

Fishscapes

Exploring a long-term perspective of fisheries
and aquatic habitat structures in the Baltic Sea
region through interdisciplinary studies

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Abstract

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Understanding fishing practices through the zooarchaeological record offers crucial insights into past human-environment interactions, subsistence strategies, and the development of the modern fishery practices. Past fishing practices varied widely depending on geographical location, environmental factors, and cultural contexts. In this thesis, I explore fish and fisheries in the Baltic Sea from different time frames. Evidence from archaeological fishbones and teeth provides a direct link to fishing practices in the past. Species diversity and anatomical distribution patterns are used to explore fishing methods. Isotope analysis on fish teeth offers further refinement of ecological patterns, including fish migration and mobility. Using zooarchaeological materials from Gotland and Åland, this thesis identifies and discusses patterns in relation to climate change and cultural shifts from the Mesolithic until the Early Modern Period. By applying the theoretical framework of negative space and values the formation of past assemblages and the remains excavated in the present are evaluated. Using strontium isotope analysis, the likely origin, fresh or brackish water, of euryhaline fish on Gotland is explored. The results indicate that fluctuations in aquatic habitat utilisation are tied to environmental shifts and influenced by cultural preferences and values. To understand how fish are transformed from living creatures to products for human consumption, Medieval zooarchaeological material from Åland was used to investigate shifting patterns in the transportation of cod from a local fishery. A possible difference in fish products was identified related to the Gotlandic sources. This has implications on how the written record might be interpreted. The aspects above are discussed in a diachronic way and modern concepts such as fishing down the food web are used to examine the sustainability of past fisheries. The findings contribute to broader discussion on past aquatic resource utilisation and fish's value and identities at different time frames in the Baltic Sea context. Highlighting the significance of fishbone analyses and the potential to incorporate archaeological data in contemporary sustainability discourse.

Keywords: Zooarchaeology, Strontium isotope analysis, mobility, Gotland, Åland, Mesolithic, Neolithic, Middle Ages

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When patterns are broken, new worlds emerge
- Tuli Kupferberg

List of Papers

This thesis is based on the following papers, which are referred to in the text by their Roman numerals. In the printed version the papers are found in Appendix II.

- I. **Krooks, B.**, Martinsson-Wallin, H., Manuscript. Understanding Human-Fish Relationships in the Gotlandic Archaeological Record.
- II. **Krooks, B.**, Boethius, A., 2024. Freshwater exploitation at Ajvide - Pitted ware culture fishing practises investigated through laser ablation facilitated strontium isotope analyses. *Quaternary Science Reviews* 344, 108967. <https://doi.org/10.1016/j.quascirev.2024.108967>
- III. **Krooks, B.**, D'Agata, C., Boethius, A. Fresh or Brackish? Laser ablated-facilitated strontium isotope analysis to identify past human fishing practices and euryhaline fish habitats on Gotland. *In review*
- IV. **Krooks, B.**, Kivikero, H. 2024. Fish species richness, resource availability and human selectivity reflected in the fishbone material from a medieval Franciscan friary in the Baltic Sea. *Journal of Island and Coastal Archaeology*, X:1-18. <https://doi.org/10.1080/15564894.2024.2405817>

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Notes on my contribution

The contribution of Beatrice Krooks to the papers included in this thesis was as follows:

- I. Development of the research idea, and writing of the original manuscript in collaboration with H.M.W.
- II. Co-developing the research idea, and designing the sample protocols. I applied for funding for analysis of the materials, and permission to sample the archaeological materials. I designed the strategies and protocols for sampling of the archaeological material, identification of the fish teeth and conducting the sample preparation. Data analysis, curation of data, and visuals were made in collaboration with A.B. Original manuscript written in collaboration with A.B.
- III. Development of the research ideas and design of the sample protocols. I applied for funding for analysis of the materials, and permission to sample the archaeological materials. I also designed the strategies and protocols for sampling the archaeological material, identification of the fish teeth and conducting the sample preparation. Data analysis and visuals were made in collaboration with C.D and A. B.
- IV. Designing the scope of the project with H.K. Data analysis, data curation, writing of original manuscript, and revisions.

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Stay fishy!

