannog construction. In the following section (7.2 local vs. regional disturbances) the disturbances associated with crannog construction will be discussed in more detail to try and infer general changes in south west Scotland and Co. Fermanagh around the time of the crannogs and to discuss local and regional disturbances. However, an understanding of crannog related disturbances in each of the proxy records will be discussed first. Crannog-associated disturbances identified in the proxies included evidence of erosion, deforestation, lake shallowing, eutrophication and acidification. The cores collected in the lakes were: Barhapple Loch (BL04), Cults Loch (TCL1) and Black Loch of Myrton (BLM01) in Scotland, while Derryhowlaght Lough (DL01) and Ross Lough (RL01) were from Co. Fermanagh.

7.1.1 Evidence of crannogs in pollen assemblages

The pollen assemblages reflect the catchment vegetation, which encompasses local grassland, woodlands and aquatic plants. When comparing the response of pollen assemblages to the crannog, it is important to note the resolution might be too low to pick up disturbances in the record, as the cores were sampled at resolutions not greater than once every eight centimetres. However, it is striking that any crannog-associated disturbances visible in the lake record appear minor (see figure 7.1.1) and can be obfuscated by long term changes. As many constructional elements of the crannog rely upon the woodlands, it would be expected that the construction would be associated with some deforestation in the pollen assemblages. Hazel branches are particularly flexible and are an essential part of most prehistoric roundhouses, in particular in the walls and roofs, while alder and oak timbers were more often used for the securing the mound and larger parts of the structure, such as flooring and the roof supports (Cavers, 2010, Crone, 2000). Large parts of the structure would be dependent upon branches and there is evidence that woodland management took place since the Neolithic (Göransson, 1986, Edwards, 1993), which can suppress (e.g. alder and lime) or enhance (hazel) pollen production (Waller et al., 2012).

The pollen assemblages from the cores indicate that the impact on the vegetation from the crannog is not a standard response, with evidence of reductions in oak trees in most crannogs, slight increases or stable levels or alder trees, both increases and reductions in birch and hazel. These responses probably depend on the size and distance of the woodlands, as the removal of patches of woodland would not stand out in a large forest, but might have more dramatic effects in smaller forests.

Furthermore, occupation of the crannog is probably associated with nearby pastures and or arable fields based upon the environmental analysis of organic deposits from Oakbank crannog in Loch Tay (Miller et al., 1998, Clapham and Scaife, 1988). As expected with archaeological sites, cereal pollen was found in almost all of the sites around the time of the crannog, although in Cults Loch this was quite a bit later. However, due to the issues with the radiocarbon dates in that core in particular, it might indicate that the crannog was actually higher up in the core (see also results discussion section 5.1). In a similar study on Lough Kinale cores, taken adjacent to crannogs indicated very high (>50%) abundance of *Hordeum*-type pollen (O'Brien et al. 2005, Selby et al. 2005), which was interpreted as crannog-based cereal processing or storage. Cereal-type pollen (e.g. *Hordeum*-type, *Avena*-type) are large pollen grains, which are unlikely to travel long distances (Edwards, 1990).

The sites in this study indicated that the first pollen PCA axis from all cores apart from Black Loch of Myrton mainly separated herb/grass and tree pollen (see figure 7.1.1). These sites all indicated a long-term trend towards more open vegetation. However, some sites indicate a gradual decrease in PCA axis 1, i.e. Barhapple Loch and Derryhowlaght Lough, while other sites indicate a gradual increase in the PCA axis 1, i.e. Ross Lough and Cults Loch, so to clarify the direction of vegetation openness an arrow is indicated in figure 7.1.1 (see pollen PCA sections in chapters 5 and 6). By comparing increases in the selected taxa to the long-term trend reflected by the first PCA axis, it is possible to check if the crannog disturbances are independent of long term vegetation changes. Indicators of wet meadows and/or pastures, such as Cyperaceae and *Plantago lanceolata*, showed an erratic response to the crannog, with some sites indicating increases while other sites show decreases of one or both indicators around the time of the crannog. The abundance of lycopodium spores represents changes in the total pollen accumulation rates, with a low abundance related to a high pollen accumulation rate (Stockmarr, 1971). As pollen might accumulate in wetlands via airborne transport as well as via water transport (Pohl, 1939), the influence of regional and local pollen input into the lake system will be discussed in the next section (7.2).

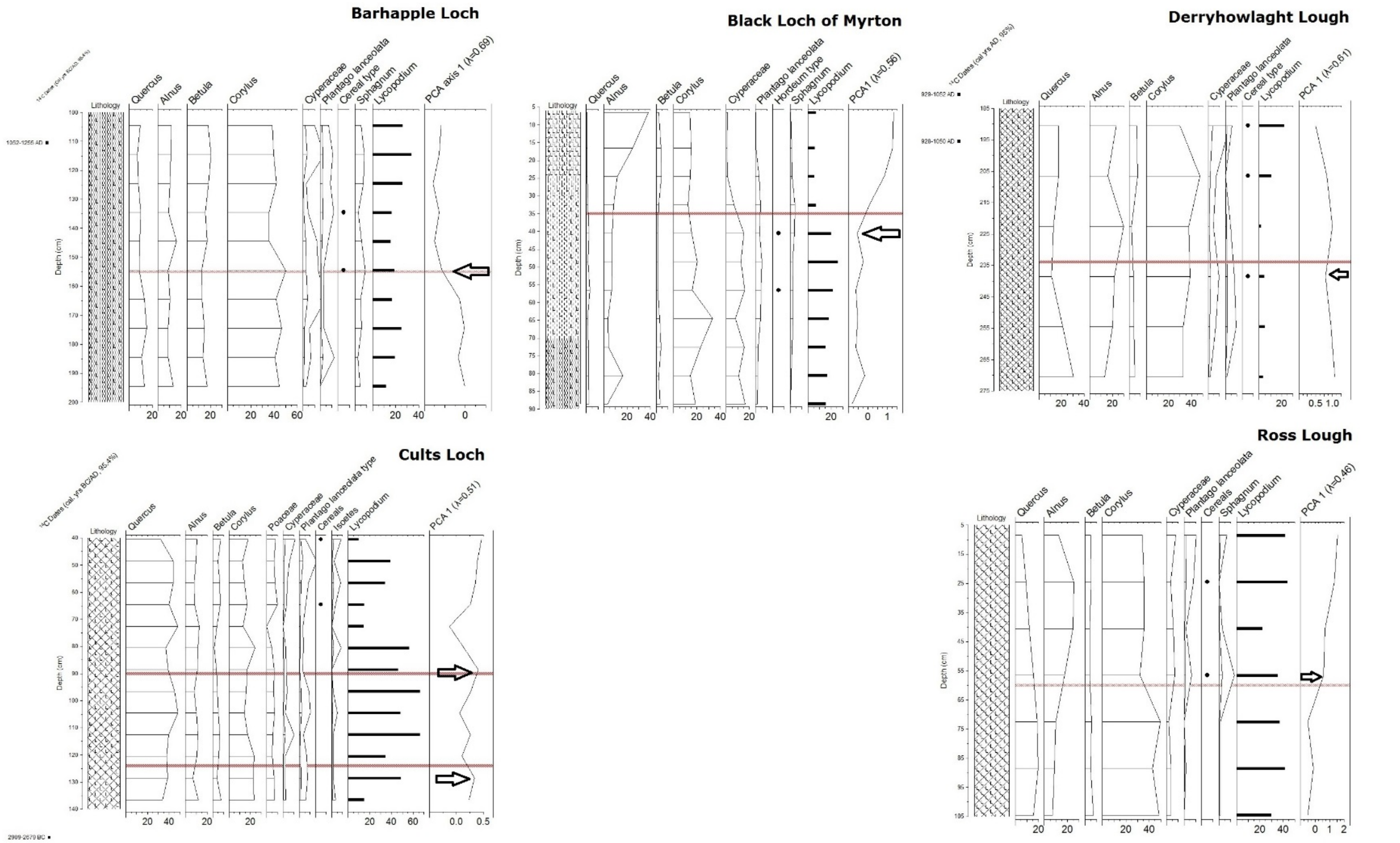


Figure 7.1.1 Selected pollen taxa of estimated crannog depths (red lines). Note Cult Loch contains two crannogs, with the promontory indicated by the lower red line, while the island crannog is the upper red line. The arrows in the PCA axes represent the direction of vegetation openness (increases in NAP)

7.1.2 Evidence of crannogs in diatom assemblages

Diatoms are influenced by physical controls such as nutrient availability as well as light availability, and can suffer from competition with other algae groups (Round et al., 2007). Furthermore, as evident from the cores from Ross Lough and Cults Loch, diatom assemblages can be influenced by dissolution, which is a result of either high silica demand or high ionic strength (Ryves et al., 2009, Ryves et al., 2006, Barker et al., 1994a). However, assuming that the diatom assemblages represent competition between diatom taxa for the available nutrients (e.g. phosphorous, nitrogen, light), some inferences can be made about the interactions of communities on the wetland ecology. Specific diatom taxa can be used to infer periods of eutrophication, shallowing, acidification and increased macrophytes (Smol and Stoermer, 2010, Jones, 2007, Battarbee et al., 2001, Smol and Cumming, 2000). For instance, indicators of eutrophication can be increases of specific genera, for example *Stephanodiscus* (Anderson, 1990a, Bigler et al., 2007, Hall and Smol, 1999) or specific taxa, such as *Asterionella Formosa*, *Fragilaria crotonensis* and *Nitzschia palea* are common in mesotrophic to eutrophic lakes (Karst and Smol, 1998, Ekdahl et al., 2007). Indicators of shallowing and increased macrophytes include reductions in planktonic taxa (Wolin and Duthie, 2001).

Centric taxa are often used to assess the trophic status of lakes. In this study planktonic taxa were rare, probably because almost all of the lakes in this study were shallow (<2m max. depth), which have prolonged periods of circulation and can be limiting on planktonic diatom blooms (Happey, 1970). The cores of Barhapple Loch and Derryhowlaght Lough have distinct periods with high amounts of planktonic taxa, of c. 20% and c.40%, respectively. The deepest lake of this study (Cults Loch, c. 8.5m max depth) is virtually barren of planktonic taxa (c. 5%, only in the uppermost sample), which indicates the lack of stratification in these lakes. Studies on river sediments have identified that planktonic taxa can be among the allogenic components in floodplains (Gaiser and Rühland, 2010, Wiklund et al., 2009, Wolfe et al., 2005), indicating that increases in centric taxa can be related to increased input from upstream lakes or the stream itself, rather than eutrophication. The effect of fluvial input into lakes depends on the hydrology of the lake, and will be discussed in the next section (section 7.2).

The higher abundances of *Aulacoseira* sp. in Cults Loch and Derryhowlaght Lough are more difficult to explain, as this genus is dependent on circulation. However, shallow lakes are continuously influenced by wind driven circulation which might promote the abundance of this genus, as its heavily silicified frustules are prone to rapid sinking when not agitated (Gibson et al., 2003). Furthermore, many taxa within the genus are adapted to low light conditions, indicating that it is able to survive when not in the epilimnion, which is why it is more commonly classified as a tychoplanktonic genus, rather than an euplanktonic taxon (Round et al., 2007, Gibson et al., 2003).

In the upper samples (30-0 cm depth) of Cults Loch and Derryhowlaght Lough, increases in mesotrophic to eutrophic planktonic taxa relates to eutrophication, which has been recorded in many lakes following intensification of agricultural land use (Bennion et al., 2004b). The genus *Stephanodiscus* is associated with increased epilimnic phosphorous (Anderson, 1990a) and the appearance of *Stephanodiscus parvus*/*minutulus* in the uppermost samples of Cults Loch and Derryhowlaght Lough probably indicates eutrophication.

The most dominant diatom genera in the study of palaeoenvironments of crannogs were *Staurosira* and *Stauroforma*, which are fragilarioids typical of shallow lakes (Sayer, 2001, Morales et al., 2010) and indicative of turbid waters in low conductivity environments. These tychoplanktonic taxa are prone to sinking and require circulation to remain in the water column (Round et al., 2007). Araphid taxa have limited trophic level information, especially in low-conductivity environments (Brugam and Patterson, 1983, Hall and Smol, 1999) so it is difficult to assess eutrophication in the diatom assemblages of the crannog lakes. The RDA analyses indicated that there is a link between the Fe/Mn ratio and most of the fragilarioid taxa (see chapter 5), and this will be discussed further in the next subsection (7.1.3).

The periphytic diatoms are the second most abundant group in this study and easily the most diverse. In an attempt to understand changes in the abundances of periphytic taxa further, they have been split in three attachment types: stalked, prostrate and motile (Round et al., 2007). These types reflect their growth environment and can indicate increases in macrophytes (stalked and prostrate), low energy environment (stalked) and abundances of epipelic taxa (motile) as indicated by diatom community studies (Hoagland et al., 1982, Kangur and Puusepp, 2010, Wang et al., 2014).

In an attempt to better understand the changes in diatom assemblages related to crannog palaeoenvironmental disturbances, a DCA was run with the diatom samples from all the cores (figure 7.1.2). This clearly separated the different lakes, with the Irish lakes relatively close together, while the Scottish lakes were further apart. This supports previous studies which identify that lakes probably have unique features (bathymetry, hydrology and nutrient inputs), providing a specific set of biota living in and around the lake (Langdon et al., 2006). Notably Barhapple Loch has quite different assemblages from the other lakes. The interpretation of the DCA axes is more complicated, as the axes are aligned with various types of diatoms. The first axis appears to show most of the stalked attachment taxa towards the left (e.g. *Eunotia* sp., *Encyonema* sp.), while towards the right there are more tychoplanktonic (e.g. *Staurosira* cf. *elliptica* and *Pseudostaurosira brevistriata*) and *Aulacoseira* sp. diatoms. The stalked diatoms, especially *Eunotia* sp., are indicative of bogs, which might reflect the high input of groundwater from the surrounding mosses (see site description section 3.2) entering Barhapple Loch. As the other lakes are all mainly towards the right side of the graph, and they may indicate that those diatom taxa better reflect shallow lakes.

The second diatom DCA axis appears to separate the Scottish and the Irish lakes. In the Dumfries and Galloway region the bedrock is mainly composed of sandstone and greywacke, while a large part of bedrock of Co. Fermanagh is the Tyrone group, which consists of limestone, sandstone, siltstone and mudstone. There are at least two indicator taxa of acidification at the lower end of the graph, *Aulacoseira alpigena* and *Stauroforma exiguiformis*, while in the upper end of the graph *Fragilaria capucina*, *Planothidium frequentissimum* and *Aulacoseira ambigua* are alkaliphilous. Therefore, the difference between the Scottish and Irish lakes might reflect the higher conductivity and alkalinity in Co. Fermanagh.

Within the graph the samples which were estimated to contain sediments contemporaneous with the crannog based on the age-depth models, are indicated by a filled symbol. In Barhapple Loch and Cults Loch the crannog samples are within the variance of the cores, whilst in the Black Loch of Myrton the samples appear separate from the other core samples, indicating a disturbance at that time of the crannog. Ross Lough and Derryhowlaght Lough show a similar response, with the crannog associated sample located away from the other samples, but this interpretation is somewhat limited as only a single sample contained crannog-associated sediments. Why these sites show the greatest disturbances probably depends upon the type of response, but also might reflect the catchment inputs, as these sites have some inflow from a stream or river (see also section 7.2).

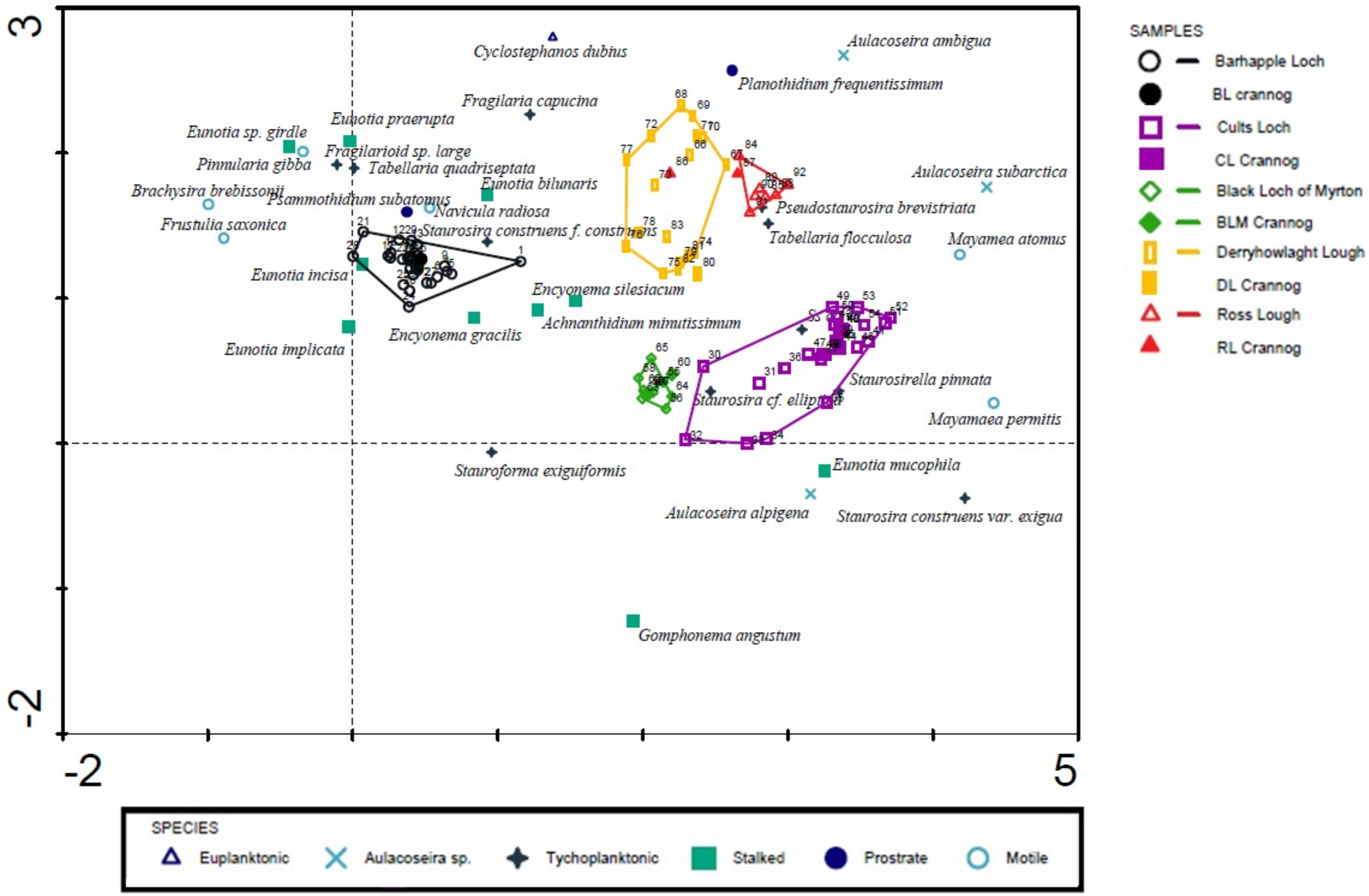


Figure 7.1.2 Diatom samples and species scores on the first two DCA axes of all the lakes combined. Crannog-related samples are indicated by filled sample symbols, while the remainder of the core is indicated by open symbols

Increased catchment disturbances occurring at the same time of the construction of the crannog could, for instance, be intensified land-use and associated deforestation. Derryhowlaght Lough indicates a shift mainly on the 2nd DCA axis, which probably mainly reflects acidification. This might indicate the increased input of humic substances from the crannog as well as local shallowing. Ross Lough indicates a shift mainly on the 1st DCA axis, indicative of more macrophytes and possibly a bog, which might be related to local shallowing from the mount, which adds a large amount of organic matter to the lake. The Black Loch of Myrton is a bit more complex, as the shift appears to be towards the upper right of the graph, which would reflect an increase in pH and macrophytes. However, as the settlement was probably built within a reedy fen, it might reflect the removal of the reeds and the addition of minerogenic matter on the site, which raised the pH slightly. From the DCA it might be inferred that the lakes in Co. Fermanagh are more sensitive to crannog-related disturbances, as both of the lakes indicated a shift of the crannog samples. Additional study on lakes with crannogs in Co. Fermanagh is essential, as currently it is unclear how sensitive these lakes are sensitive to, for instance, enhanced catchment disturbances or the large catchment in general. Further studies would benefit from the selection of lakes with small catchments, similar to Cults Loch and Barhapple Loch.

Diatoms assemblages were able to provide substantial information on palaeoecological disturbances related to crannogs. As the construction of crannogs will increase the shoreline of the lake, increases in macrophytes can be an indicator of the crannog. The importance of the genera *Aulacoseira* and *Stephanodiscus* is also evident from study on taxonomic distinctiveness and eutrophication, where these genera were among the key indicators of eutrophication in lakes in Ireland (Leira et al., 2009). The palaeoecological interpretation of shallow lakes would benefit from more investigation, as many of the dynamics of tychoplanktonic diatoms are poorly understood. For instance, do fragilarioids have a more competitive winter population, which allows for rapid spring blooms? Or are they driven by increases in phosphorous or rather silica. Studies that analysed the resource requirements of specific taxa (Kilham and Kilham, 1982) would be essential to further understanding the interspecies competition of tychoplanktonic diatoms.