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Abbreviations and Glossary

Abbreviations

BP – Calibrated ^{14}C dates
Bp – Uncalibrated dates
EJD – Enameloid Dentine Junction
FBC – Funnel Beaker Culture
FDFW – Fishing Down the Food Web
GL – Guta Lagen
HFG – Hunter-Fisher-Gathers
KJB- King James Bible
LA-MC-ICP-MS – laser ablation-multi collector-inductively coupled plasma-mass spectrometry
MWP – Medieval Warm Period
NISP – Number of Identified Specimens
NSP – Number of Specimens
PWC – Pitted Ware Culture
Sr – Strontium
TL – Total length estimation
WBA – Water Body Alignment

Glossary

Agglomeration event – Gathering of fish (for spawning)
Anadromous – Fish that migrates from saline to freshwater to spawn
Catadromous – Fish that migrates from fresh to saline water to spawn
Dispersal – movement from the birth/natal site
Enameloid – Fish teeth enamel
Euryhaline – Fish that can live in various salinities
Fidelity – lack of, or limited dispersal from birth/natal site
Oceanodromous – Fish that live and migrates in saline water
Photic zone – Upper most layer of water that receives sunlight
Potamodromous – Fish that live and migrates in freshwater

1. Introduction

Fish have long been a key source of sustenance for humans. The first substantial utilisation and consumption of aquatic species originates in the Upper Pleistocene, where the increased consumption of aquatic species has been suggested as a dietary driver in the biocultural evolution of *Homo sapiens* during the Late Stone Age of Africa, and later the Upper Palaeolithic of Eurasia (Klein 2009). During the Holocene fish were an important staple food for the Meso- and Neolithic hunter-fisher-gathers of Northern Europe – subsequent later agricultural societies continued to consume fish on a regular basis. For many centuries humans viewed the oceans as bottomless resources, brimming with an abundant, never-ending, fish supply. However, this perception has been proven false in the last century with overfishing and the extraction of marine resources now part of global geopolitics (UN Goal 14 | Conserve and sustainably use the oceans, seas and marine resources for sustainable development).

Non-academic publications such as Kurlansky (1999, 2006, 2008, 2020, 2021), Svensson (2019), and Fränstam & Tell (2022, 2024) and the televisual media (such as “Fiskarnas rike” [Kingdom of Fish, 2021-2025]) highlight how human-fish interactions are as important today and for the future as they were in the past. However, in order to understand fully the complex journey that brought us to where we are today, we must consider factors such climatic changes (small and large), ecological systems and human interactions with the environment and other humans, as well as human selectivity of what to fish and eat within various time frames. To understand humans’ complex journey from the past to the present we rely on studies from archaeological excavations, vernacular history and written historical sources in tandem with environmental history. In this thesis I will explore this journey by analysing the human-fish relationships in a Baltic Sea area setting, ranging from the Mesolithic (Scandinavian Early Stone Age) until the Mediaeval times, an almost 9000 years journey.

Fishbones from archaeological excavations play a central role in exploring and interpreting past human-fish interactions, however, fish skeletal material is often not recovered at the same level, or analysed with the same care, as other archaeological evidential materials. This lack of attention reflects how

some archaeologists undervalue the recovery and analysis of fishbones, which I believe stems from a lack of understanding of the imbedded information and probative values they contain.

My research is based on the proposition that by giving fish, and in this case, the fishbone materials from archaeological excavations, a “voice”, we can achieve more holistic interpretations of the past. To do this, interdisciplinary approaches are integrated into the research aims and design of this thesis. Fishbones not only reflect human resource use and selectivity in the past but also represent fish that were once living entities in an ecosystem, which is now lost to time. Furthermore, from a cognitive perspective, fishing requires the knowledge and tools to catch fish but also, more importantly, knowledge of aquatic habitats and the behaviour of fish populations. Whilst archaeology provides evidence of tools and parts of consumed fish, we often lack direct evidence of the aquatic habitats in which the fish once lived in, and one of the intentions of my research is to fill this void

Works like Hoffmann’s *The Catch* (2023), Arnold’s *Medieval Riverscapes* (2024), and Barrett & Orton’s *Cod and Herring* (2016) have presented various approaches to understanding Medieval and Historical fisheries in Europe. Building upon these studies, I expand the concepts of Social Zooarchaeology (Russel 2011; Overton & Hamilakis 2013) and Ethnoichthyology (Svanberg & Locker 2020), developing methodological approaches that can lead to more holistic interpretations. The works mentioned above focus on the European Middle Ages and the fishing of freshwater or marine species. In landlocked sites, freshwater fish could be caught locally, while marine fish needed to be transported there. However, for archaeological sites located along the Baltic Sea coast—both past and present—interpreting the origins of euryhaline fish (see glossary) is more complex.

During the Holocene, the Baltic Sea underwent numerous changes in salinity, temperature, and water levels, which affected both fish and human environments (see Figure 1). To explore these aspects, I employed both disciplinary and interdisciplinary approaches in the case studies central to this work. A methodological and theoretical framework (paper I) was developed to guide the design of papers II-IV. The case studies in papers II-IV are geographically and temporally diverse, focusing on two Baltic Sea islands: Gotland and Åland. Archaeological fishbone materials from five sites, spanning a timeframe from c. 9000 BP to c. 350 bp (see Figure 1), were analysed. By synthesising the results from these papers and applying the framework outlined in paper I, my research expands upon the discussions and interpretations achievable with this approach.

The dating of materials and sites is reported in both BCE/AD and BP in the papers depending on publishing standards of the specific journals. For consistency, all dates in this thesis are presented in BP (calibrated ^{14}C dates) and bp (uncalibrated dates or relative chronology).

1.1 Aims

The primary aim of my studies is to analyse and understand how fish-bones from archaeological excavations contain information on the intertwined relationship of human-fish-environments from the past with a pathway to the present. The secondary aim is that through diachronic studies of fishbones, to show changes in habitat structure and human aquatic utilisation and relate this to the bigger climatic and cultural shifts of the past. This I argue can be used to inform better ways to conduct archaeological research as well as inform fishing and aquatic habitat protection in the present.

Four central research questions are addressed:

1. How do preconceived perceptions and values of fishbones impact the relationship between the archaeologist and fishbones as source materials? (Addressed in paper I, and chapter 8.3)
2. How can we get in-depth knowledge of past and present fish mobility, paleohabitat structures and human interactions with them? (Addressed in papers II and III, and chapter 8.1)
3. How can we understand the human-fish relationship better by using a wider range of sources and perspectives? (Addressed in papers I, III and IV, and chapters 8.2 and 8.3)
4. Can research on archaeological fishbone assemblages from archaeological sites accumulated in different climate and environmental stages during the Holocene inform us on the pathway to the current situation and conservation strategies for the future? (Addressed in papers I-IV and chapter 8.3).

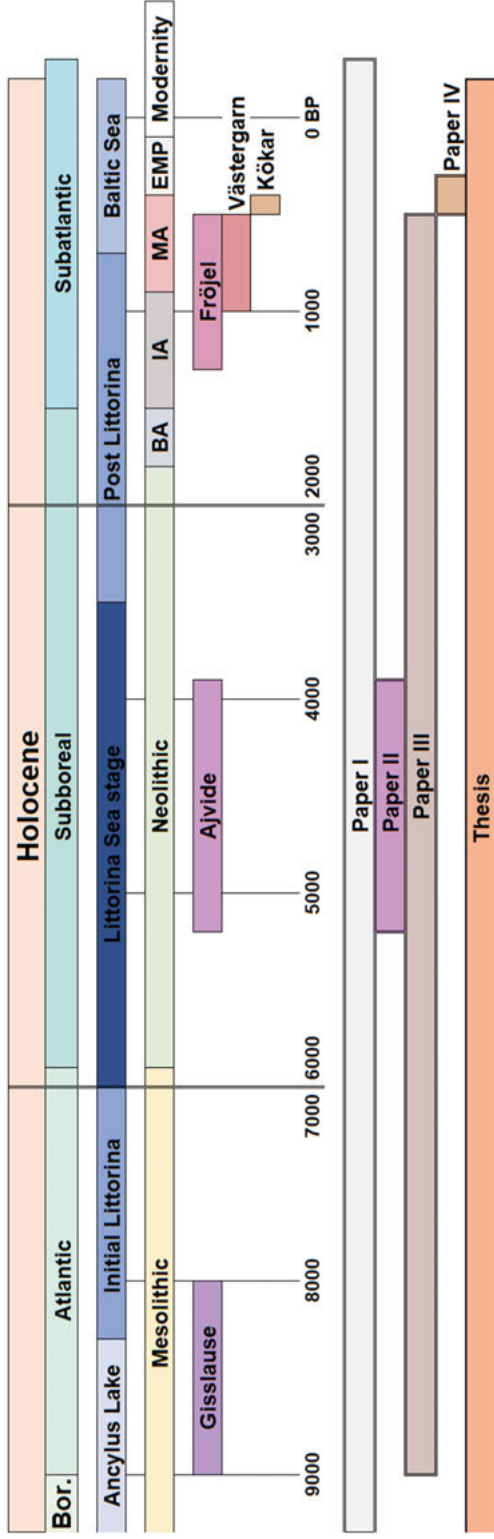


Figure 1. Timeline in BP dates showing the timespan of the thesis with the Geological epoch, climatic periods, the Baltic Sea phases (darker blue indicates higher salinity), archaeological/ historical period and the dating of the sites. Bronze Age (BA), Iron Age (IA), Middle Age (MA), Early Modern Period (EMP). At the bottom the five boxes show how the Papers are situated temporally. The ranges 2000-3000 BP and 6000-7000 BP is collapsed since no material was analysed from these periods.