7.1.3 Evidence of crannogs in geochemical records

In this study the cores from the lakes with crannogs were analysed by loss-on-ignition, magnetic susceptibility and X-ray fluorescence. Interpretation was complicated as all these analyses are influenced by both local (e.g. crannog) and regional (e.g. catchment) disturbances. As the next section (7.2) will attempt to disentangle local and regional disturbances in the cores, this section will focus on probable crannog-derived disturbances in the geochemical data.

The mounds of crannogs are problematic, as they can be composed of timbers, bracken and other plant materials, as well as cobbles, sands and soils (Cavers, 2010, Dixon, 1984b, Crone, 2000). Crannog structures include wattle-and-daub from the walls and floor deposits and hearth linings, which were probably rich in clays (Dixon, 1984b, Cavers, 2010, Crone, 2000). Therefore, it is likely that the construction of the mound and their structures adds large amounts of both minerogenic and organic matter to the lake. Ratios of organic matter to minerogenic matter of crannog mounds are unknown, but are likely to vary between crannogs as the builders used the materials that we the most accessible materials. The advantage of long lake records with both prior and post construction records is that they allow a better understanding of background sediment composition and where disturbances are located in the core.

Some of the cores (Derryhowlaght Lough, Black Loch of Myrton) indicate a reduction in the OM of c. 5% around the time of the crannogs (figure 7.1.3 and 7.1.4), probably related to increased accumulation of diagenetic materials, for example from disturbance and aeration of the sediments, which can be related to increases in Cu/Ti (Croudace et al., 2006, Rothwell et al., 2006) around the time of the crannogs. Furthermore, the crannog structures are prone to collapse and deterioration, which can be a reason for abandonment, as was identified in Buiston crannog (Crone, 2000). However, this was not always the case as structures on Drumclay appear to have been built up repeatedly over several centuries, although eventually abandoned (SMA, 2014, BBC, 2014). The structural instability might explain the high variable OM and MS after the construction of the crannog in Barhapple Loch, Black Loch of Myrton, Derryhowlaght Lough and Ross Lough.

The interpretation of the XRF analyses in relation to the crannog palaeoenvironments is complicated, as similar to the LOI and MS, the major component of the crannog-derived disturbances is the input of organic and minerogenic material from the crannog. Indicators of more resistant minerals (K, Ti, Zr) against an indicator of clay (Rb) probably reflects changes in sediment source/provenance and will be discussed further in the local and regional disturbances section (section 7.2). However, an erosion event might be indicative of the crannog due to the addition of minerogenic material to the lake during collapse or destruction of the superstructures and mound. The abandonment of crannogs is not that well understood, although the Buiston crannog did have evidence of slumping (Crone, 2000) in the final phases of occupation.

The Fe/Mn and Si/Ti ratios can reflect changes in the lake ecosystem related to the crannog. The distinct drops in the Fe/Mn ratio probably reflects Mn input from peatlands, pools or other semi-contained water sources during spring floods (Pontér et al., 1992, Björkvald et al., 2008). Furthermore, The lakes analysed are almost all shallow (<2m maximum depth), indicating the lakes are probably polymictic (Scheffer, 2004). The exception is Cults Loch (c. 8.5m max depth), which is mostly shallow (<3m depth), but has a deep basin from where the core was collected. The occupation of the crannog probably leads to some eutrophication, as the human occupants and livestock (Clapham and Scaife, 1988) would most likely dump their waste straight into the lake, which would be a source of nitrogen and phosphorous. The Si/Ti ratio reflects changes in silicate productivity (Boyle, 2001, Croudace et al., 2006, Rothwell et al., 2006) and is likely to increase during periods of diatom blooms, which might occur due to eutrophication driven by human occupation of the crannog.

The geochemical records are probably heavily influenced by catchment processes, but can still provide valuable information of disturbances. However, it is important to understand catchment processes, as they can dramatically alter the hydrology and geochemistry of the lake and the visibility of the crannog-related lake disturbances. Erosional indicators (LOI, MS and XRF K/Rb, Ti and Zr) are highly variable around the time of the crannog construction in most of the sites, which is probably related to continuing disturbances from the inherent instability of the crannog and associated slumping and revetment (Cavers, 2010) adding minerogenic and organic matter to the adjacent lake sediments. Most of the sites indicate elevated levels of Cu/Ti around the time of the crannog, reflecting increased diagenetic material. Local geochemical indicators, such as Si/Ti have a highly variable response, while the Fe/Mn of the lakes was probably influenced by the influx of manganese from semi-enclosed water sources such as adjacent peats. Therefore, it is important to understand catchment processes, as they are can dramatically alter the hydrology and geochemistry of the lake, which will be explored further in the next section.

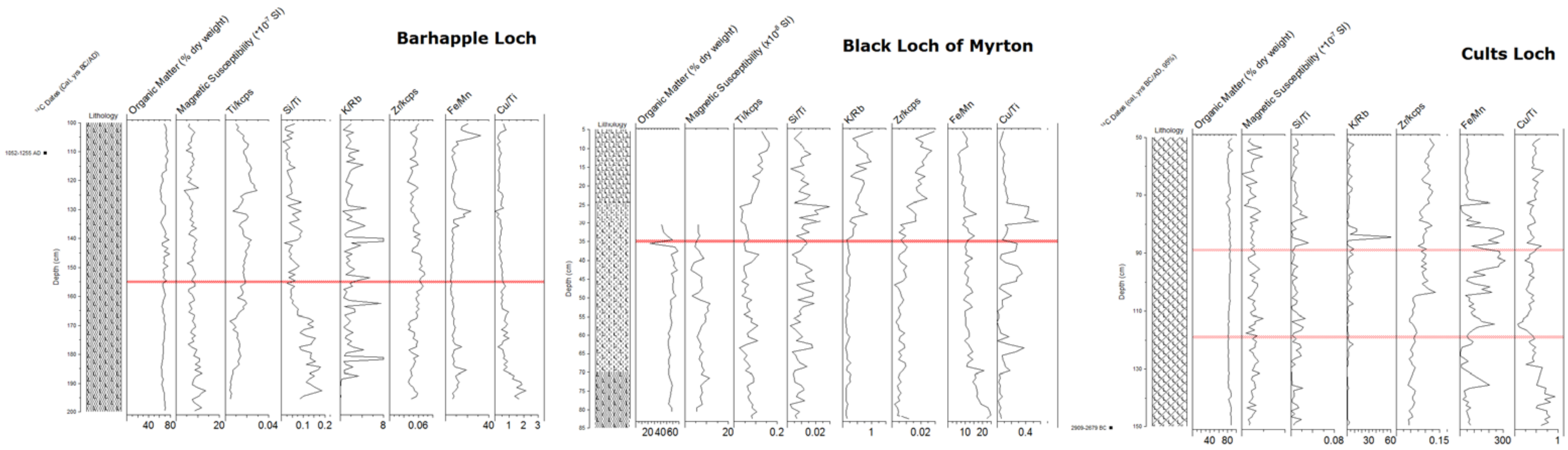


Figure 7.1.3 Summary of geochemical records around the time of the crannogs (indicated by the red lines), as estimated by the Bacon age-depth model (Cults Loch, Barhapple Loch) or as estimated by interpretation of stratigraphy (Black Loch of Myrton). Cults Loch contains two crannogs, with the promontory site indicated by the bottom line and the island crannog indicated by the upper red line

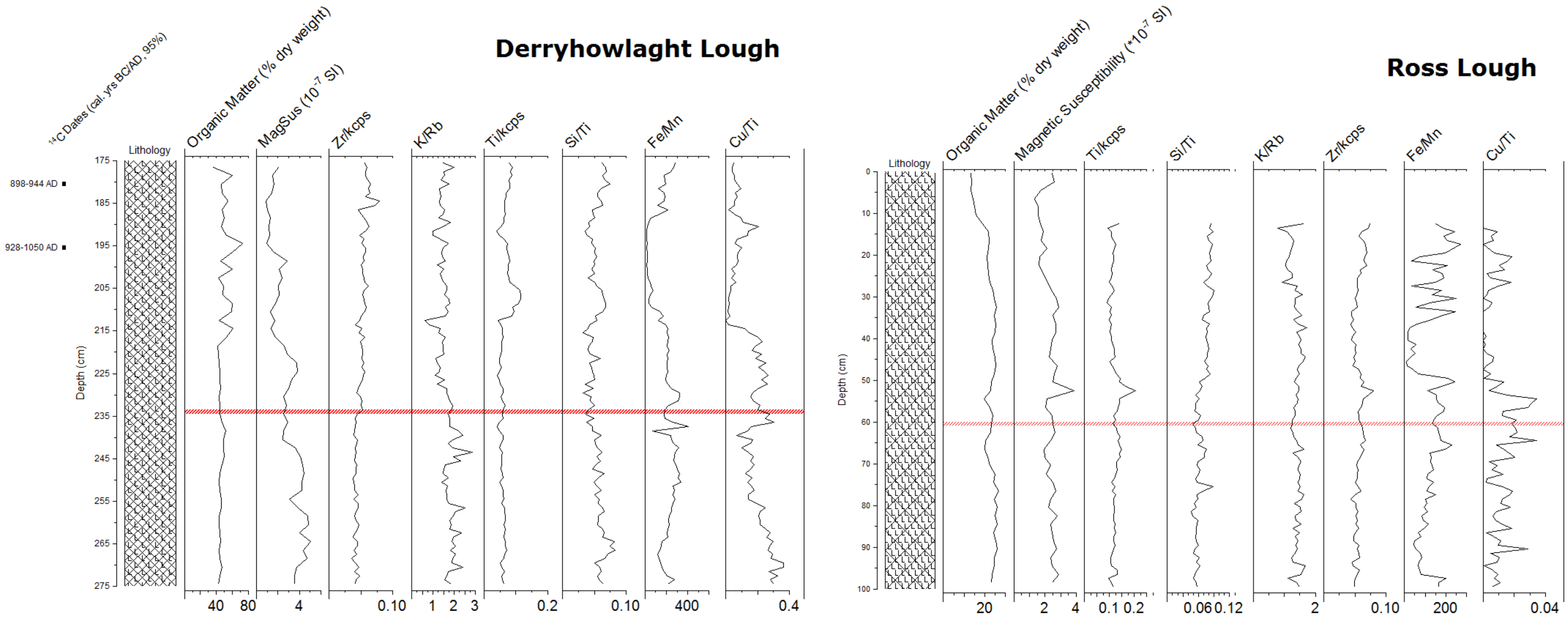


Figure 7.1.4 Summary of geochemical records around the time of the crannogs (indicated by the red lines), as estimated by the Bacon age-depth model (Derryhowlaght Lough) or as estimated by interpretation of multi-proxy analysis (Ross Lough)

7.2 Local vs. regional disturbances in the lake sediments

7.2.1 Catchment hydrology

To assess the proxies used in this project, the hydrology of the lakes will be compared. In principal the lakes should show a similar response (e.g. shallowing, eutrophication, deforestation and hypoxia) to the construction and occupation of their crannog, given their relatively narrow size and depth range. However, as the lakes have different lake and catchment sizes, the impact of the crannog will differ and could possibly be differentially diluted. Furthermore, with limited information on the occupation history of most of the sites, especially the two lakes from Co. Fermanagh, it is difficult to know if reduced evidence of the crannogs in the lake sediments is due to the fact that impact was limited, or if the lake was insensitive to crannog-related disturbances.

To assess the amount of allogenic material entering the lake compared to authigenic material, the lake area (A_L) and the catchment area (A_C) of the sites (table 7.2.1) were compared. By comparing the ratio of the lake size against the catchment size (A_L/A_C) it is possible to infer the effect of within-lake disturbances against catchment disturbances (Dearing and Foster, 1986, Harrison et al., 2002). This will affect the proxies in different ways, but probably both local and distal disturbances to the catchment will stand out in the record. In modelling studies assessing the effect of changes in precipitation on lake level in lakes of varying sizes and catchments, it was demonstrated that in lakes with an A_L/A_C smaller than 1:10 the change in lake level are increasingly diminished (figure 7.2.1) under a 200 mm reduction in precipitation, while under a 100 mm reduction in precipitation a significant reduction could be produced when the A_L/A_C was less than 1:2. Although precipitation and lake levels have different dynamics than for instance the effect of deforestation on erosion rates and nutrient input, the A_L/A_C ratio can be used to assess the probably extent that catchment disturbances will be picked up in the lake record.

Table 7.2.1 Lake and catchment characteristics. The pollen source is based on the basin size (Jacobson and Bradshaw, 1981), with an additional regional pollen signal if the lake has a stream inflow.

Site Name	$Area_{lake}$ (ha)	$Area_{catchment}$ (ha)	A_L/A_C ratio	Lake hydrology	Main pollen source
Cults Loch	6.66	67	1:10	Atmosphere controlled	Extra-local + Regional
Barhapple Loch	4.33	53	1:12	Atmosphere controlled	Extra-local + Regional
Black Loch of Myrton lake (mire)[1]	0.25 (3.65)	20093	1:80000 (1:5500)	Reservoir	Local + Regional Extra-local + Regional
Ross Lough partial (Ross Lough river system)	36.5	698 (9979)	1:19 (1:273)	Reservoir	Regional
Derryhowlaght Lough	5.13	1179	1:230	Reservoir	Extra-local + Regional

[1] The lake size is based on the 1st Edition OS map from 1848, though the lake was probably already partially drained at that time. The Black Loch of Myrton mire is an estimate based on the extent of the Black Loch plantation, which probably reflects the size of the mire.

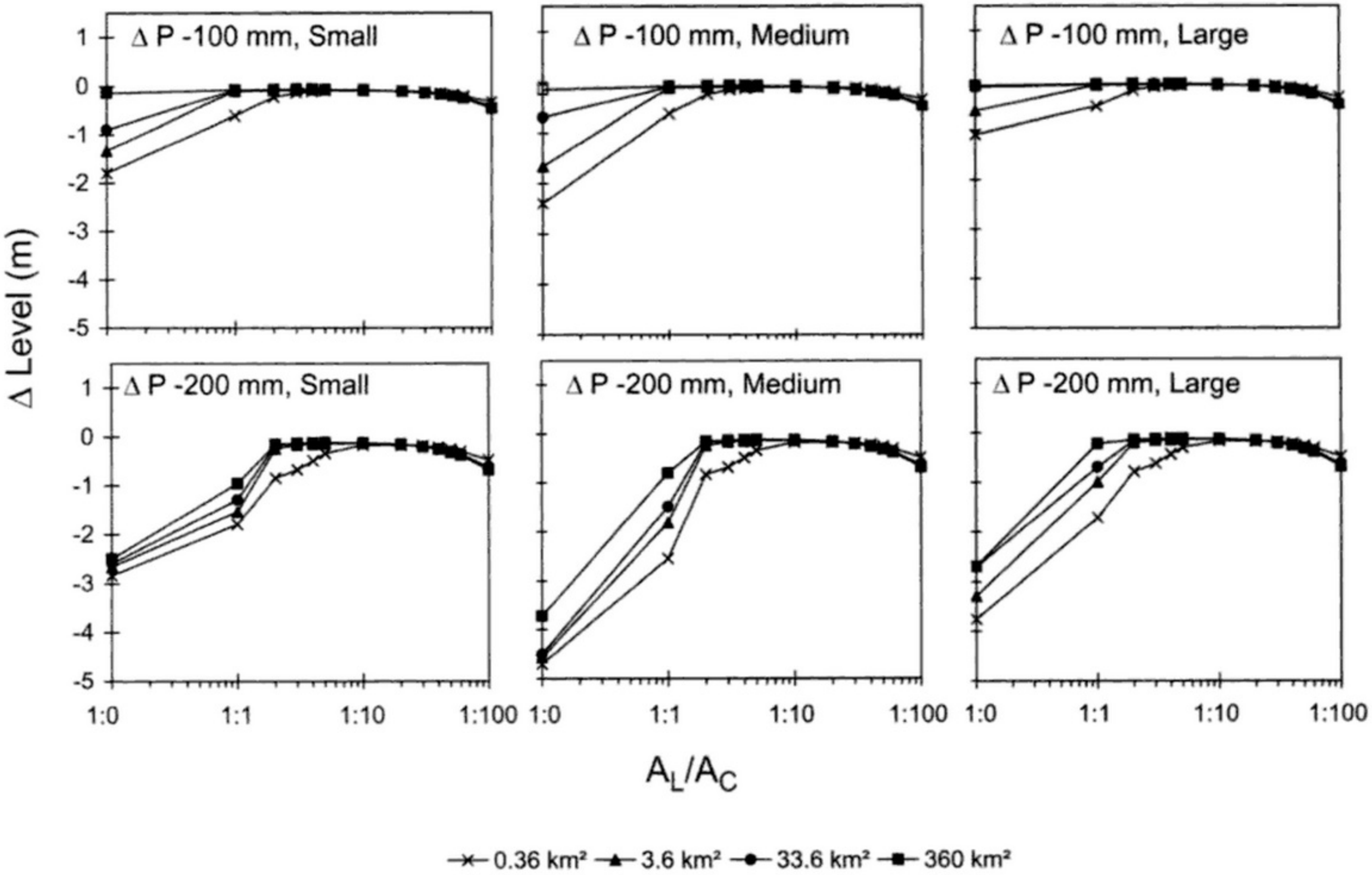


Figure 7.2.1 Sensitivity test of impact of changes in precipitation and associated lake level changes in lakes of different sizes (small, medium large) with different AL/AC ratios. From Harrison et al. (2002)

Furthermore, the study lakes could be assigned to three categories: atmosphere controlled lakes (P-E), amplifier lakes (R-E) and reservoir lakes (R-O). The main source of input for atmosphere controlled lakes is precipitation (P) and for amplifier lakes the main source is runoff (R), while evaporation (E) is the main loss of water for both. Reservoir lakes are mainly fed by runoff, while outflow (O) is the main water loss.

Black Loch of Myrton reflects a core was taken from the wetland surrounding the open body of water. Although a series of cores was taken along transects to determine the extent of the wetland, it indicated that the wetland makes up large parts of the Black Loch plantation. The Black Loch of Myrton lake size is based on the area of the lake from the 1st edition OS map. However, the core was not collected from the lake, as at the time of coring its location and size are uncertain. As the lake is part of the wetland system of the Black Loch, the actual size of the mire is much larger than the extent of the lake, reflected in the peat content of the cores along the transects (site description BLM). Although these water bodies are quite different in size, the very large size of the catchment means that the water body has an A_L/A_C ratio much smaller than 1:100, indicating that disturbances in core BLM01 most likely reflect regional activities.

The Co. Fermanagh lakes have a low A_L/A_C ratio, which is mainly driven by the size of the catchment. Both Derryhowlaght Lough and Ross Lough are probably reservoir lakes, as they are connected to a river system and driven by run-off and outflow (Street-Perrott and Harrison, 1985, Mason et al., 1994). Derryhowlaght Lough is part of a tributary of the River Erne, with water flowing in from Lough Corban and a stream that has its source near Lisbellaw (see site description), while it flows out directly into the River Erne from Derryhowlaght Lough. The immediate area around Derryhowlaght Lough (<350m distance) makes up only 3% of the total catchment, so almost all of the precipitated water entering the lake will have travelled from further away. This is reflected in the low A_L/A_C ratio of 1:230 of Derryhowlaght Lough. Given the large catchment size of Derryhowlaght Lough (table 7.2.1), it is likely that local disturbances would have to be large to be picked in the Derryhowlaght Lough record, as it is very likely to become diluted from distal input.

The Ross Lough – Sillees river system has a similarly low A_L/A_C ratio (1:273), indicating a very large catchment. However, it is slightly complicated by the hydrology of the lake, as Ross Lough probably has a distinct eastern and western basin (see site description). The Sillees River originates near Lough Achork in the Lough Navar Forest and flows for 27.6km before reaching Ross Lough. The catchment of the Sillees River up to Ross Lough is almost 10,000 ha, while the entire Sillees river catchment is 16,630 ha. As the core was taken from the eastern basin c. 10m from the crannog, it is probably influenced to a lesser extent by the river system. The partial eastern part of the Ross Lough – Sillees river catchment is much smaller, making up only 1.8% of the entire Ross Lough – Sillees river catchment. Although Ross Lough is the largest lake in this study, the eastern catchment, which is assumed to be mainly affecting sediments near the crannog, is not that big relatively, as indicated by a lower A_L/A_C ratio, so it probably picks up local disturbances quite well, although it might still be influenced by disturbances further away in the catchment.

There is a striking difference between the Scottish lakes and the Northern Irish lakes, as the Scottish lakes are smaller, but more importantly have a much smaller catchment. Barhapple Loch and Cults Loch are small kettle lakes, where the catchment hydrology indicates that the water source is within 1km of the lake, which means that there should be mainly a local signal in the lake sediments. This is reflected by an A_L/A_C ratio around 1:10, which indicates that disturbances picked up in the record are probably local. These two lakes are mainly precipitation fed, while being controlled by outflow into stream systems. Barhapple Loch flows into the Dergoals burn and in the past might have flowed in the Barlae Burn and subsequently Tarf Water, based on the contour lines of the area, indicating that it might have been a reservoir lake during the Neolithic/Bronze Age. An interesting idea might be to investigate whether reservoir are more suitable lakes for long-term crannog occupation, as they have less variable lake levels. This is not always the case, as Loch Tay is a reservoir lake but it has a 1 meter variation in lake levels (Dixon, 1982b).

The A_L/A_C ratio of the lakes analysed in this study indicate that they have widely varying ranges from which they might receive input. Of the Scottish lochs, Cults Loch and Barhapple Loch probably reflect mainly local changes as indicated by the low A_L/A_C ratio. The lakes from Co. Fermanagh have much larger catchments, indicating that the disturbances picked up in the cores have a higher chance of reflecting human impact from further away, as well as local disturbance. Black Loch of Myrton also has a large catchment, and given the small size of the lake/mire, distant disturbances probably reflected most strongly in the core, limiting its use for detecting settlement-related disturbances. However, given the large amount of peat in the sediments underneath and surrounding the crannog, it should probably be viewed as a wetland rather than a lake settlement.

The proxies will reflect different input sources into the lake system. The pollen assemblages are mainly influenced by basin size, which has been investigated via modelling studies by

Sugita (1994, 2007a, 2007b), indicating that although Cults Loch and Barhapple Loch fall within the small lake category, they will still largely reflect regional vegetation. However, these studies do not take into account fluvial input and so are not directly applicable to Derryhowlaght Lough, Ross Lough or Black Loch of Myrton. Furthermore, episodic events, such as flood pulses, have been shown to dominate (c. 90%) the fluvial transport of pollen assemblages (Brown et al., 2007, Brown et al., 2008), but these do reflect catchment vegetation. Furthermore, pollen assemblages have distinct sources, with local pollen originating within 20m of the lake, while extra-local pollen are from plants between 20 and several hundred metres from the basin and regional pollen from further away (Jacobson and Bradshaw, 1981). It might be inferred that the latter lakes probably have a much higher regional signal in the pollen assemblages from the fluvial input. Wetland peat cores often have a much higher local pollen signal (Prentice, 1985, Jacobson and Bradshaw, 1981), which might reflect the high amounts of wet woodland taxa in the Black Loch of Myrton. The geochemistry is more complicated, as it depends on the specific elements analysed, which can have very distinct interactions within the lake-catchment ecosystem. For instance, the magnetic susceptibility will be dominated by catchment erosion, although if the erosion is low it will be dominated by organic matter accumulation, which is mainly driven by within-lake processes (Dearing, 1999).

The diatoms are probably dominated by a local signal, as the frustules originate within the aquatic system before they sediment (Round et al., 2007, Jones, 2007, Battarbee et al., 2001). However, the interpretation of diatom assemblages of lakes with an inflow benefit from sampling the streams to determine common fluvial taxa. Stream inputs have been inferred from specific taxa more common in turbid fluvial environments, such as *Aulacoseira granulata* in Southern Australia (Gell et al., 2005, Leahy et al., 2005) or *Staurosirella pinnata* in Western Canada (Wolfe et al., 2005).

7.2.2 Regional palaeoenvironmental change: south west Scotland

To determine overarching responses of the proxies, the various results from the two regions (south west Scotland and Co. Fermanagh) will be discussed. Responses of local indicators, mainly the diatoms and the geochemistry, will be analysed to determine their application, in combination with the site A_L/A_C ratios. On a regional scale, the pollen analysis (see also table 7.2.1) and geochemical erosion indicators can be compared to test if catchment disturbances are synchronous. The cores from Cults Loch, Barhapple Loch and the Black Loch of Myrton can be compared to reconstruct changes in their palaeoenvironment. Although the core of the Black Loch of Myrton has not been dated directly, stakes from the palisade indicated two possible occupation phases, between 770 and 200 cal. yrs BC. This minimum age range was then applied to the depths at which cereal pollen were found in the core from BLM01 (between 35 and 68 cm, see appendix A.3). These depths are indicated in the diagrams.

The diatom data indicates that all the cores are dominated by tychoplanktonic diatoms, mainly *Staurosira* cf. *elliptica*, *Staurosira construens* spp. and *Stauroforma exiguiformis*, indicating turbid waters and low conductivity (Sayer, 2001). In the Black Loch of Myrton and Barhapple Loch, there are high amounts of periphytic taxa, mainly stalked taxa *Achnanthidium minutissimum* and *Eunotia* sp., representing macrophytes and a low energy environment, indicative of a wetland (Gaiser and Rühland, 2010). Cults Loch is different, as the assemblages indicate high amounts of the small naviculoid *Mayamaea atomus*, a motile epipelic taxon indicative of a highly organic environment (Lange-Bertalot, 1997). In Cults Loch, euplanktonic taxa are almost absent from the core, occurring only in the uppermost sample and probably related to recent eutrophication. However *Aulacoseira subarctica* occurs up to 35% in the assemblage. It is a heavily silicified tychoplanktonic taxon that is prone to sinking and requires circulation to take advantage of epilimnic nutrients (Gibson et al., 2003). Furthermore the taxon is shade tolerant and benefits from extended autumnal mixing, for example during mild winters (Horn et al., 2011). The presence of *Aulacoseira* in Cults Loch and euplanktonic taxa in Barhapple Loch might represent eutrophication in these cores. The Black Loch of Myrton is more or less barren of centric diatoms, so eutrophication is difficult to explore. The diatom assemblages from Black Loch of Myrton are dominated by epiphytic and epipelic taxa, with rare centric diatoms probably derived from flooding phases (see also discussion in section 5.3.3).

In an attempt to determine regional changes in south west Scotland, the radiocarbon-dated cores from Cults Loch and Barhapple Loch were compared using their diatom and pollen assemblages (figure 7.2.1), while the core from Black Loch of Myrton represents only a short period of time so has reduced value in long-term regional comparisons. One of the most pronounced changes in this regional record is the increase in the abundance of centric diatoms between 5200 and 3600 cal. yrs BP. In Barhapple Loch the maximum in planktonic diatoms is reached between c. 4450 and 3750 cal. yrs. BP, while in Cults Loch the increase in *Aulacoseira* sp. is complicated by the length of the core, but lasted until 4600 cal. yrs. BP. Increases in planktonic diatoms might be related to a higher water table, although increased nutrient levels are a more likely cause of increases in centric diatoms, especially the genus *Stephanodiscus*.

A higher water table might be attributed to climatic instability, as the 4.2k BP event is widely described as a wet phase in bog records from the British Isles (Hughes et al., 2000, Barber et al., 2003, Barber, 2007, Mauquoy et al., 2008, Daley and Barber, 2012). However, given the diachronicity of the events in cores BL04 and TCL1, as well as the evident link with vegetation changes, it probably indicates that these changes are related to human impact, rather than climatic disturbances. As all of these lakes were outflow controlled, they are probably not sensitive to precipitation. The area around the Galloway Hills has extensive evidence of deforestation since the Bronze Age and human activity has been linked to increased erosion rates (Edwards et al., 1991, Jones et al., 1987).

In Barhapple Loch, increases in *Aulacoseira* sp. coincide with a higher minerogenic matter content and higher abundances of non-arboreal pollen (see also chapter 5.2), which provides a tentative link between deforestation, catchment erosion and increased abundance of centric diatom taxa. It is likely that the increased abundances of centric diatoms in these cores are a response to higher nutrient levels, as the centric taxa identified in Barhapple Loch and Cults Loch are mainly mesotrophic. As the RDA analyses (chapter 5) indicated a relationship between fragilarioid diatoms and the Fe/Mn ratio, it might indicate that during periods of reduced spring flooding (high Fe/Mn) these fragilarioid taxa thrive in the lakes, while they are quickly out-competed by centric taxa when more nutrients enter the lake from the floods (low Fe/Mn).

A second phase of increased abundances of centric diatoms takes place in the upper part of the cores, starting around 2400 cal. yrs BP, although the increased abundance is of reduced intensity compared to the lower interval of higher centric diatoms. Furthermore, these phases appear diachronous, with increased abundance of *Aulacoseira* sp. in Cults Loch between 2400 and 1550 cal. yrs BP and between 900 cal. yrs BP and the top of the core (c. 1912 AD), while there is an increased abundance of *Aulacoseira* sp. in Barhapple Loch between 1400 and 850 cal. yrs BP. The middle increase (from 2400 to 1550 cal. yrs BP) in *Aulacoseira subarctica* in Cults Loch coincides with a deforestation phase and is probably related to activity around the lake, predating the crannogs in Cults Loch by approximate 500 years. It might be related to the ring ditches and enclosures that surround Cults Loch, which are currently undated.

The pollen assemblages of the Scottish sites (figure 7.2.2) have extensive evidence of short-term woodland disturbances, with fluctuations in arboreal pollen abundances. Over the length of the core there is a trend of deforestation, with increases in both NAP and anthropogenic indicators, reflected in the PCA axes. Dominant taxa in the sites are mainly *Quercus*, *Corylus* and *Alnus* at the bottom of the core, while towards the top of the cores Poaceae and Ericaceae pollen increase, reflecting a more open vegetation.

The timing of the deforestation phase in the bottom of the core appears significantly different when comparing the south west of Scotland and Co. Fermanagh lakes. In Dumfries and Galloway the AP have already been reduced (c. 60% and below) prior to the construction of the crannog, indicating that deforestation has already taken place. The Late Neolithic-Bronze Age transition, which shows extensive deforestation in the region (Tipping, 1997, Tipping, 1995, Jones et al., 1989) precedes most of the crannogs in south west Scotland, which are mainly dated to the Iron Age (Cavers, 2010, Henderson et al., 2006, Henderson et al., 2003). This indicates that settlements had already had some impact upon the landscape and the crannogs were probably part of the communities in the region, rather than isolated sites. Furthermore, one could argue that crannogs represent a continuation of the occupation of these areas and do not necessarily signify new groups taking advantage of these areas. Although the lakes themselves were not inhabited prior to the construction of the crannog, it is likely that they were already an important resource for the inhabitants of the regions. In the upper part of the core there are often several further reductions in AP during and/or after the estimated crannog construction in the cores relating to intensified land use in the catchment vegetation, signifying intensified land use during the Medieval and post-medieval periods.

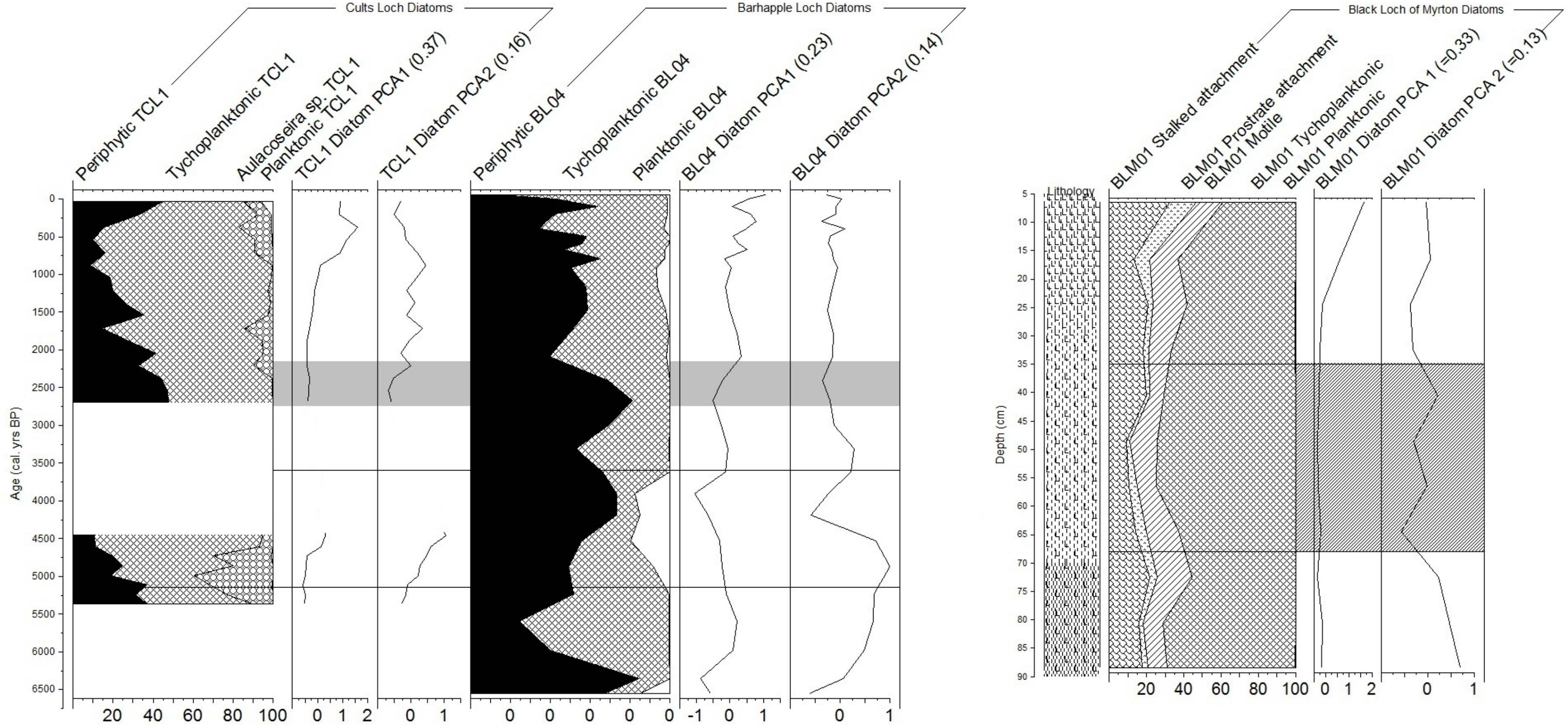


Figure 7.2.2 Summary of diatom assemblages from Barhapple Loch, Cults Loch and Black Loch of Myrton. The cores have been calibrated using the radiocarbon dates to check the cores for coinciding disturbances (dark lines), while the Black Loch of Myrton is currently undated, though the dashed area indicates the probable depth of settlement related deposits

Prior to 1500 cal. yrs. BC, Barhapple Loch shows a steadily increasing amount of NAP, while in Cults Loch the NAP increases. This probably reflects a strong local signal, with limited evidence of coinciding regional-scale disturbances. Pollen assemblages from water bodies can reflect very local environments and be heavily influenced by for instance fluvial input (David, 1991) and flooding phases (Brown et al., 2007). Around 2250 cal. yrs BC there is a peak in arboreal pollen in Barhapple Loch, while this occurs later in Cults Loch, around c. 1750 cal. yrs BC. Both lakes show increases in arboreal pollen above 1750 cal. yrs BC, indicating synchronous deforestation around the lakes. Given the extensive evidence of megalithic structures in the region (RCAHMS, 1912), as well as a Neolithic religious site near Dunragit (Thomas, 2015), it is probable that deforestation was substantial, with small scale clearances in the region (Tipping, 1994).

Under the assumption that climatic signals would occur synchronously in the Scottish lakes, the dated cores from Cults Loch and Barhapple Loch indicate poor synchronicity. A possibility might be that the radiocarbon dates on the core are incorrect, especially as Cults Loch has many issues with the radiocarbon dates, as two out of three radiocarbon dates were rejected and the top of the core was dated using a maximum in XRF lead content. Although studies at other Scottish sites have been able to detect climatic changes, these sites were further north (e.g. Dalton et al., 2005) or were peat records from bogs and mires (e.g. Chambers et al., 1997, Anderson et al., 1998, Langdon and Barber, 2005, Blundell and Barber, 2006, Tipping et al., 2008), which are more sensitive to climatic disturbances. When mainland Scotland was compared from bog-wetness records, it became evident that climate-inferred changes are asynchronous and regional (Langdon and Barber, 2005).

As Ross Lough is currently without a chronology, an estimate has been made of the timing of events and the location of the crannog using indicators by comparing the proxies to the analyses from Derryhowlaght Lough. This means that regional inferences are heavily dependent upon the chronology of Derryhowlaght Lough. Prior to the construction of crannogs in Co. Fermanagh the AP are much higher (c. 90% and above) than in south west Scotland and it would appear that the major deforestation events took place after the main crannog construction phase. The increased land use during the medieval periods in Ireland might be driven by extensive land use of ecclesiastical communities (Stout and Stout, 1997, Hall, 2005). The pollen assemblages from Derryhowlaght Lough are similar to evidence from other pollen records in Northern Ireland (Hall, 2005, Brown et al., 2005, Edwards and Whittington, 2001, Hall, 2003, Kerr et al., 2009, Mitchell, 1956), indicating that in Ireland the main deforestation phase did not take place until the end of the Early Christian period.

The geochemistry of the cores was compared, indicating that overall the cores are quite different, with only a few proxies showing concurrent shifts in the records (figure 7.2.3). In this examination K/Rb, MS and OM were selected as they represent changes in sediment components and grain size, while the Fe/Mn reflects changes to the pH and/or lake circulation and the Si/Ti reflects changes in biogenic silica and lake productivity (Engstrom and Wright Jr., 1984, Rothwell et al., 2006, Croudace et al., 2006). The MS and the XRF Si/Ti do not show coinciding increases in the core. The Fe/Mn ratio appears to show a similar increase in both cores around 3500 cal. yrs. BC, which represents shift towards more alkaline conditions, limiting Mn deposition in the lakes. It might be related to increased allogenic catchment input, which would be the main source of material with a higher pH. There is some evidence of a higher pH from a slightly higher carbonate matter in the cores (see section 5.1.2 and 5.2.2 on Cults Loch and Barhapple Loch geochemistry).

A similar coinciding increase is located at a depth of c. 1250 cal. yrs. AD. Both cores have a high OM content (>60%), but there is only one phase where the cores seem to respond at the same time. Around 2700 cal. yrs. BC both the cores seem to indicate a reduction in organic matter. However this appears to a far greater extent in Barhapple Loch, while in Cults Loch this is a minor decrease. Both events are probably driven by catchment deforestation and erosion, as both cores indicate increases in NAP around this time (figure 7.2.2). Finally in the top of the cores, around c. 250 cal. yrs AD and c. 1250 cal. yrs AD, there is a sharp peak in the K/Rb ratios in both cores. Although this peak in the K/Rb is mainly driven by very low amounts of Rb, relative increases in K are indicative of erosion from the catchment (Rothwell et al., 2006, Croudace et al., 2006).

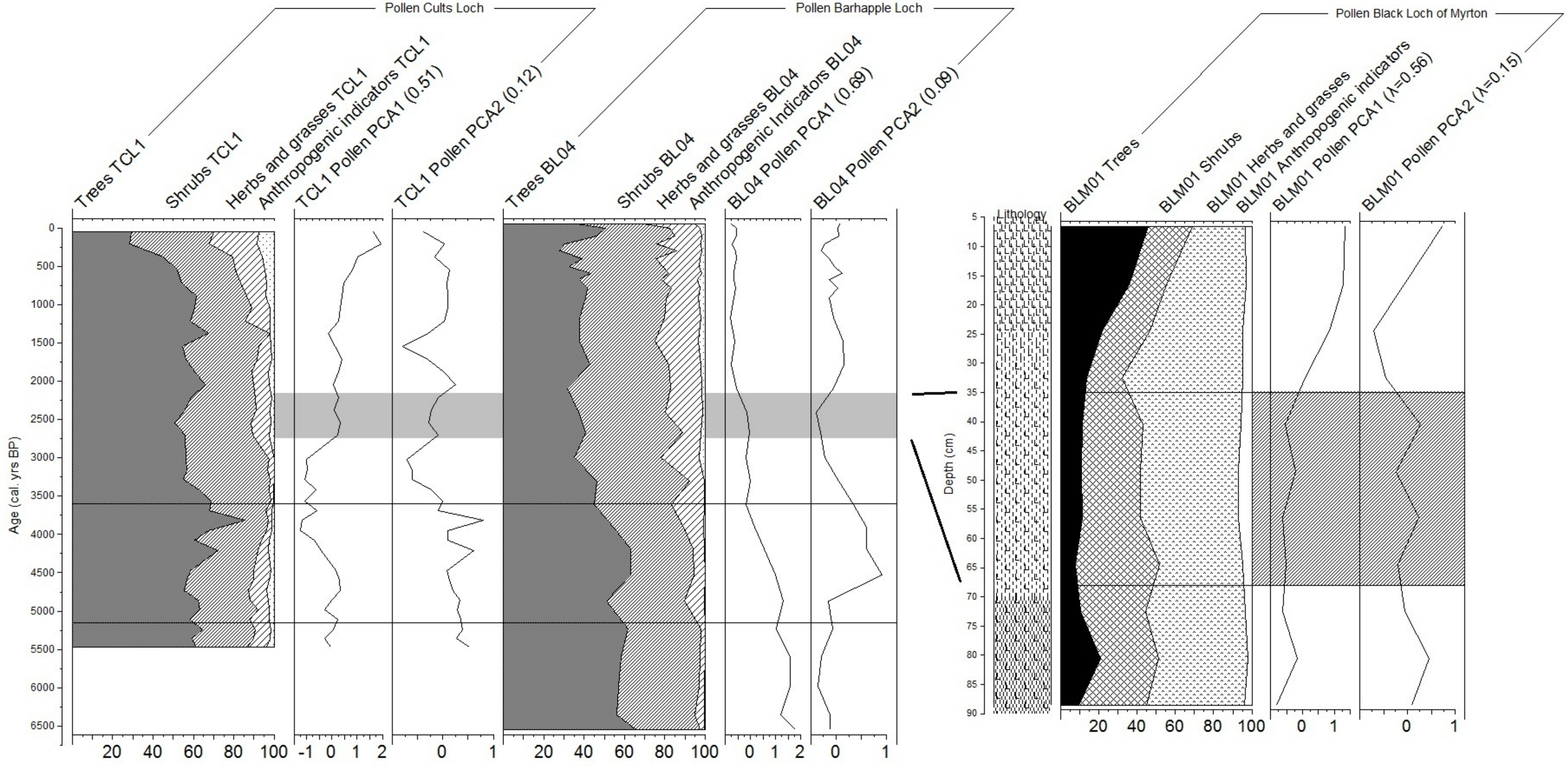


Figure 7.2.3 Summary of pollen assemblages from Barhapple Loch, Cults Loch and Black Loch of Myrton. The cores have been calibrated using the radiocarbon dates to check the cores for coinciding disturbances (dark lines), while the Black Loch of Myrton is currently undated, though the dashed area indicates the probable depth of settlement-related deposits

Care has to be taken with the interpretation, due to issues with the chronology in the upper part of the cores (see section 5.1.2 and 5.2.2 on cults Loch and Barhapple Loch chronology), which is largely based on a peak in the Pb/Ti indicating the maximum in lead deposition around 1970 AD. A maximum in catchment erosion during the medieval period is another tentative link of regional activity linked between the sites, as the Cults Loch crannog in the centre of the lake was dated to around this time (92-380 cal. yrs AD). Around 1250 AD Norman Lords enhanced control of Dumfries and Galloway with the establishment of small castles and abbeys, which probably led to increased regional deforestation and associated erosion. Furthermore, Barhapple Loch lies adjacent to the main road connecting Stranraer and Glenluce to Newton Stewart, which was marked on 18th Century maps (Roy, 1747-1755). Cults Loch lies near Castle Kennedy (<1km), which probably has a Norman origin. There was also the appointment of John, Lord Kennedy as Keeper in 1482 (RCAHMS, 1912). Around 1191 AD Glenluce Abbey was constructed as a Cistercian Order and reflects another source of regional human impact (Oram, 2001). Glenluce Abbey lies between Cults Loch and Barhapple Loch (see appendix A.2). In Dumfries and Galloway, it appears that the diatom and pollen assemblages from the cores from Cults Loch and Barhapple Loch show asynchronous fluctuations in the records. This indicates that these proxies are not driven by regional, but rather local disturbances. This makes these proxies very suitable for the purpose of crannog-related disturbances and should be considered an essential part of further crannog palaeoenvironmental disturbances.