1.2 Thesis Structure

This thesis adopts a thematic chronological structure. In chapter 1 the introduction and aims of the overall project are presented, together with signposts to the research themes within the papers where specific questions have been analysed and discussed. Chapter 2 contains the background of the study. This chapter is made up of five parts: 2.1 presents an overview of the development of the Baltic Sea during the Holocene, 2.2 gives an introduction into fishes as biological entities and how this facilitates the interpretation of archaeological fishbones, and 2.3 presents the relevant research history from a diachronic perspective. In section 2.4 the sites used in the study are introduced, and finally, section 2.5 presents the materials used in the case studies. Chapter 3 presents the theoretical framework used in this thesis. Chapter 4 gives an overview of the methods used and their limitations. Chapters 5 to 7 briefly presents the results and summaries of papers I to IV.

In chapter 8 the results of the papers are discussed in relation to the overall aim of the research project, this chapter is separated into three main parts: 8.1 Fishy information: This chapter explores and highlights the fishscapes interactions on Gotland from a diachronic perspective using Strontium isotope analysis of euryhaline fish teeth (papers II and III). Spanning a timeframe from 9000 to 600 cal. BP and habitat structure shifts in water bodies on Gotland and around the island are presented and related to climatical events and ecological information. 8.2 Fishy business: Using zooarchaeological materials and written sources different aspects of fish as products are discussed. Based on the anatomical distribution pattern of cod on Åland (paper IV), the difference between local and imported products are identified. This discussion is expanded with the few written sources from Gotland and other information on fish as products in the Baltic Sea area during the Middle Ages and Early modern period. 8.3 Swimming with the Fishes: Explores and discusses how the knowledge of these past fishscapes might be utilised in shaping improved fishscapes in the present and future for humans and fish alike (papers I-IV).

Finally, chapter 9 summarises the research and discusses research gaps identified in the project.

2. Background

2.1 Holocene Development of the Baltic Sea

The Baltic Sea is one of the largest brackish water bodies in the world and has undergone significant transitional phases since the last Ice Age. At its maximum extent, the Scandinavian Ice Sheet nearly reached latitude 48° N, and was estimated to have covered about 6,600,000 square km and attained a thickness of up to 3,000 metres (Makkaveyev *et al.* 2022; Jungdal-Olesen *et al.* 2024) causing compression of the underlying land mass. As the ice retreated isostatic rebound processes ensued, which are still ongoing today. At the same time sea levels rose due to melting continental ice mass, which combined with isostatic rebound, created a complex shoreline displacement on Gotland and the Baltic region in general. The Baltic Sea has subsequently shifted from being a post-glacial freshwater lake, to a marine, and subsequently a brackish water body.

A vast amount of research has been published on environmental change in the Baltic Sea basin over the last 10,000 years (e.g., Svensson 1991; Björck 1995; Mörner 1995; Wastegård *et al.* 1995; Sohlenius *et al.* 1996, 2001; Bennicke & Jensen 1998; Jensen *et al.* 1999; Andrén *et al.* 2000a, 2000b; Bennicke *et al.* 2000; Emeis *et al.* 2000, 2002, 2003; Christiansen *et al.* 2002; Gustafsson & Westman 2002; Berglund *et al.* 2005; Andrén *et al.* 2007; Björck *et al.* 2008; Röbller *et al.* 2011; Binczewska *et al.* 2018; Rosentau *et al.* 2021). Many of these studies highlight the temporal variability in environmental processes, depending on the material studied and the region. However, they recognise three main stages environmental shifts—the Ancylus Lake, Littorina Sea, and Baltic Sea—which are discussed to varying extents and understanding in the literature. While there is some ambiguity in the sediment and diatom samples, and the chronology is not absolute, research provides a likely timeline for these major environmental shifts (see Figure 1).

These environmental changes have impacted the aquatic habitats available throughout the region, as well as the extent of landmass suitable for human occupation. The following descriptions of the various stages of the Baltic Sea will highlight different aspects of these changes in both aquatic and terrestrial environments within the Baltic Sea basin.