The geochemistry has some intervals where the cores indicate synchronous fluctuations. These take place around 5500 cal. yrs BP, 4600 cal. yrs BP, 1550 cal. yrs BP and 700 cal. yrs AD. The prehistoric dates reflect Neolithic deforestation and catchment erosion, with some intermittent evidence in the pollen records. Evidence of an extensive Neolithic ceremonial complex was uncovered near Dunragit (Thomas, 2015), which is related to the establishment of settlements and the elevated K/Rb levels in Cults Loch and Barhapple Loch around this time. The Early and High Medieval disturbances are related to the establishment of castles and abbeys during the reign of the Norman Lords of Galloway (Oram, 2001, Anderson, 1908), which must have had a regional impact. From the Scottish sites in the crannog palaeoenvironmental project there is limited evidence of climatic shifts driving the ecosystem, with human impact the main driver of catchment and lake disturbances (Dearing et al., 2006a, Dearing et al., 2006b, Messerli et al., 2000) since at least the middle Neolithic (c. 3000 cal. yrs BC).

These Neolithic and Medieval phases might reflect periods when regional connectivity was high and human impact took place over larger areas at roughly the same time. It might also reflect times when there was a dominant ruler in the area connecting the region, as these changes took place at more or less the same time, which requires some coordination. Furthermore, the lack of coincident disturbances during the Early Iron Age supports the established theory that the Galloway region was heavily fragmented during the pre-Roman Iron Age (Armit and Ralston, 1997, Armit, 2006). This is supported by a low amount of large hill forts (over 2.5 ha) in the region, compared to the rest of southern Scotland (Cunliffe, 2009, p. 217). However, the south west of Scotland during the Iron Age is underrepresented in the archaeological literature and would benefit from large-scale regional studies to tie in the rich evidence. Recent projects that have tried to compare specific settlement sites or Iron Age sites in general are a much needed addition to the understanding of the region (Cavers, 2010, Poller, 2005).

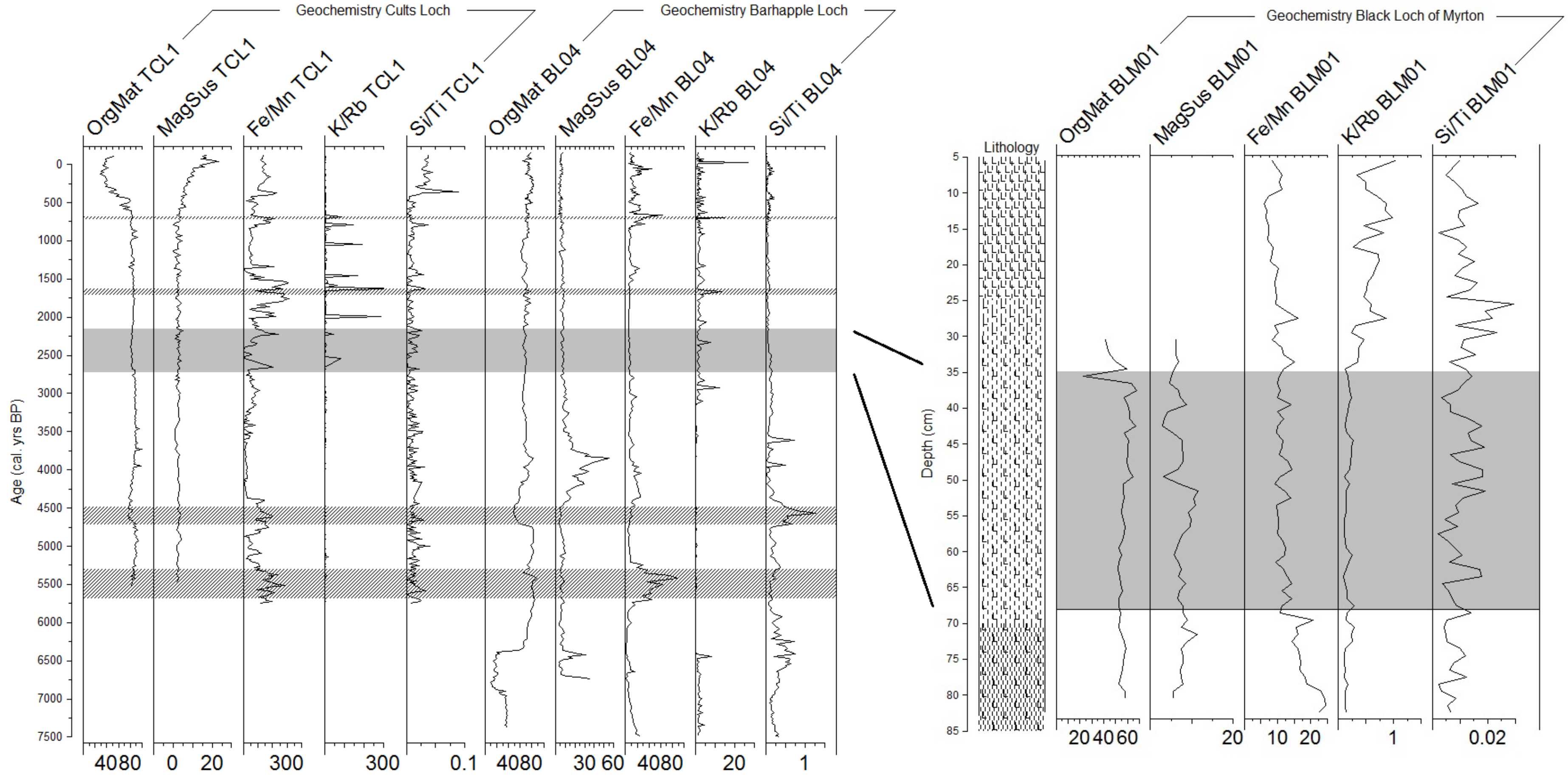


Figure 7.2.4 Selected geochemical proxies from Barhapple Loch, Cults Loch and Black Loch of Myrton. The cores have been calibrated using the radiocarbon dates to check the cores for coinciding disturbances (dashed area), while the Black Loch of Myrton is currently undated, though the grey area indicates the probable depth of settlement-related deposits

7.2.3 Regional palaeoenvironmental change: Co. Fermanagh

The cores from Derryhowlaght Lough and Ross Lough can be compared to reconstruct changes in their palaeoenvironment. As reviewed previously (see section 1.5.2 and chapter 6), Co. Fermanagh was probably influenced by different kingdoms the first millennium AD, as it is located at the borders between the kingdoms of the Northern Uí Néill, Connachta and Aírgíalla. Furthermore, at the same time as the occupation of many of crannogs, monastic sites were established on Lough Erne (Devenish Island, Inishmacsaint and White Island) and the lakes were an important part in St. Patrick's pilgrimage towards Lough Derg on the east coast. The establishment of monasteries will have a dramatic effect on the landscape vegetation, with the creation of large areas of cultivation and the required materials for construction (Hall, 2005).

Derryhowlaght Lough has an age-depth model with some complications (see section 6.1.2), so the core can be used to relate regional disturbances to historical events, but care has to be taken with the interpretation of the timing of the events. Although the core from Ross Lough has not been dated, the pollen assemblages indicate a substantial reduction in woodlands above 72 cm depth, which might be synchronous with a similar deforestation event in Derryhowlaght Lough (figure 7.2.4) dated to c. 1070 cal. yrs BP. An estimate of the secondary elm decline in Ross Lough can be made, which is located at a depth of c. 112 cm. The first increases (up to 0.6%) in *Plantago lanceolata*, supports this date, as it provides similarities with the secondary elm decline of Tattenamona Bog, which was dated to c. 1200-1400 BC (Mitchell, 1956). The elm decline has been more accurately dated in Lough Catherine, Co. Tyrone by Hirons and Edwards (1986), which also discusses inherent issues with relative and absolute pollen methods. It was estimated that human activities took place up to an estimated 365 years before the elm decline, indicating that it was probably a factor, but a concomitant disease explanation cannot be excluded.

These two depths are used to create tentative age-depth model for RL01. The major deforestation around Ross Lough precedes the occurrences of cereal pollen in RL01, indicating that that the event identified between 56 and 24 cm depth is more likely a result of the extensive deforestation. The end of the Early Christian period stands out in the vegetation history of several sites across Ireland (Mitchell, 1956, Hall, 2003, Hall, 2005, Brown et al., 2005, Kerr et al., 2009) and might relate to intensification of land use, as well as the onset of Viking raiding-bases (Mitchell, 1956, Charles-Edwards, 2000a).

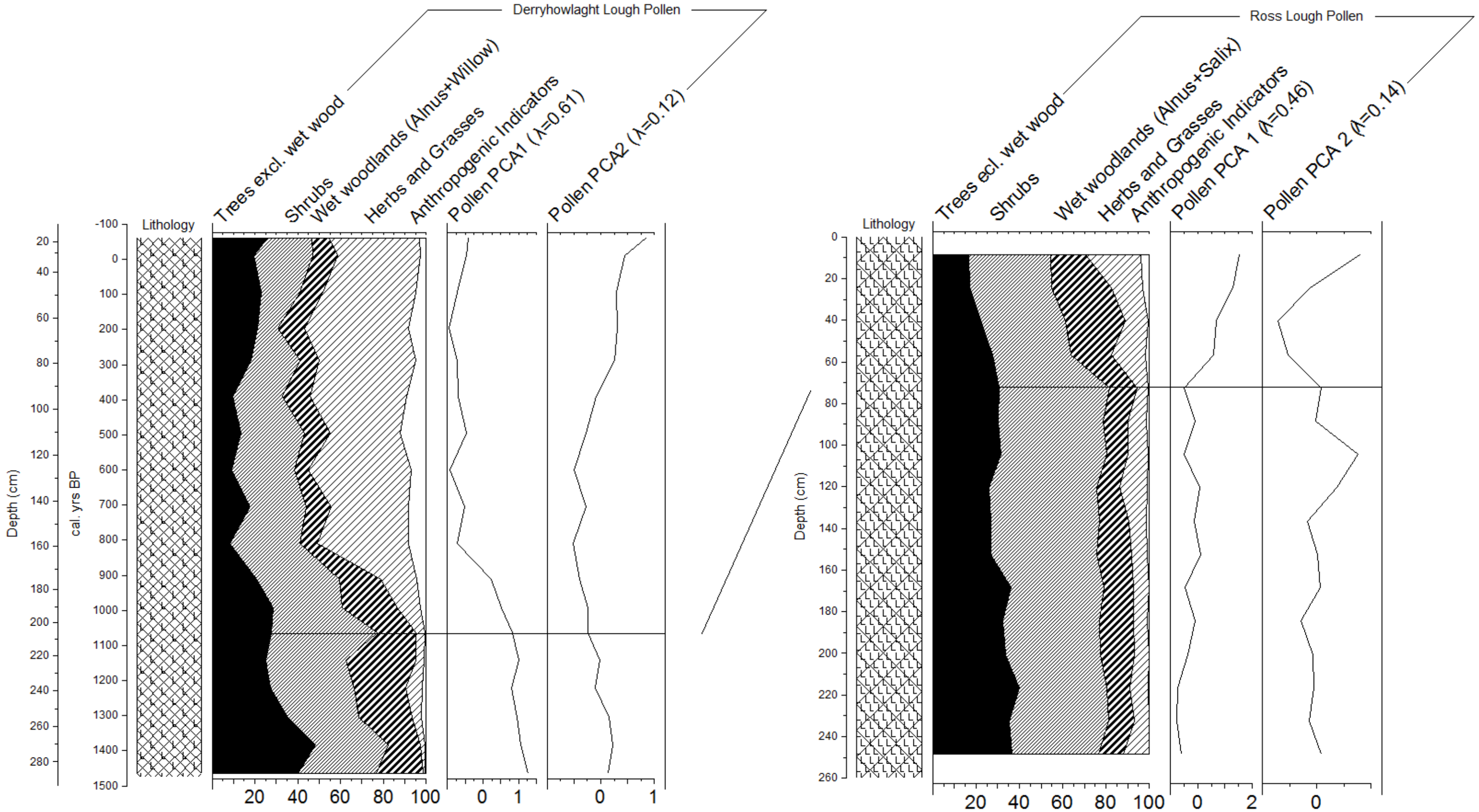


Figure 7.2.5 Pollen summary diagrams of Derryhowlaght Lough and Ross Lough, with the start of the major deforestation (horizontal line) used as a marker to infer an age estimate for Ross Lough

When comparing the diatom records from Derryhowlaght Lough and Ross Lough (see figure 7.2.5), there are increases in planktonic diatoms in both cores, which in Ross Lough takes place close to the time of the crannog, as indicated by the presence of cereal pollen. In Derryhowlaght Lough the radiocarbon dates suggest this interval is a second occupation phase, as it takes place c. 200 years after the construction of the crannog.

The occupation phase on the Derryhowlaght crannog (see also results chapter 6.1) is inferred from increases in planktonic diatom taxa, indicative of higher nutrient levels, as well as increases in stalked diatom taxa, indicative of a higher amount of macrophytes. The diatom assemblages are complicated by the lack of environmentally indicative diatoms in most of the Ross Lough core (see chapter 6.2).

Therefore regional interpretation is limited to around the time of the deforestation events in both cores, which are assumed to be more or less contemporaneous. The diatom record indicates that together with the deforestation phase in both cores, there are increases in planktonic diatoms and stalked diatom taxa, while tychoplanktonic diatoms are reduced. The relationship between planktonic diatoms and additional nutrient loading in shallow lakes has already been discussed previously and probably reflects a shift towards a lower silica to phosphorus ratio (Kilham and Kilham, 1982, Van Donk and Kilham, 1990).

The role of run-off is also evident from the geochemistry (see figure 7.2.6), as both Derryhowlaght Lough and Ross Lough indicate increases in erosional indicators, such as the MS and the K/Rb around the deforestation event. It is difficult to assess if the peak in MS is synchronous, as the slope is quite different and the baseline fluctuations are quite different. This is probably related to differences in size and catchment of the bodies of water.

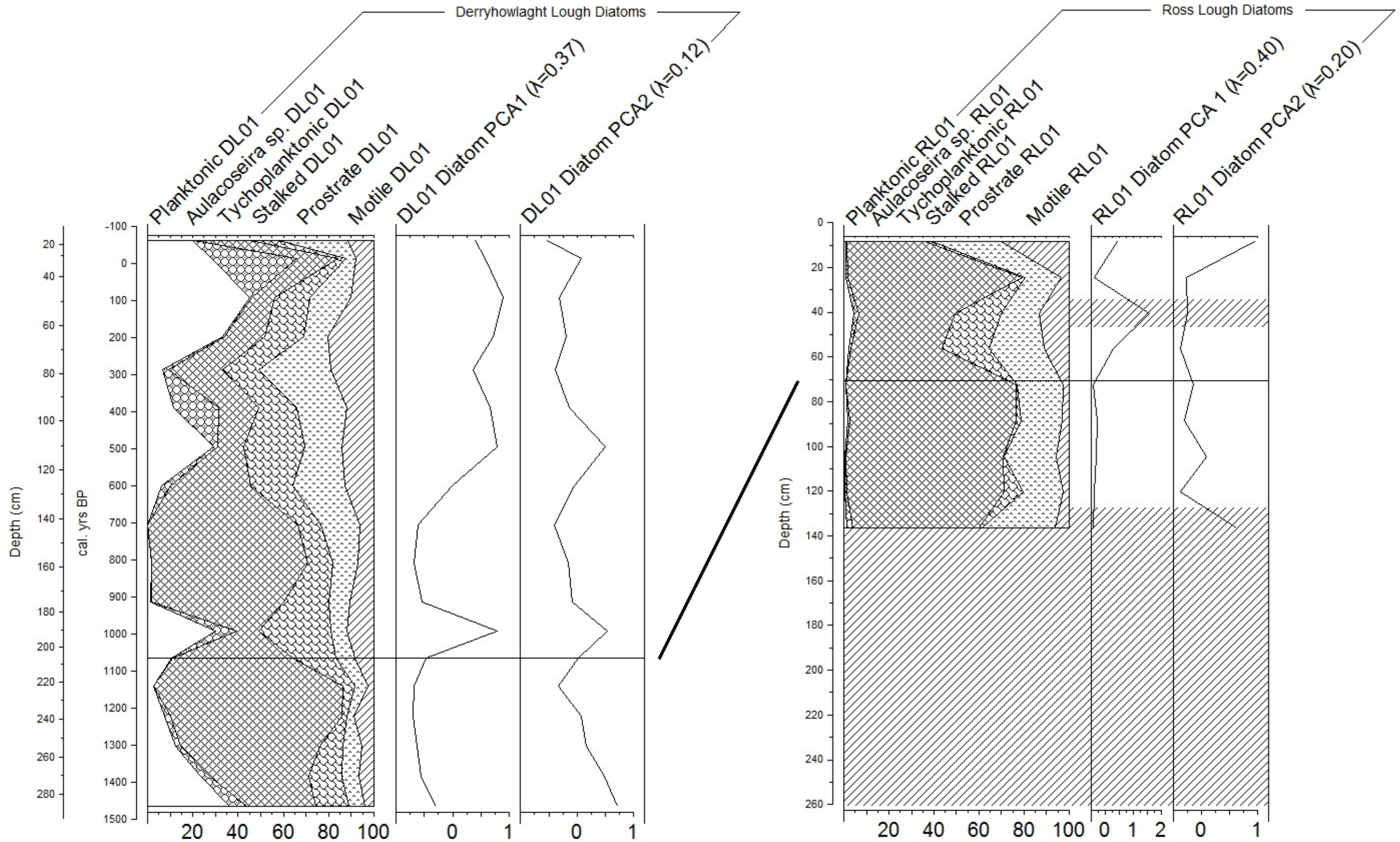


Figure 7.2.6 Co. Fermanagh diatom assemblages, grouped by attachment type and included the first two PCA axes. Derryhowlaght was aligned with its age-depth model, while Ross Lough is currently undated. The horizontal line reflects the main deforestation event in both cores (see also figure 7.2.4)

Due to limitations in the age-model of Ross Lough, it is difficult to robustly interpret large parts of the regional environmental history of Co. Fermanagh. Furthermore, there are additional crannogs in the lake, one small submerged crannog near the currently emerged one, near where the core was taken. A detailed study of the crannogs on and around Lough Gara (Fredengren, 2002) demonstrated a Bronze Age phase, based on radiocarbon dates in some of the stone platforms, so it is a possibility that one of the crannogs in Ross Lough has had a similar phase. Human presence near Ross Lough from a large suite of finds near the Sillees river has been described by Carrol (1992), indicating stone age burnt bones and implements as well as Bronze Age, Iron Age and Early Christian metal artefacts.

Derryhowlaght and Ross Lough are on either side of Upper Lough Erne, where opposing kingdoms were located for most of the periods (Charles-Edwards, 2000b, see also figure 1.5.1), with the lakes providing a natural boundary. The topography of Co. Fermanagh is complex, with many lakes interspersed between the drumlins. The region is ideal for exploring the relationships between crannogs, as the Early Medieval history of the Irish kings is chronicled by the Annals of Ulster (1895) and the occupation history of crannogs might be linked to shifts in power between the kingdoms.

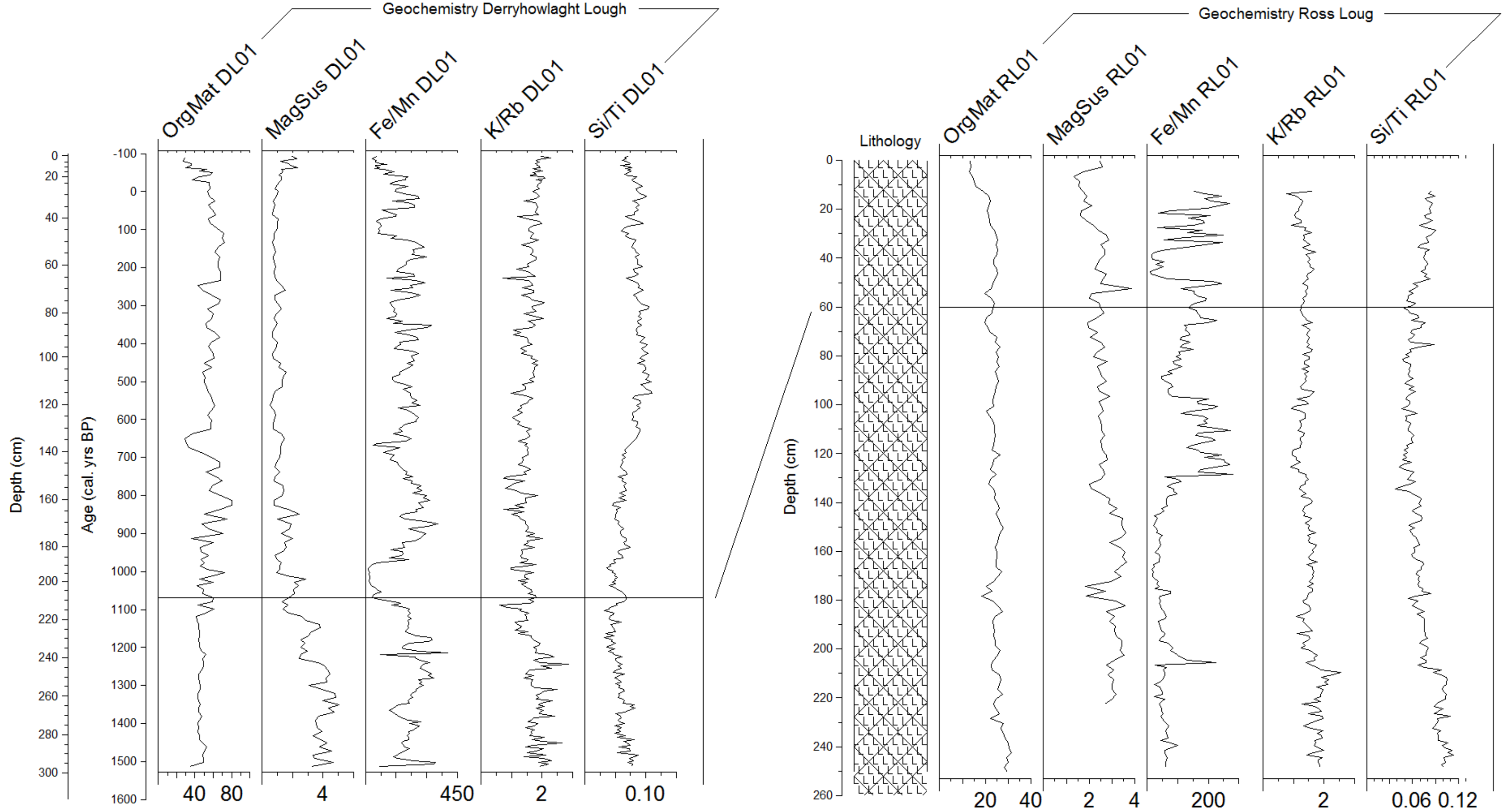


Figure 7.2.7 Co. Fermanagh selected geochemical data, with the horizontal line reflecting the main deforestation phases in the cores from Derryhowlaght Lough and Ross Lough

Chapter 8: Conclusions

The historical monument database indicates that the main crannog construction period in south west Scotland appears to be the Iron Age (c. 800 cal. yrs BC – 300 cal. yrs AD). This most likely represents a period of highly fragmented communities and shifts in power between Chieftains. In Co. Fermanagh, the main construction phase is the Early Medieval period (c. 300 AD – 900 AD), indicating a similarly fragmented period with different kings in control of the region at different times.

The sediment cores taken in close proximity to the crannogs indicate the complexities that surround these sites. All of the sites were subject to some disturbance around the inferred time of the construction of the crannogs, with some of the sites indicating eutrophication and reductions in the pH, while most sites indicate some deforestation. This indicates that the impact that the crannogs can have upon the lake ecology is poorly comparable between sites and each site has to be assessed individually to disentangle the crannog-related disturbances. The interpretation is limited by the sampling resolution, which might not pick up short-term disturbances.

The diatom assemblages provided excellent information on local disturbances in the lake and identified eutrophication and acidification disturbances, which were probably related to the crannog building and occupation. However, the interpretation would benefit from a greater understanding of shallow lake ecology and tychoplanktonic diatoms, which are not that well understood. The XRF analysis provided information on catchment erosion (K/Rb, Zr and Ti) and helped improve the age-depth model of several sites by assessing the lead accumulation in the upper sediments. Furthermore, the XRF corroborated information from the loss-on-ignition and magnetic susceptibility, which also identified likely phases of catchment erosion. The pollen assemblages were instrumental in understanding human activities in the catchment, as well as pinpointing crannog occupation phases in some sites by the presence of cereal pollen.

There are several notable differences between the Scottish and the Northern Irish crannogs. The Scottish sites indicate that the crannogs follow the major Bronze Age disturbances in the regions, as evident from deforestation and erosional events that took place around 1500 cal. yrs B.C. Furthermore, the Medieval Period can be classified as the other main disturbance phase in the region, supporting the widespread evidence of Norman forts and abbeys in the region. Thus, considering the occupation history of south west Scotland, crannogs appear to have been constructed and inhabited during two major human impact phases in the region.

In contrast, the Northern Irish crannogs appear to have been constructed before or near the start of the major deforestation phase in the catchment. As the catchments of the Northern Irish lakes are quite large, this would indicate dramatic changes to the landscape. As almost all crannogs have robust defensive features (e.g. palisades and the surrounding water), the concentration of crannog construction during the Early Medieval period probably indicates that this period was of increased conflict over ownership and use of the landscape. However, the interpretation of Northern Irish crannogs is hampered by a smaller set of sites studied and the lack of an age-depth model on one of the sites, therefore interpretations on a regional scale are limited.

Overall, the palaeoecological investigation of crannogs yielded a substantial amount of information regarding the occupation history of these ubiquitous sites in Scotland, Northern Ireland and Ireland. Furthermore, the south west of Scotland and Co. Fermanagh represent regions with a high concentration of crannogs, which when analysed in greater number and detail can dramatically improve our understanding of these Iron Age and Early Medieval communities. Furthermore, the connectivity between Scotland and Ireland during these periods is an aspect which requires more in-depth research, as there are clearly many similarities between the prehistoric and early historic communities of these regions.

8.1 Future research

As is evident from this thesis, it is important to invest in constructing a robust age-depth model, as interpretation is limited without one. This opens up more research into lake level changes and climate change during the periods analysed. Careful selection of field sites is imperative, as the drumlin landscape offers plenty of lakes without an inflow, which have smaller catchments and are probably more sensitive to crannog-related disturbances. Alternatively, if regional human impact is explored, lakes with a larger catchment would be suitable, similar to Ross Lough and Derryhowlaght Lough.

The research would have benefitted from a high sampling resolution, however, that requires a robust chronology or good evidence of the depths associated with the crannog. It is recommended that funding is set aside to produce an age-depth model early in the project. The possibility of applying novel palaeoecological techniques to these sites might also be explored, for instance isotope analysis, biomarkers and/or aDNA. These techniques might could a better understanding of everyday life on crannogs, such as types of livestock and main sustenance sources.

This thesis also leads to these follow-up research questions:

- Are the apparent gaps in southern Ireland driven by the distribution of lakes or were there simply less crannogs built here?
- The crannog distribution needs a comparison to waterway connectivity; Are crannogs associated with well connected, wealthy areas?
- Are crannogs distributed along borders of kingdoms in frequent conflict?
- Is the construction of crannogs limited by the hydrology of the lakes; are reservoir lakes more suitable as they are less influenced by changing lake levels?
- As evident in Barhapple Loch, how dramatically did the regional hydrology change during the lake prehistoric periods and what might have been the impact on local communities?
- Does each cultural period (e.g. Iron Age, Early Medieval) possess a unique set of disturbances that might help to identify it in the palaeoecological records?
- How distinct was the regional climate in Northern Ireland and south west Scotland during the main crannog building phases?

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Appendix A Additional site maps and images

A.1 Cults Loch

Figure A.1.1 Plan of the piles (dark spots) and timbers (elongate outlines) indicating the structure of the promontory crannog in Cults Loch. Courtesy of AOC Archaeology.

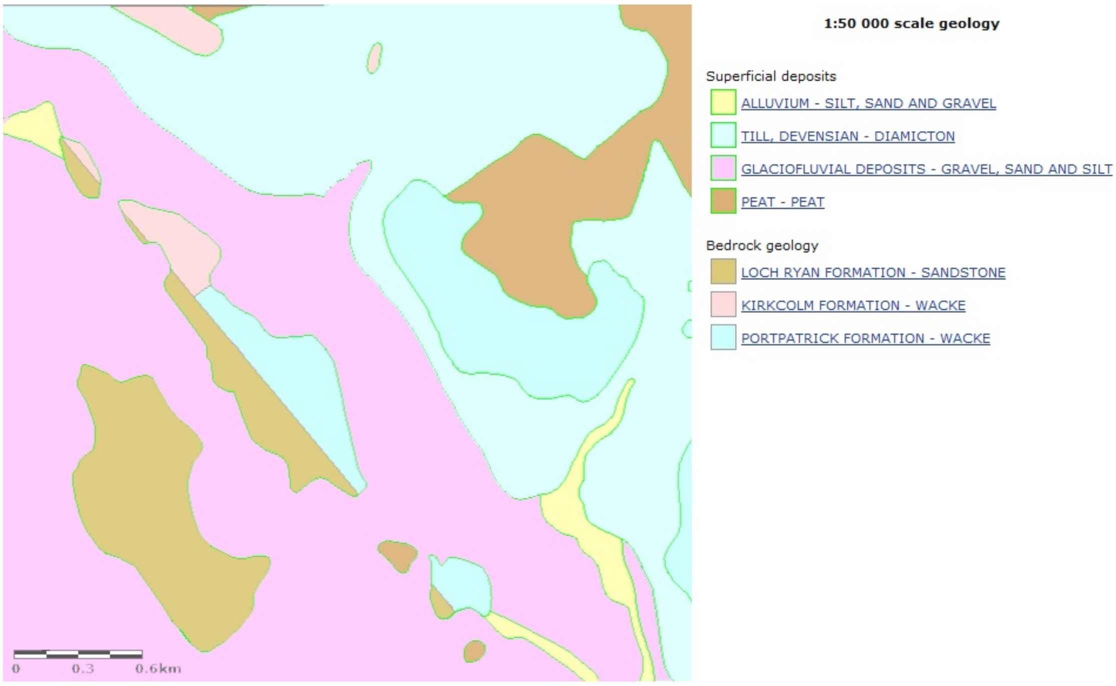


Figure A.1.2 Geological map of Cults Loch and the Castle Kennedy lakes. Adapted from the BGS map viewer

A.2 Barhapple Loch

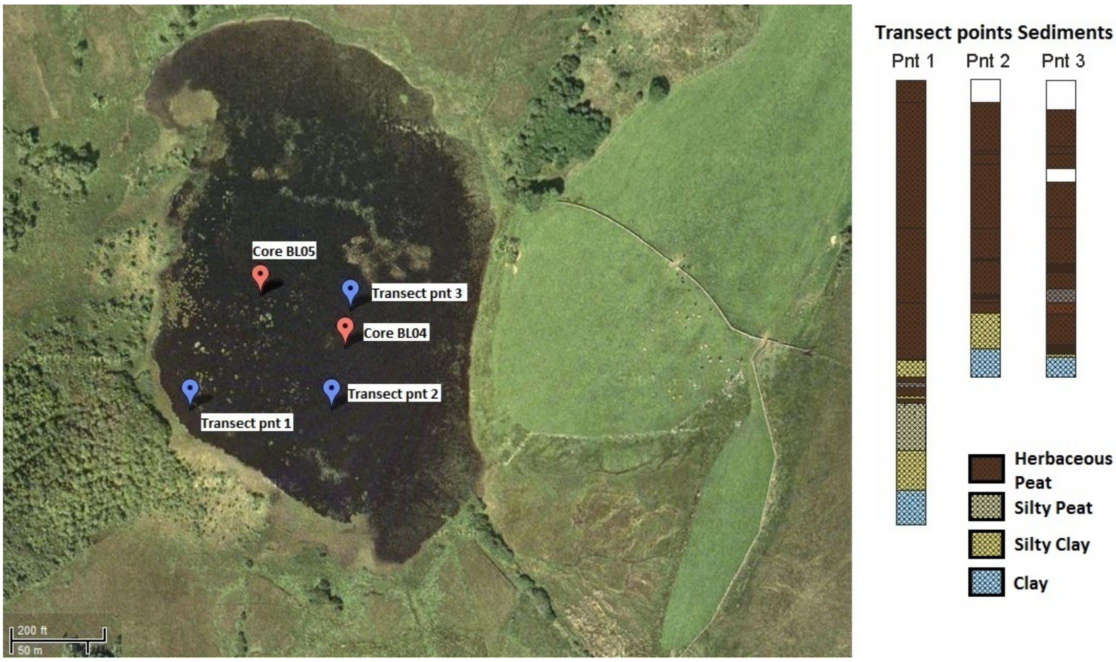


Figure A.2.1 Coring locations and sediment stratigraphy of explorative cores from Barhapple Loch

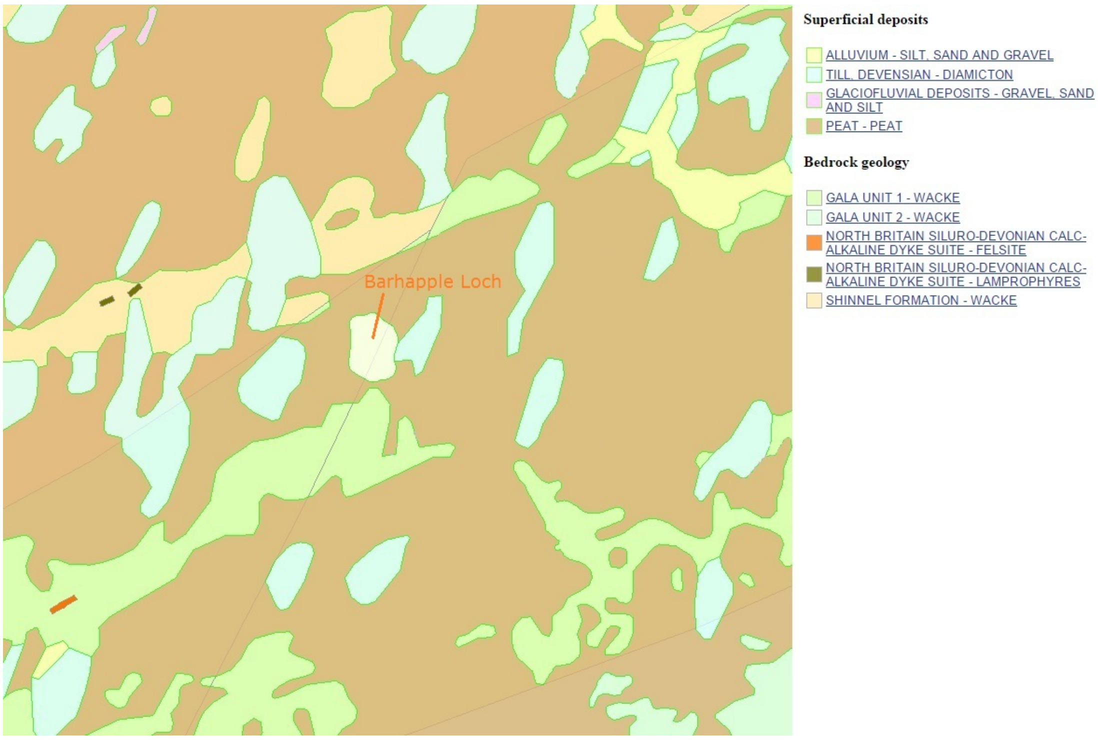


Figure A.2.2 Local geology around Barhapple Loch, indicating superficial and bedrock geology. Adapted from online BGS map viewer

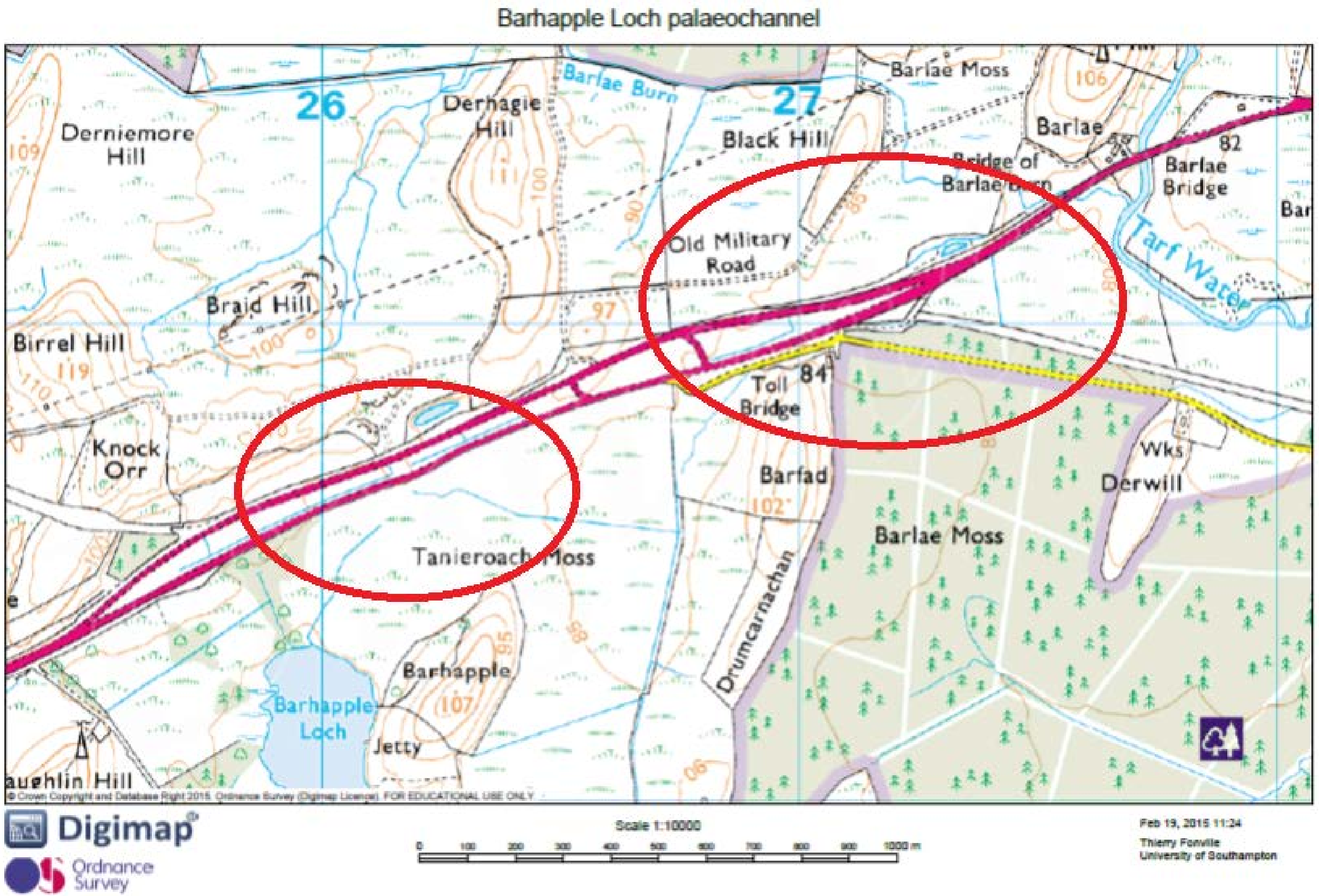


Figure A.2.3 Local map of the region towards the north-east of Barhapple Loch, with Tarf Water in the upper right corner and the Barlae Burn in the top. The red circles indicate possible connections between these water bodies and the moss surrounding Barhapple Loch, supporting the case for a palaeochannel.

A.3 Black Loch of Myrton

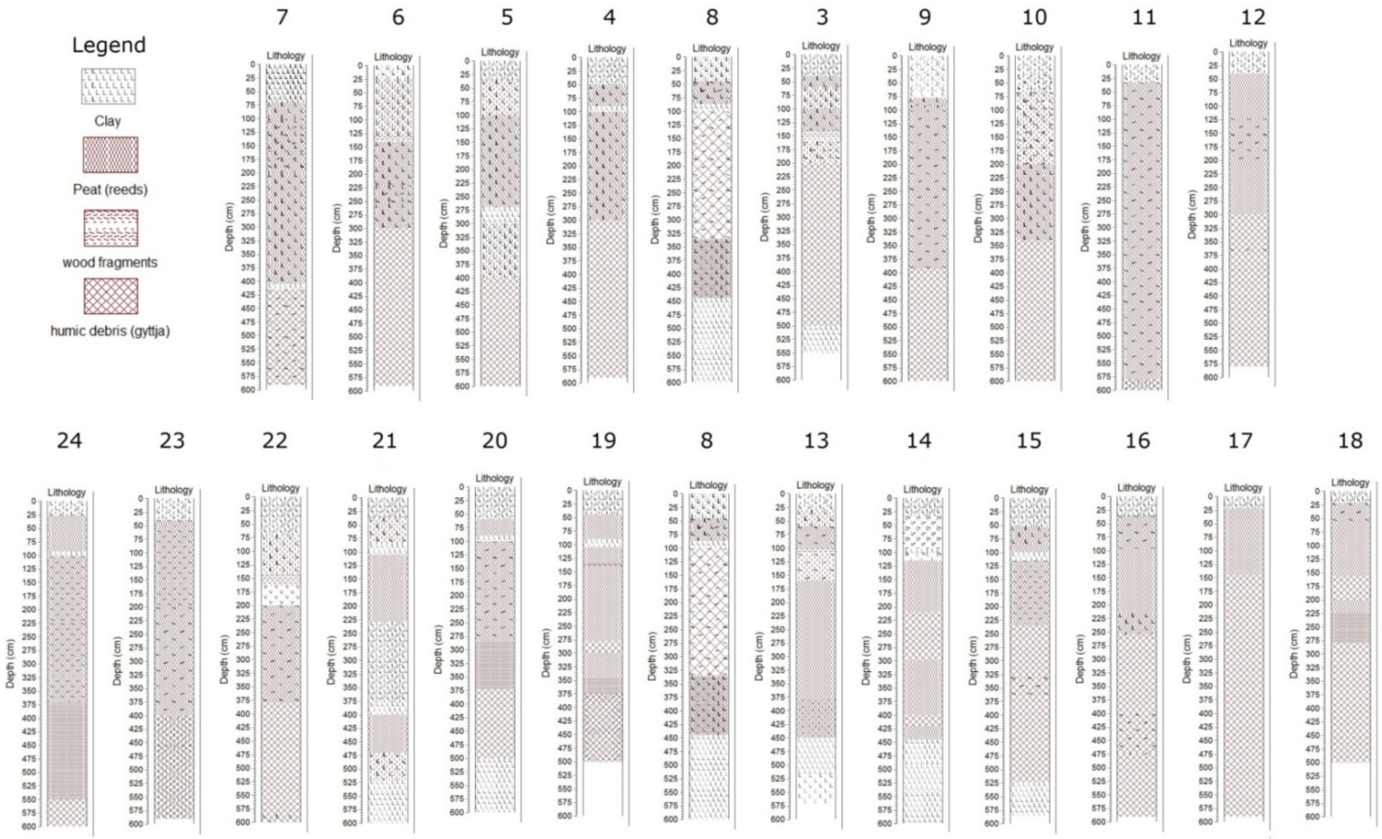


Figure A.3.1 Stratigraphic logs of the explorative coring around Black Loch of Myrton, indicating that the sediments are dominated by reedy peats. This supported the archaeological evidence that no mound was constructed underneath the superstructure. From Fonville (2015).

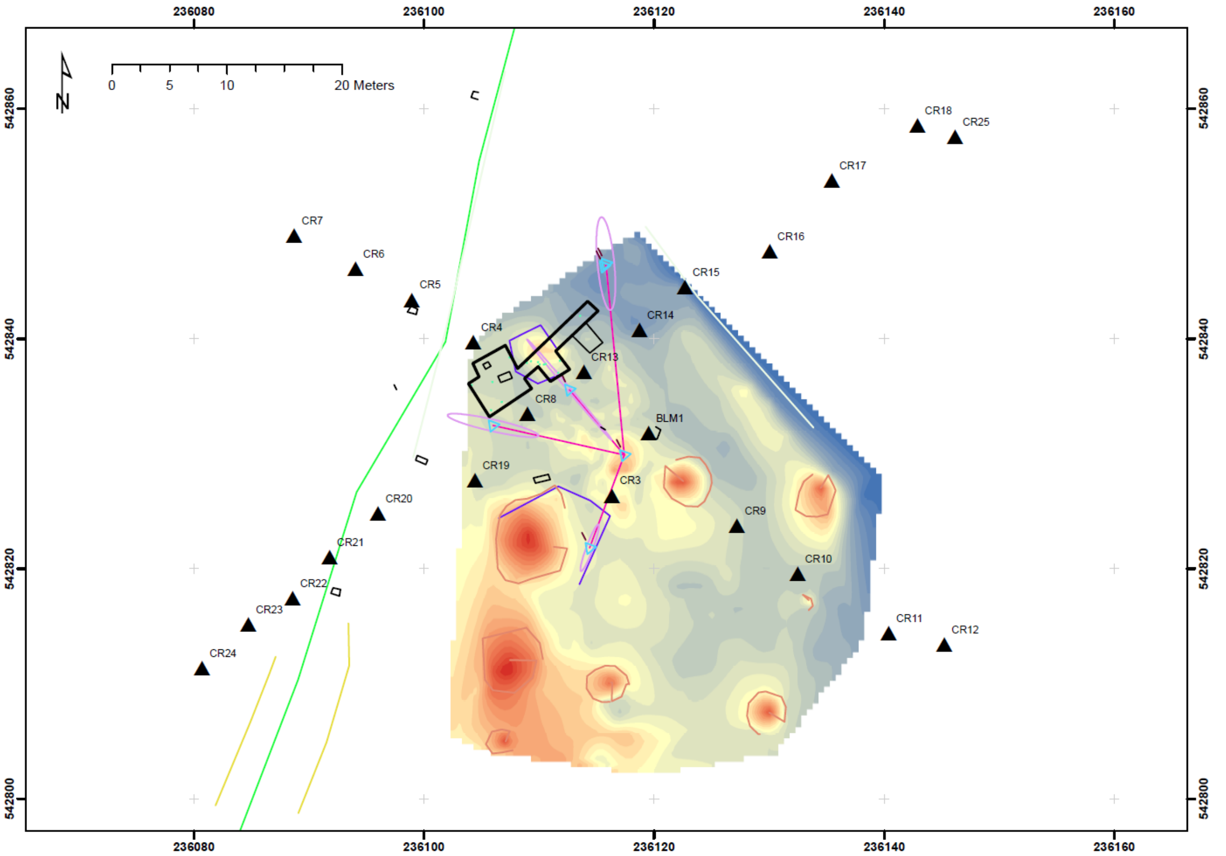
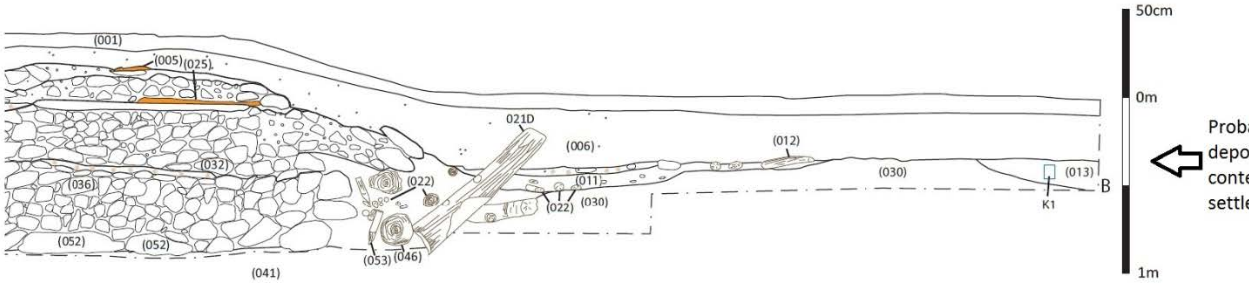
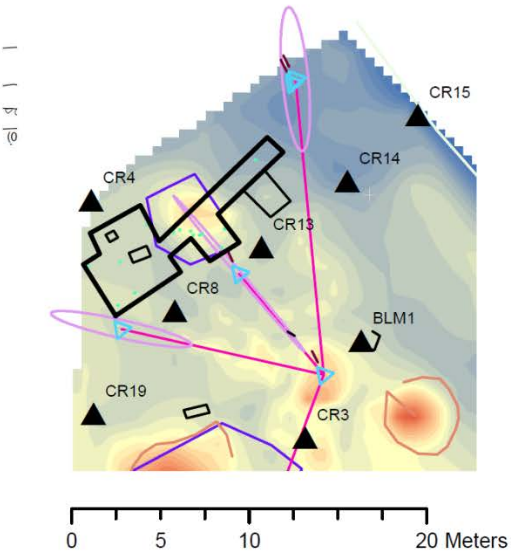
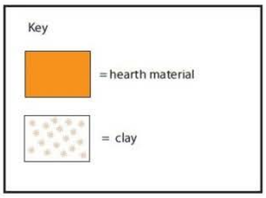


Figure A.3.2 Map of the Black Loch of Myrton, indicating the location of the explorative cores, as well as the core used in the analysis (BLM01). The black outline indicates the location of the excavation trenches, while the red area indicate raised surfaces, which probably related to other settlement structures. From Crone and Cavers 2015.







Local plan of the excavation (black outline) and coring locations. BLM01 denotes th
investigated in this thesis. The red area indicate raised surface as measured by the

Figure A.3.3 South-facing cross section of Black Loch of Myrton excavation. Underneath the settlement deposits was a continuous deposit of highly decomposed peat, identified as context [30]. This deposit was located at a depth of c. 30-50cm at the most proximal part of the excavation. These depths are assumed to be underlying the settlement in the core BLM01 as well.

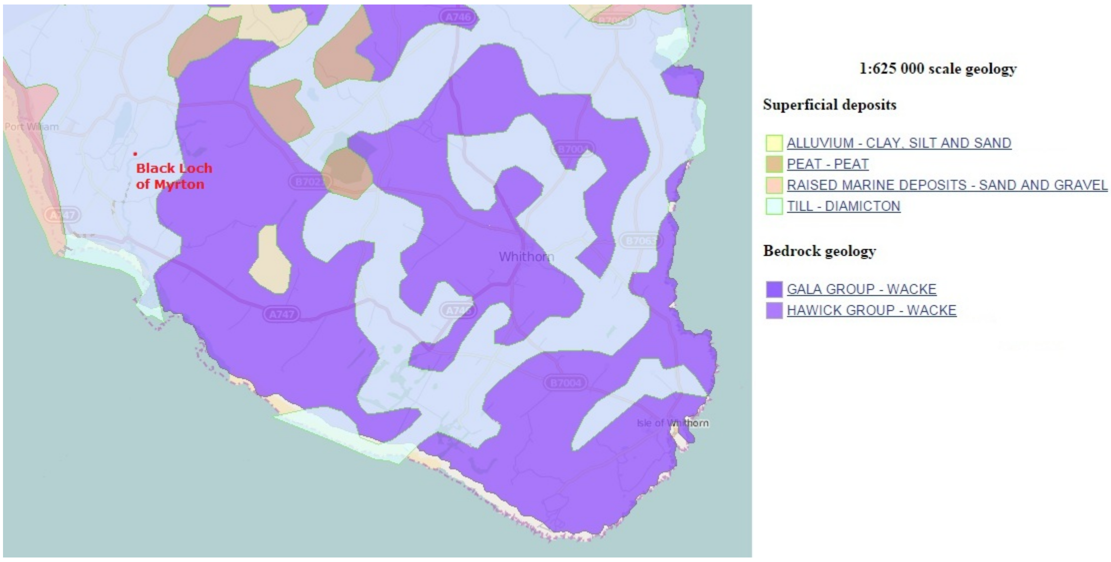
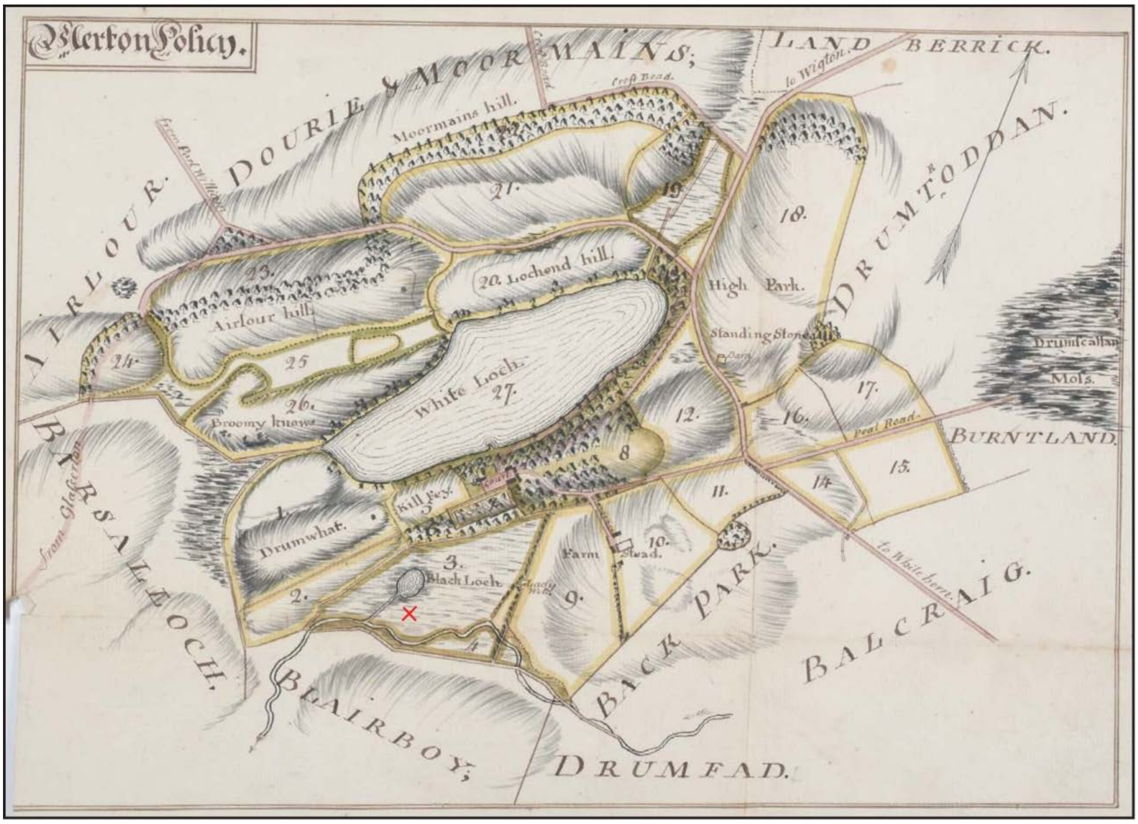


Figure A.3.3 Geological map of the catchment of the Monreith Burn, with the location of the Black Loch of Myrton indicated.



A.3.4 John Gilone's plan of the Merton Policy (Monreith Estate) drawn in 1777/8. The Black Loch is visible and the approximate location of the site is marked with a cross.

A.4 Derryhowlaght Lough

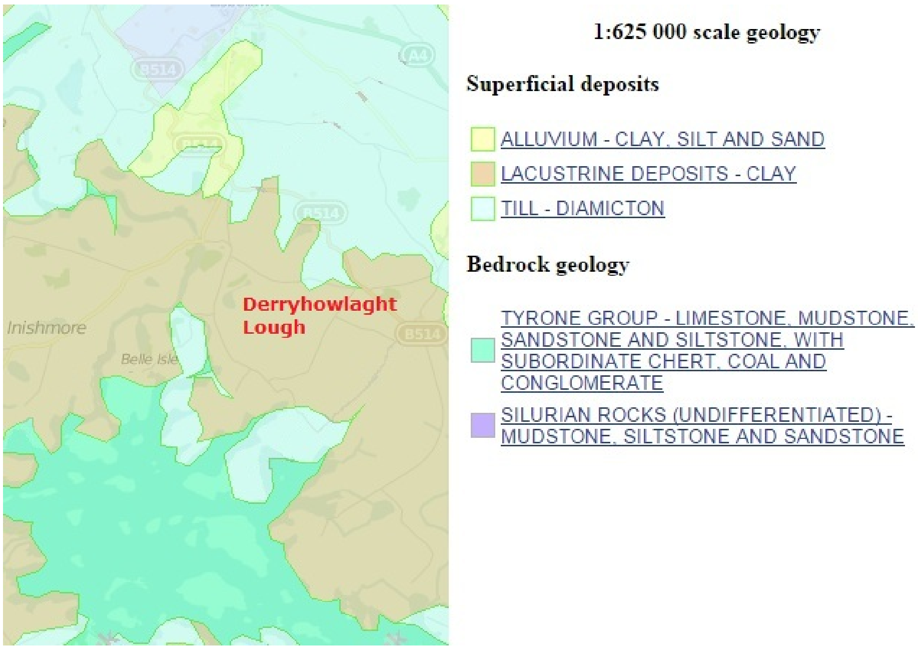
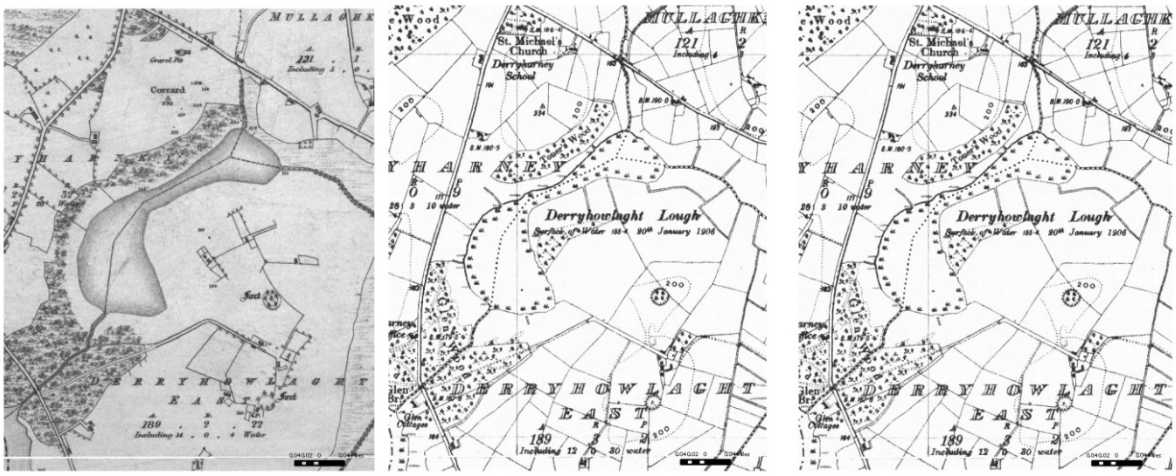
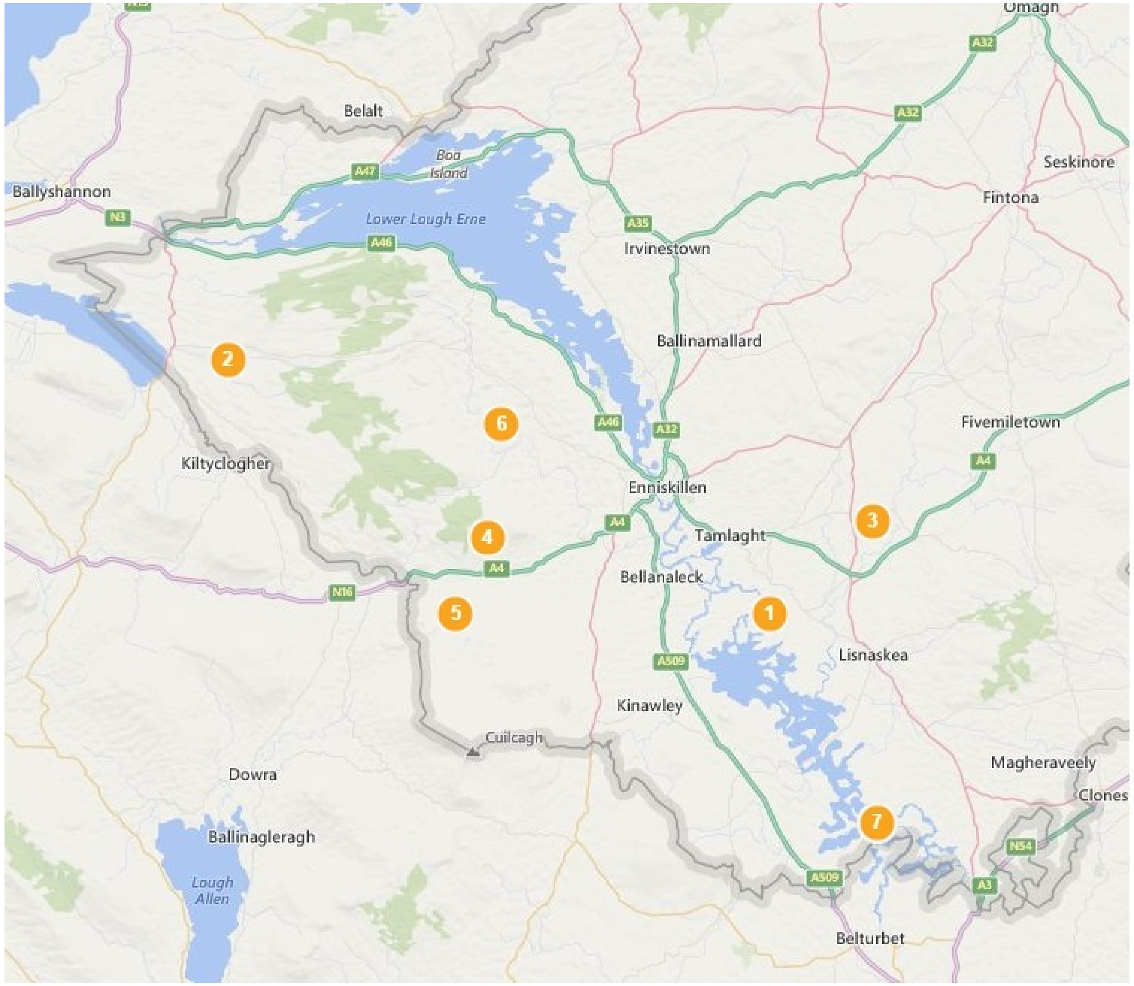


Figure A.4.1 Geological map of the area surrounding Derryhowlaght Lough. Adapted from the online BGS map viewer.



1829-1835 1831-1904 1857-1932

Figure A.4.2 Historical maps (1829-1932) of Derryhowlaght Lough prior to the Drainage Act implemented since 1881. The catchment vegetation indicates that some deforestation took place.



1) Derryhowlaght Lough
2) Glen West
3) Tattenamona Bog
4) Gortahurk Bog
5) Hanging Rock Wood
6) Carran Lough
7) Lough Nalughoge

Figure A.4.3 Locations of pollen sites in Co. Fermanagh, as mentioned in Mitchell (Mitchell et al., 2013). Adapted from Google Earth.

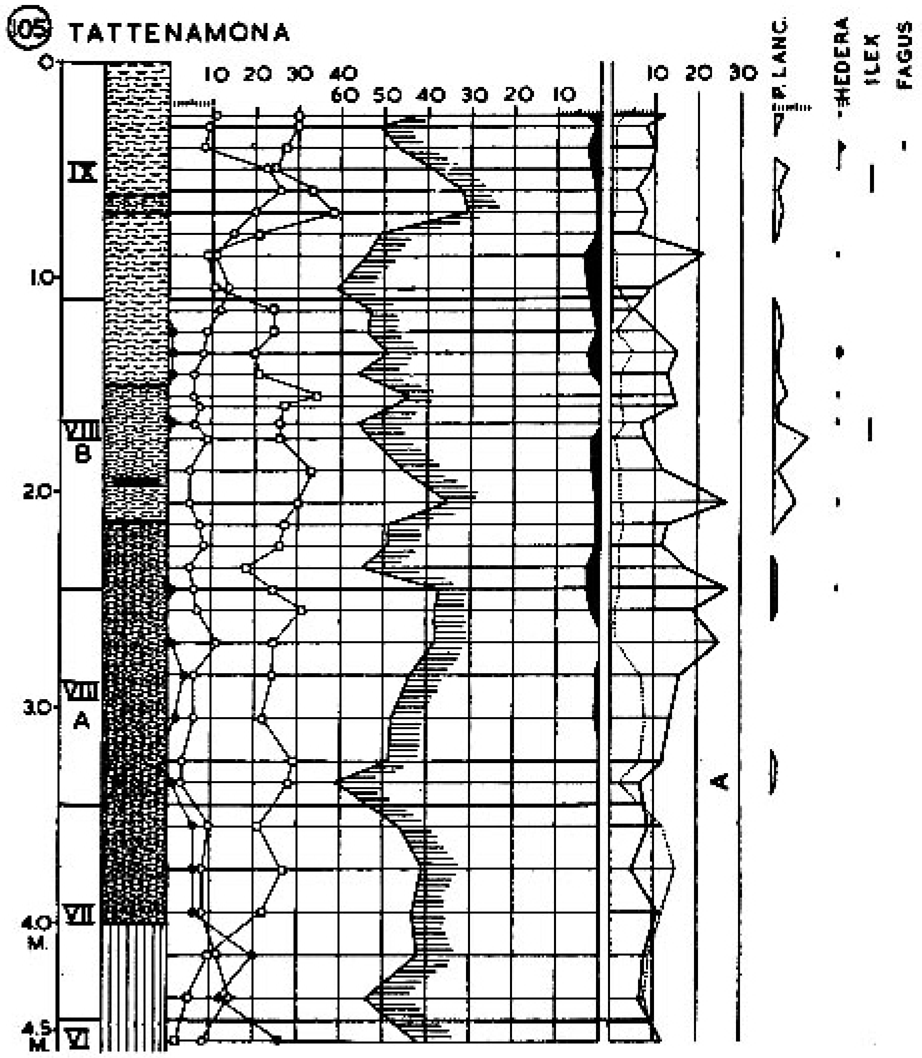


Figure A.4.4 Pollen diagram of Tattenamona bog, from (Mitchell, 1956)

A.5 Ross Lough

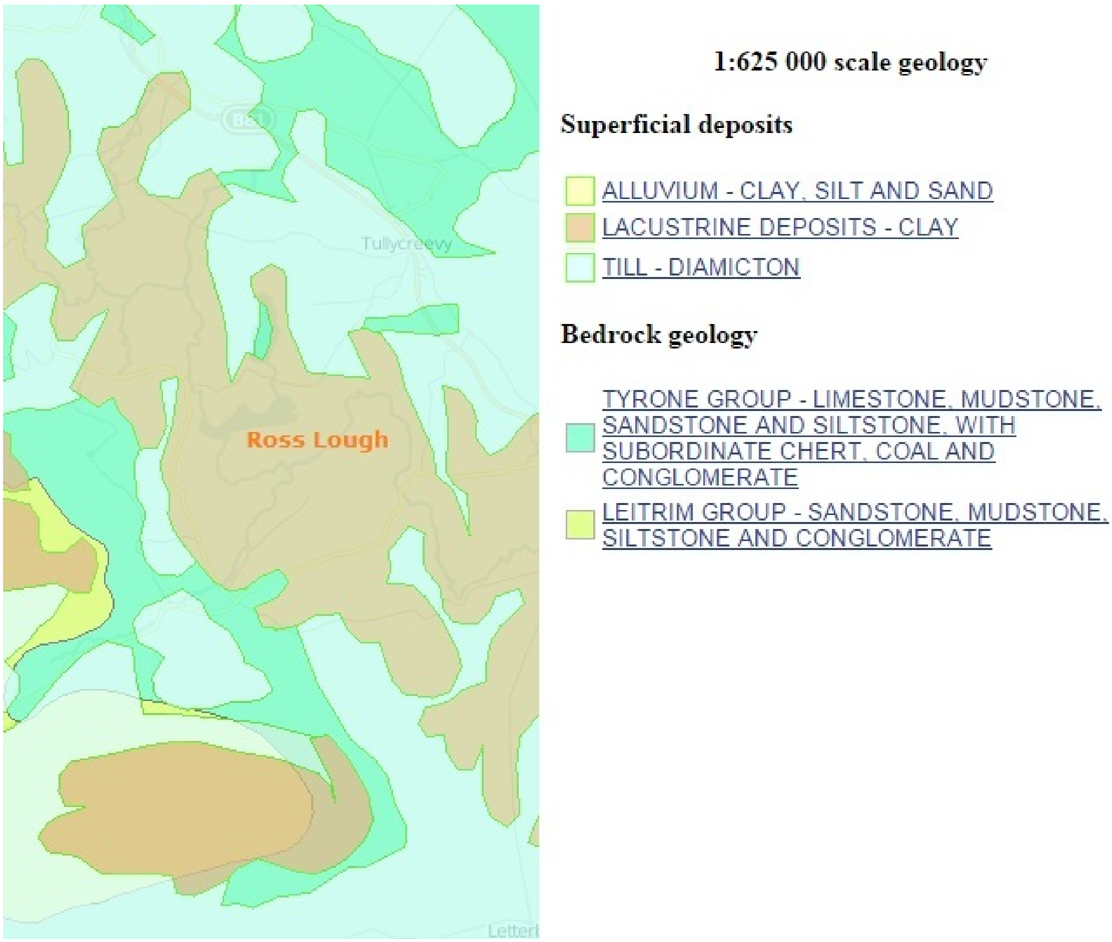
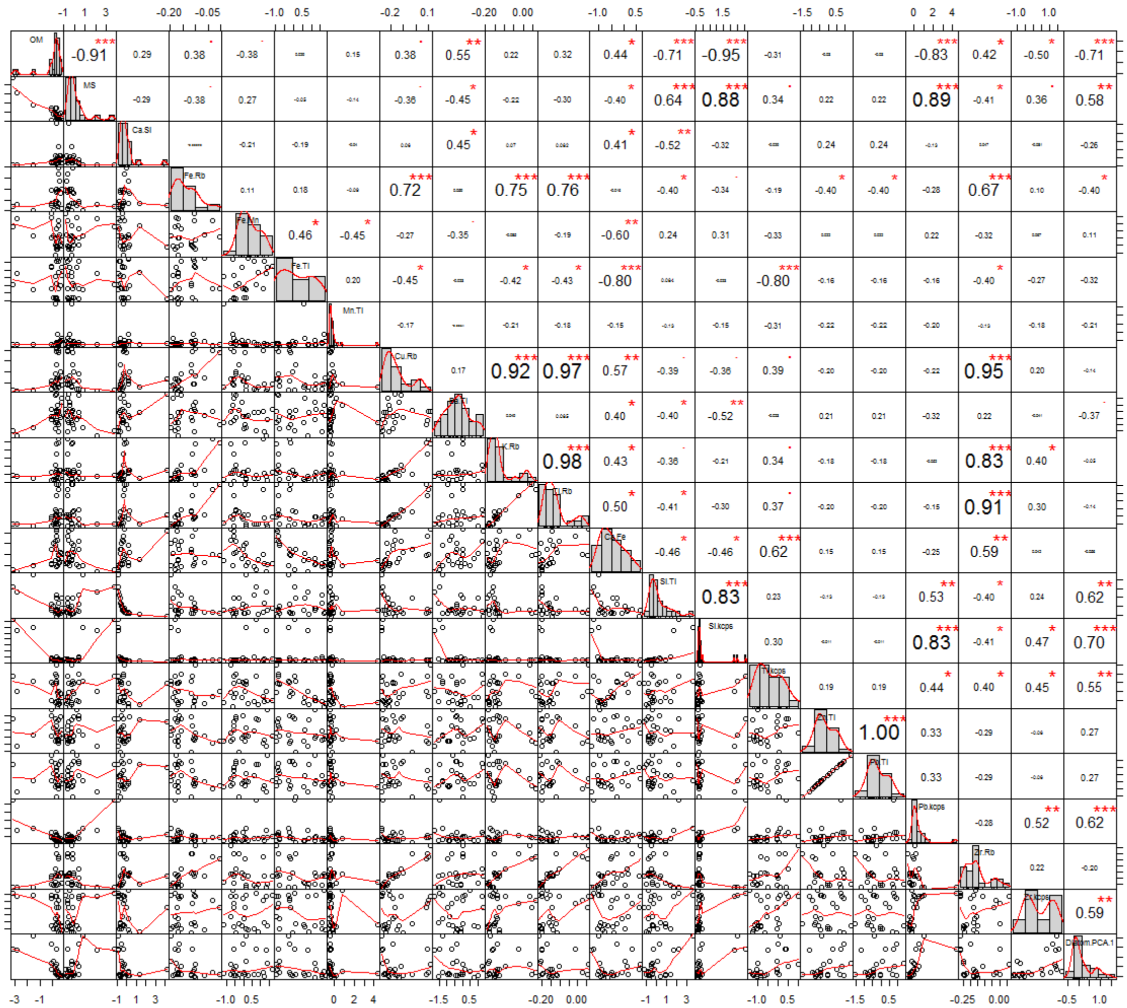


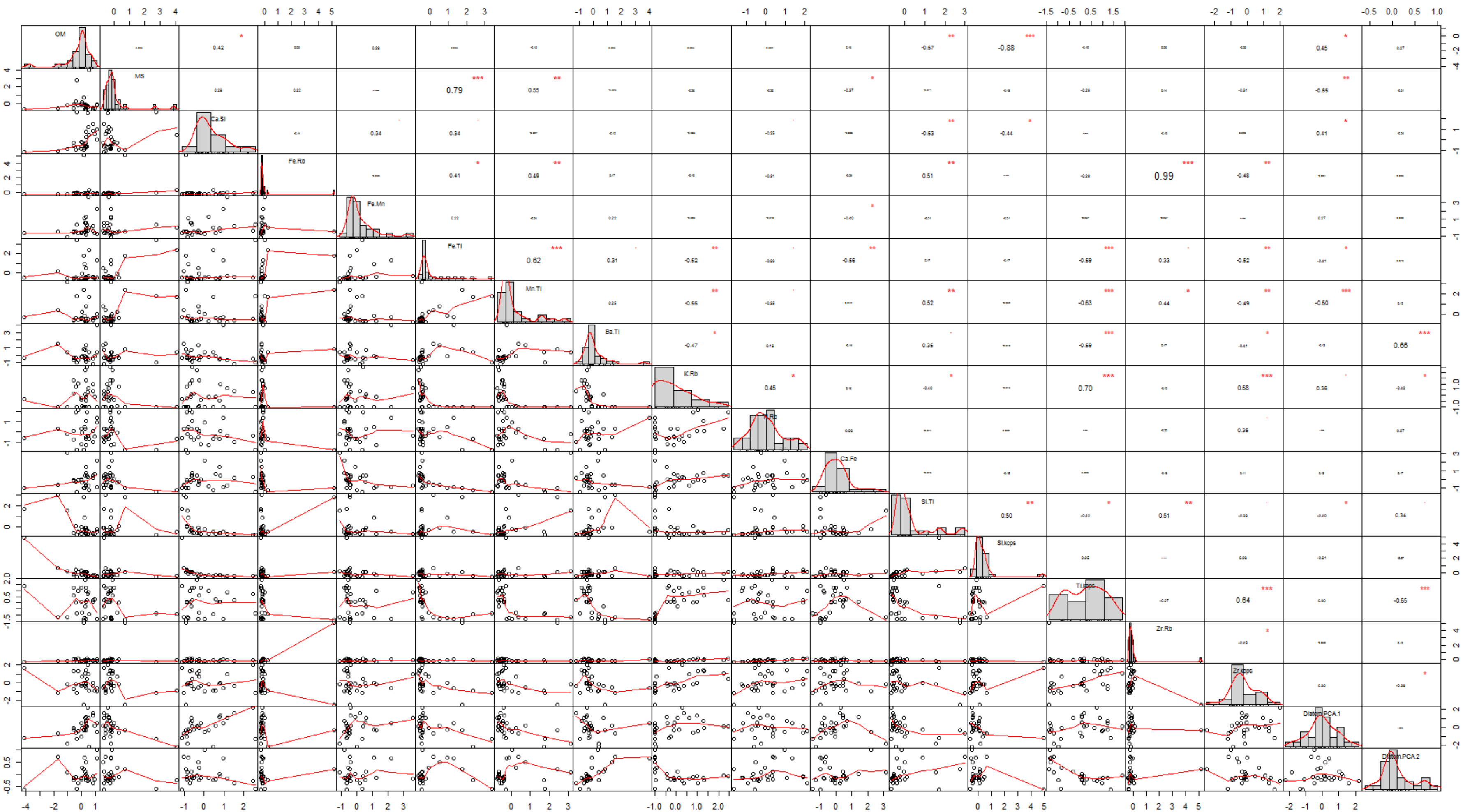
Figure A.5.1 Geological map of the area surrounding Ross Lough. Adapted from the online BGS map viewer

Appendix B Correlations between geochemical variables and diatom PCA 1

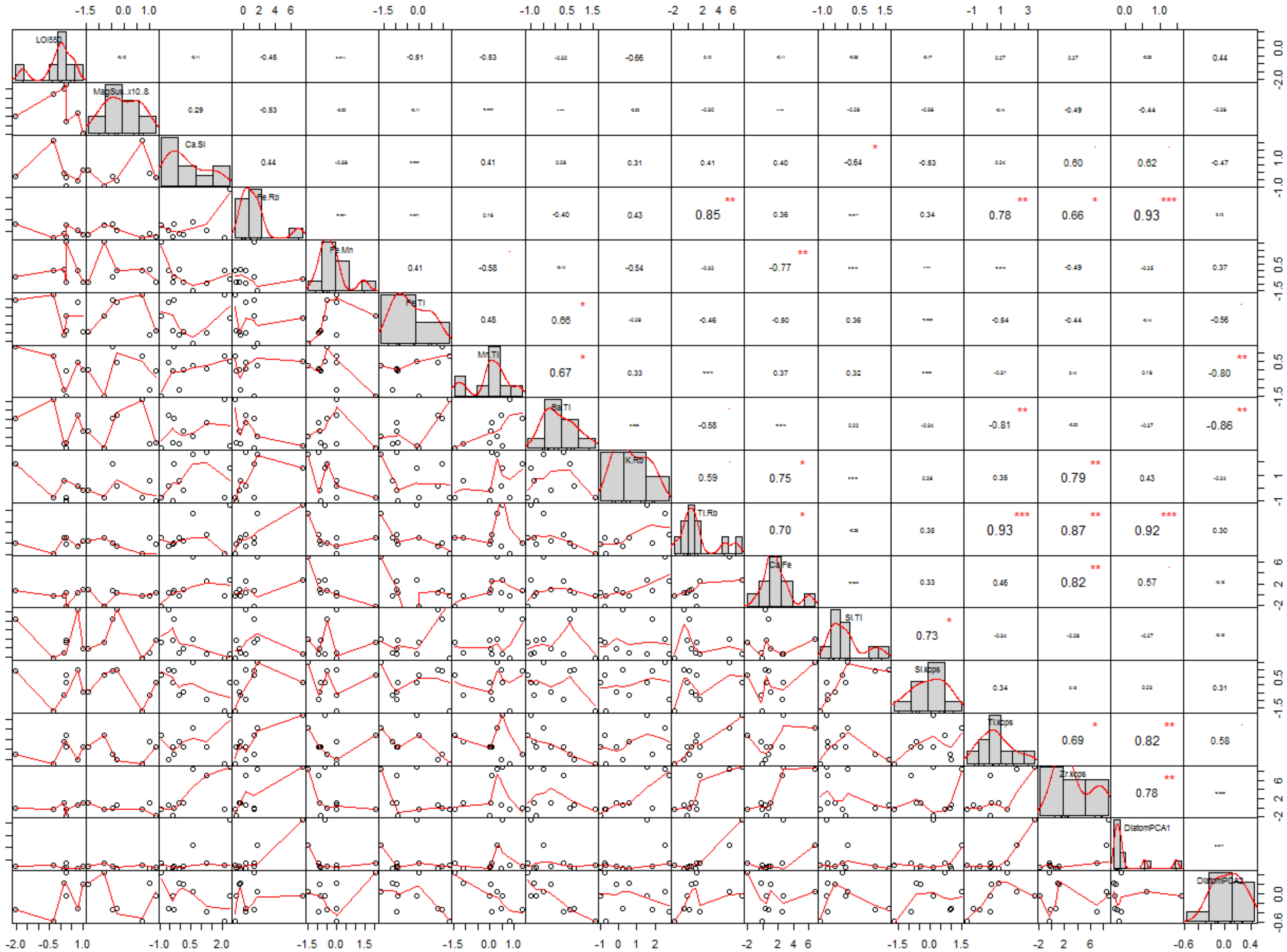
B.1 Cults Loch



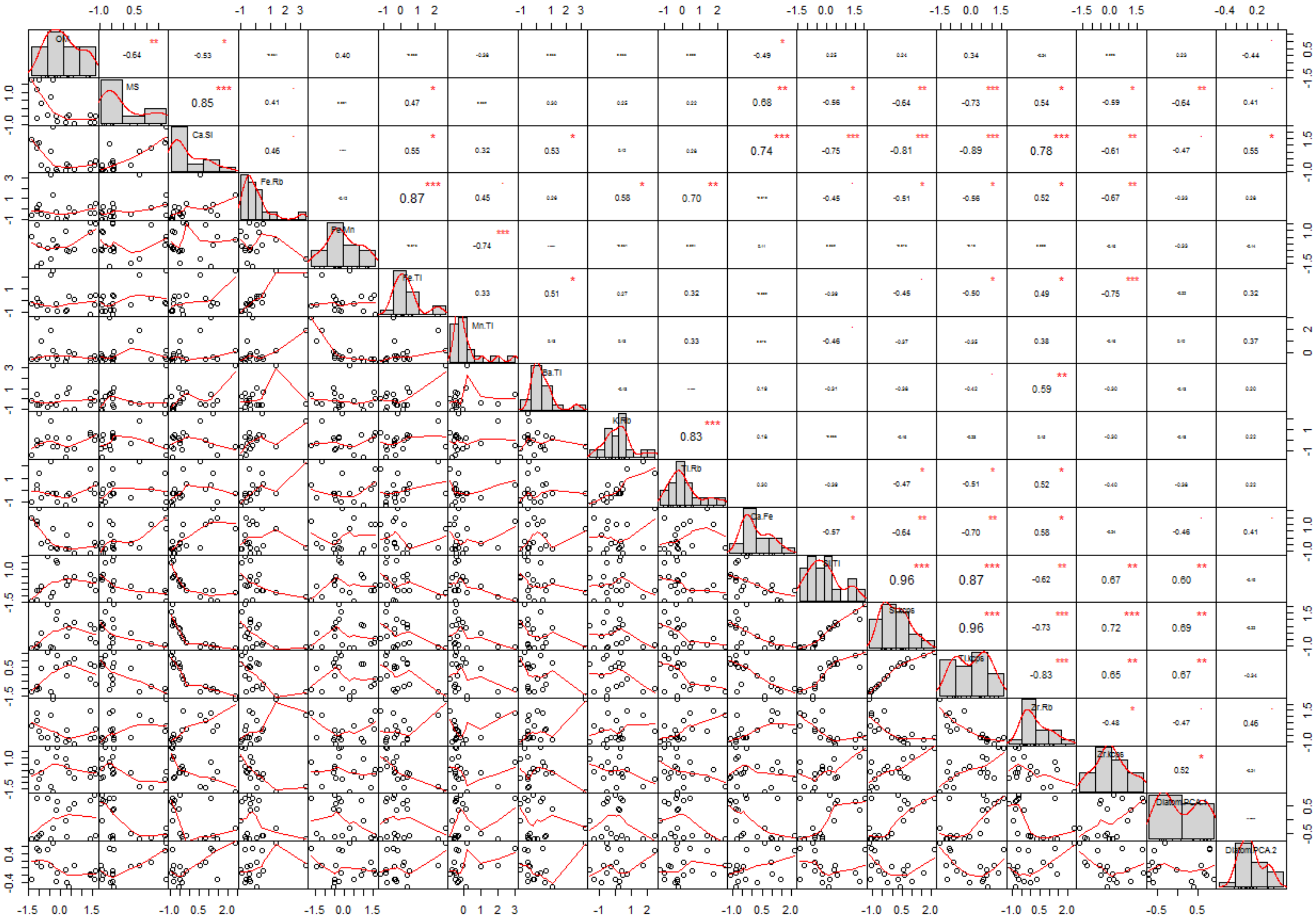
B.2 Barhapple Loch



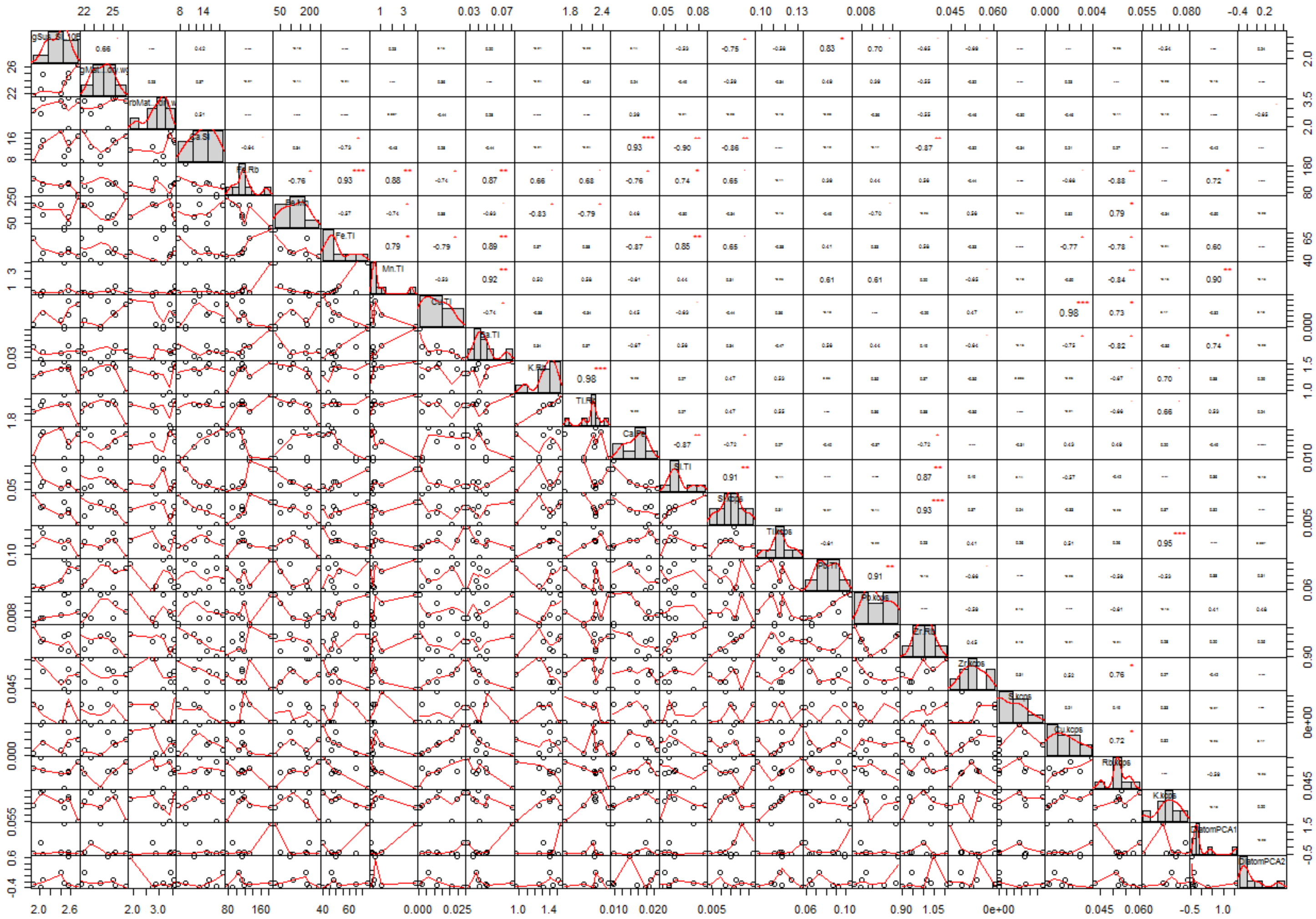
B.3 Black Loch of Myrton



B.4 Derryhowlaght Lough



B.5 Ross Lough



Appendix C Code for adding calibrated dates in Bacon

The code below was sent to me by Maarten Blaauw and is to be used after running the Bacon age-depth analysis. With it you can add additional calibrated probability density functions to the graph, which are not part of the age depth model. If you want to remove them all, you can recreate the original graph by using the function “agedepth()”.

```
plotdate <- function(d, mu, sdev, exx=20, col=rgb(1,0,0,.5), treshold=1e-6,
rotate.axes=TRUE)
  {
    cc <- read.table("Curves/3Col_intcal13.14C")
    prob <- cbind(cc[,1], dnorm(cc[,2], mu, sdev))
    prob[,2] <- prob[,2] / sum(prob[,2])
    prob <- prob[prob[,2] > treshold,]
    pol <- cbind(c(prob[,1], rev(prob[,1])), d+exx*c(prob[,2],-rev(prob[,2])))
    if(rotate.axes)
    pol <- cbind(pol[,2], pol[,1])
    polygon(pol, col=col, border=col)
  }
```

After adding this additional function to the R interface, you can plot additional dates in the figure using the function:

```
plotdate(d, mu, sdev)
```

For “d” you will have to fill in the depth of the sample, while “mu” is the radiocarbon date and “sdev” is the error of the sample.

Note that if you use a different calibration curve, for example if using the southern hemisphere calibration curve, you have to change the line “cc <- read.table(“Curves/3Col_intcal13.14C”) to include the correct calibration curve.

Appendix D Crannog Database all radiocarbon dates

Code	country	Location	Radiocarbon date
KILA 015	Ireland	Lough Gara, E Inch Island	8100 ± 100 BP
KILA 015	Ireland	Lough Gara, E Inch Island	8160 ± 50 BP
KILA 015	Ireland	Lough Gara, E Inch Island	5270 ± 50 BP
KILC 21	Ireland	Lough Gara, SW-shore	2610 ± 50 BP
BOYL 026	Ireland	Boyle River	2640 ± 45 BP
KILC 21	Ireland	Lough Gara, SW-shore	2680 ± 25 BP
KILA 016	Ireland	Lough Gara, W Inch Island	2690 ± 20BP
KILC 21	Ireland	Lough Gara, SW-shore	2690 ± 30 BP
KILN 007	Ireland	Upper Lough Gara, E-side	2700 ± 20 BP
KILC 21	Ireland	Lough Gara, SW-shore	2710 ± 40 BP
KILN 007	Ireland	Upper Lough Gara, E-side	2730 ± 30 BP
KILC 21	Ireland	Lough Gara, SW-shore	2740 ± 25 BP
KILC 21	Ireland	Lough Gara, SW-shore	2770 ± 20 BP
Lough MacNean Lower IV	N-Ireland	Lough MacNean Lower	2695 ± 37 BP
Craggan	Scotland	Loch Tay	2500 ± 35 BP
Oakbank	Scotland	Loch Tay	2510 ± 50 BP
Redcastle	Scotland	Beauly Firth	2510 ± 50 BP
Loch Migdale	Scotland	Loch Migdale	2515 ± 40 BP
Carn Dubh	Scotland	Beauly Firth	2530 ± 50 BP
Milton Morenish	Scotland	Loch Tay	2530 ± 50 BP
Oakbank	Scotland	Loch Tay	2545 ± 55 BP
Loch Avich	Scotland	Loch Avich	2560 +/- 50 BP
Dall Bay South	Scotland	Loch Tay	2560 ± 35 BP
Oakbank	Scotland	Loch Tay	2560 ± 50 BP
Dunwalton Loch III	Scotland	Dunwalton Loch	2560 ±70 BP
Monzievaird	Scotland	Loch Ochtertyre	2560±70 BP
KILA 016	Ireland	Lough Gara, W Inch Island	2130 ± 20 BP
KILA 016	Ireland	Lough Gara, W Inch Island	2140 ± 20 BP
KILA 46	Ireland	Lough Gara, SE-shore	2150 ± 25 BP
KILA 016	Ireland	Lough Gara, W Inch Island	2170 ± 30 BP
KILA 016	Ireland	Lough Gara, W Inch Island	2200 ± 30 BP
KILA 46	Ireland	Lough Gara, SE-shore	2210 ± 20 BP
Barean Loch	Scotland	Barean Loch	2140 ± 60 BP
Dubh Loch	Scotland	Dubh Loch	2030 +/- 50 BP
Phopachy	Scotland	Beauly Firth	2030 ± 60 bp
Tombreck	Scotland	Loch Tay	2040 ± 35 BP
Dumbuck	Scotland	Firth of Clyde	2040 ± 50 BP
Dumbuck	Scotland	Firth of Clyde	2060 ± 50 BP
Milton Loch II	Scotland	Milton Loch	2060 ± 50 BP
Phopachy	Scotland	Beauly Firth	2060 ± 50 BP
Milton Loch I	Scotland	Milton Loch	2080 ± 50 BP or 130 ± 50 BC?
Dumbuck	Scotland	Firth of Clyde	2090 ± 50 BP
Barhapple Loch	Scotland	Barhapple Loch	2130 ± 30 BP
Firbush	Scotland	Loch Tay	2140 ± 55 BP
Barean Loch	Scotland	Barean Loch	2140 ± 60 BP

Redcastle	Scotland	Beauly Firth	2150 ± 60 BP
Cameron Bay	Scotland	Loch Tay	2160 ± 80 BP
Erskine	Scotland	Firth of Clyde	2170 ± 60 BP
Croftmartaig	Scotland	Loch Tay	2210 ± 50 BP
Erskine Bridge II	Scotland	Firth of Clyde	2210 ± 50 BP
Erskine	Scotland	Firth of Clyde	2210 ± 50 BP
Redcastle	Scotland	Beauly Firth	2220 ± 70 BP
Croftmartaig	Scotland	Loch Tay	2230 ± 50 BP
Loch Arthur	Scotland	Loch Arthur	2240 ± 60 BP
Dorman's Island	Scotland	Whitefield Loch	2250 ± 50 BP
Loch Arthur	Scotland	Loch Arthur	2260 ± 50 BP
Redcastle	Scotland	Beauly Firth	2310 ± 50 BP
Ederline Boathouse	Scotland	Loch Awe	2320 ± 45 BP or 370 ± 45 BC?
Redcastle	Scotland	Beauly Firth	2330 ± 50 BP
Cults Loch III	Scotland	Cults Loch	2340 ± 50 BP
Milton Loch I	Scotland	Milton Loch	2350 ± 100 BP or 400 ± 100 BC?
Oakbank	Scotland	Loch Tay	2360 ± 60 BP
Dall Bay North	Scotland	Loch Tay	2400 ± 35 BP
Dall Bay South	Scotland	Loch Tay	2400 ± 35 BP
Milton Boathouse	Scotland	Loch Tay	2400 ± 35 BP
Milton Morenish	Scotland	Loch Tay	2400 ± 35 BP
Oakbank	Scotland	Loch Tay	2405 ± 60 BP
Oakbank	Scotland	Loch Tay	2410 ± 60 BP
Craggan	Scotland	Loch Tay	2420 ± 35 BP
Milton Boathouse	Scotland	Loch Tay	2425 ± 35 BP
Eilean Nam Breaban	Scotland	Loch Tay	2430 ± 35 BP
Milton Loch I	Scotland	Milton Loch	2440 ± 100 BP
Oakbank	Scotland	Loch Tay	2450 ± 50 BP
Old Manse	Scotland	Loch Tay	2460 ± 35 BP
Dall Bay North	Scotland	Loch Tay	2465 ± 35 BP
Old Manse	Scotland	Loch Tay	2465 ± 35 BP
Fernean (Hotel)	Scotland	Loch Tay	2475 ± 55 BP
Redcastle	Scotland	Beauly Firth	2480 ± 50 BP
Loch Leathan	Scotland	Loch Leathan	2480 ± 80 BP
Old Manse	Scotland	Loch Tay	2485 ± 35 BP
Oakbank	Scotland	Loch Tay	2490 ± 50 BP
Oakbank	Scotland	Loch Tay	2490 ± 50 BP
	Scotland	Loch Glashan	1500 ± 35 BP
Loch Seil	Scotland	Loch Seil	1500 ± 50 BP
Eilean Nam Breaban	Scotland	Loch Tay	1520 ± 50 BP
	Scotland	Loch Glashan	1530 ± 50 BP
Loch Drumellie	Scotland	Loch Drumellie	1560 BP
Buiston	Scotland	Buiston	1580 ± 50 BP or 370 ± 50 AD
Buiston	Scotland	Buiston	1640 ± 50 BP or 310± 50 AD
	Scotland	Loch Glashan	1650 ± 35 BP
Loch Glashan	Scotland	Loch Glashan	1650 ± 40 BP
Buiston	Scotland	Buiston	1680 ± 50 BP or 270 ± 50 AD
Redcastle	Scotland	Beauly Firth	1750 ± 90 BP

Cults Loch I	Scotland	Cults Loch	1790 ± 50 BP
	Scotland	Loch Glashan	1790 ± 35 BP
	Scotland	Loch Glashan	1815 ± 35 BP
Black Loch	Scotland	Black Loch	1840 ± 50
Dumbuck	Scotland	Firth of Clyde	1910 ± 50 BP
Morenish	Scotland	Loch Tay	1930 ± 35 BP
Morenish	Scotland	Loch Tay	1940 ± 50 BP
Phopachy	Scotland	Beauly Firth	1940 ± 60 BP
Morenish	Scotland	Loch Tay	1950 ± 35 BP
Erskine	Scotland	Firth of Clyde	1950 ± 50 BP
Tombreck	Scotland	Loch Tay	1950 ± 50 BP
Buiston	Scotland	Buiston	1950 ± 50 BP or 0 ± 50 AD
Loch Migdale	Scotland	Loch Migdale	1957 ± 40 BP
Morenish	Scotland	Loch Tay	1970 ± 35 BP
Tombreck	Scotland	Loch Tay	1970 ± 35 BP
Erskine	Scotland	Firth of Clyde	1970 ± 50 BP
Barlockhart	Scotland	Barlockhart	1975 ± 45 BP
Barlockhart	Scotland	Barlockhart	1980 ± 40 BP
Cameron Point	Scotland	Loch Lomond	1990 ± 50 BP
Phopachy	Scotland	Beauly Firth	1990 ± 50 BP
KILA 011	Ireland	Lough Gara, E-shore	1040 ± 20 BP
BOYL 038	Ireland	Boyle River	1110 ± 25 BP
KILC 022	Ireland	Lough Gara, SW-shore	1110 ± 25 BP
KILN 012	Ireland	Lough Gara, N-Callow Lough	1120 ± 60 BP
KILA 011	Ireland	Lough Gara, E-shore	1130 ± 30 BP
KILC 022	Ireland	Lough Gara, SW-shore	1160 ± 30 BP
KILC 022	Ireland	Lough Gara, SW-shore	1170 ± 30 BP
KILC 022	Ireland	Lough Gara, SW-shore	1170 ± 30 BP
BOYL 038	Ireland	Boyle River	1180 ± 20 BP
KILF 005	Ireland	Lough Gara, Lagoon in NW	1180 ± 20 BP
KILC 022	Ireland	Lough Gara, SW-shore	1180 ± 40 BP
KILC 020	Ireland	Lough Gara, SW-shore	1190 ± 20 BP
KILA 034	Ireland	Lough Gara, SE-shore	1190 ± 60 BP
KILC 020	Ireland	Lough Gara, SW-shore	1230 ± 20 BP
KILC 022	Ireland	Lough Gara, SW-shore	1240 ± 30 BP
KILC 022	Ireland	Lough Gara, SW-shore	1290 ± 30 BP
Corragh Lough	N-Ireland	Corragh Lough	1010 BP?
Ross Lough	N-Ireland	Ross Lough	1150 BP?
Lough Barry	N-Ireland	Lough Barry	1170 ± 46 BP
Derryhowlaght Lough	N-Ireland	Derryhowlaght Lough	1181 BP?
Lochearnhead	Scotland	Loch Earn	1200 BP
Dall Bay North	Scotland	Loch Tay	1245 ± 35 BP
Craggan	Scotland	Loch Tay	1270 ± 35 BP
Craggan	Scotland	Loch Tay	1300 ± 35 BP
Dall Bay North	Scotland	Loch Tay	1330 ± 35 BP
	Scotland	Loch Glashan	1400 ± 40 BP
	Scotland	Loch Glashan	1415 ± 35 BP
Dunwalton Loch III	Scotland	Dunwalton Loch	1440 ± 50 BP

Buiston	Scotland	Buiston	1430 ± 50 BP
Buiston	Scotland	Buiston	1430 ± 50 BP or 520 ± 50 AD
Dall Bay North	Scotland	Loch Tay	1435 ± 35 BP
Milton Loch III	Scotland	Milton Loch	1460 ± 70 BP
Milton Loch III	Scotland	Milton Loch	1470± 50 BP
Llangorse lake	Wales	Llangorse Lake	1059 BP?
BOYL 038	Ireland	Boyle River	0720 BP?
Ballynahinch	Ireland	Ballynahinch	906.5 BP
BOYL 038	Ireland	Boyle River	0970 ± 30 BP
Keenaghan Lough	N-Ireland	Keenaghan Lough	0567.5 BP?
Ballydoolagh Lough	N-Ireland	Ballydoolagh Lough	0566 BP?
Ballydoolagh Lough	N-Ireland	Ballydoolagh Lough	0595 BP?
Lough Yoan 2	N-Ireland	Lough Yoan	0796 BP?
Kilturk Lough	N-Ireland	Kilturk Lough	0821 BP?
Lough MacNean Lower II	N-Ireland	Lough MacNean Lower	0838 BP?
Drumgallan Lough	N-Ireland	Drumgallan Lough	0885 ± 35 BP
Eilean Nam Faoileag	Scotland	Loch Rannoch	0660 ± 50 BP
Lochrutton Loch	Scotland	Lochrutton Loch	820 ± 50 BP
Lochrutton Loch	Scotland	Lochrutton Loch	830 ± 50 BP
Eilean Nam Faoileag	Scotland	Loch Rannoch	0840 ± 60 BP
BunnohoneLough	N-Ireland	Bunnohone Lough	0148.5 BP?
Drumgay Lough	N-Ireland	Drumgay Lough	0150 BP?
Pad Lough	N-Ireland	Pad Lough	0150 BP?
Mill Lough	N-Ireland	Mill Lough	0213.5 BP
Mill Lough	N-Ireland	Mill Lough	0230 BP?
Parkhill Lough	N-Ireland	Parkhill Lough	0302 BP?
Lough Raymond	N-Ireland	Lough Raymond	0376 BP ?
Mullyduff Lough	N-Ireland	Mullyduff Lough	0395 BP?
Tattycam Lough	N-Ireland	Tattycam Lough	0402 BP?
Aghnahinch Lough	N-Ireland	Aghnahinch Lough	0403 BP?
Lankill Lough	N-Ireland	Lankill Lough	406 BP
Lough Corbank	N-Ireland	Lough Corbank	0450 ± 45 BP
Mount Sedborough Lough	N-Ireland	Mount Sedborough Lough	0460 ± 40 BP
Carn Dubh	Scotland	Beauly Firth	0280 ± 50 BP

Appendix E Map data and tiles

Cults Loch, Barhapple Loch and Black Loch of Myrton map tiles and contours:

All downloaded using EDINA Digimap Ordnance Survey Service, <http://digimap.edina.ac.uk>

Mastermap 1:1000 Raster [TIFF geospatial data, scale 1:1000]

Cults Loch tiles: NX 1261, NX 1260, NX 1259, NX 1159, NX 1161, NX 1160

Barhapple Loch tiles: NX2457, NX2458, NX59, NX2557, NX2558, NX2559, NX 2657, NX2658, NX2659, NX2757, NX2758, NX2759, NX2460, NX2560, NX2660, NX2760

Black Loch of Myrton tiles: NX3542, NX3543, NX3642, NX3643, NX3742, NX3743

Mastermap 1:25 000 Raster [TIFF geospatial data], Scale 1:25000

Black Loch of Myrton tiles: NX33, NX34, NX43, NX44

Terrain 5 Contours [SHAPE geospatial data], Scale 1:10000

Cults Loch contours: NX15NW and NX16SW

Barhapple Loch contours: NX25NE, NX25NW, NX26SE

Black Loch of Myrton contours: NX34SE, NX34SW, NX33NE, NX43NW, NX44SW

Derryhowlaght Lough and Ross Lough world imagery

Source: ESRI, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

SRTM GDEM tiles 1 arc-second (30m) from UGS EarthExplorer http:/earthexplorer.usgs.gov/

N54_w005_1arc_v3, N54_w006_1arc_v3, N54_w007_1arc_v3, N54_w008_1arc_v3, N54_w009_1arc_v3, N55_w005_1arc_v3, N55_w006_1arc_v3