2.1.1 Ancylus Lake (c. 9500 – 8300 BP)

From around 9500 BP the freshwater Ancylus Lake was situated between the glaciers in the North and landmasses in the South (Björck 1995). Björck's (1995) chronology of the Ancylus Lake defines three stages, the *Ancylus transgression* (9500- 9200 BP), the *Ancylus regression* (9200-9000 BP) and the *Non-Dammed Ancylus Lake stage* (9000-8000 BP). Later studies have highlighted spatial variability in the drainage and potential onset of the following Ancylus-Littorina transgression (Emeis *et al.* 2000, 2002, 2003; Sohlenius *et al.* 2001; Christiansen *et al.* 2002; Binczewska *et al.* 2018; Strandberg *et al.* 2020). During the Ancylus Lake, some marine species such as the ringed seal (*Pusa hispida*) became adapted to freshwater conditions (Storå 2001; Ukkonen *et al.* 2014; Bro-Jørgensen 2021). Based on the archaeological record the fish in the Ancylus Lake were freshwater species, such as perch (*Perca fluviatilis*), pike (*Exos lucius*), fourhorn sculpin (*Myoxocephalus quadricornis*), European whitefish (*Coregonus* sp.) and burbot (*Lota lota*) (Liljegren & Lagerås 1993). During the Non-Dammed Ancylus Lake stage, the intrusion of saline water started to change species composition.

There are however conflicting data on when and for how long this transitional stage lasted (c.f. Bennike & Jensen 1989; Björck 1995; Sohlenius *et al.* 1996, 2001; Emeis *et al.* 2002; Berglund *et al.* 2005; Björck *et al.* 2008). Since there is no clear transition line between the fresh- and brackish water stages in sediment cores (Sohlenius *et al.* 2001; Emeis *et al.* 2002), it has been argued that this transgression period (c. 1300 years) entailed several saline water influxes (Emeis *et al.* 2002: 213). The Ancylus – Littorina transgression period correlates to the 8.2ka event, when the Laurentide ice sheet damming the Lakes Ojibway and Agassiz in the current Hudson Bay area, collapsed causing a rapid increase of freshwater input into the Atlantic Ocean (Barber *et al.* 1999; Gregoire *et al.* 2012; Ullman *et al.* 2016; Parker & Harrison 2022). This caused a period of rapid sea level rises and cooling of the climate, with an estimated global temperature drop of 1 to 1,5° C (Alley & Ágústsdóttir 2005; Morrill *et al.* 2013; Affolter *et al.* 2019; Parker & Harrison 2022).

2.1.2 Littorina Sea (c. 8300 – 700 BP)

Following Andrén *et al.* (2000a) the Littorina Sea Stage is divided into three phases: the *Initial Littorina* Sea stage (ca. 8300–7000 BP), the *Littorina Sea* stage (ca. 7000–3500 BP), and the *Post-Littorina Sea* stage (c. 3500–700 BP). The period 8000–5000 BP correlates to the Holocene temperature optimum with c. 2°C warmer temperatures than 1850 pre-industrial temperatures. This period is also associated with less rainfall, resulting in low water levels in

lakes across northern Europe (Negendank 2002; Seppä *et al.* 2005). The earliest saline diatoms from the Gotland Basin have been dated to around 7900 BP, indicating some mixing of saline and freshwater (Sohlenius *et al.* 2001: 228). The influx of saline water increased the nutrient and oxygen load in the water, leading to higher biological production in the photic zone (see glossary) (Emeis *et al.* 2002). These changes are reflected in nitrogen (N) and carbon (C) isotopic signatures in sediment cores, where a decline in $\delta^{15}\text{N}$ and an enrichment of $\delta^{13}\text{C}$ indicate heightened bio-productivity and increasing salinity (Emeis *et al.* 2002). The increasingly saline waters led to the arrival of marine species, as the Danish Straits became wider and deeper, allowing larger marine mammals to reach areas in the Baltic Basin (Bro-Jørgensen 2021).

Fish remains from all modern Baltic Sea species have been identified in materials dated to the Littorina Sea (Liljegren & Lagerås 1993). Sea-level changes were drastic during the Littorina Sea, with the Littorina maximum peaking around ca. 5000 BP, the water mass is estimated to have been twice that of the modern Baltic Sea (Kliewe & Janke 1991; Emeis *et al.* 2002) and salinity double of the current values (Westman *et al.* 1999). Following the Littorina maximum (ca. 5000–4500 BP), a sea-level regression shaped the “modern” coastal areas (Emeis *et al.* 2002). Three salinity peaks been observed in sediment cores from the Gotland Basin (Emeis *et al.* 2002). During the ca. 5000 BP Littorina maximum, the highest rates of organic $\delta^{13}\text{C}$ concentrations, and diatoms were identified in sediment cores, indicating favourable conditions for marine life in the Gotland Basin (Emeis *et al.* 2002). After this peak in salinity and sea-level rise, a regression period followed, lasting until around 3000 BP.

In sediment cores from the Gotland Basin, increases in $\delta^{13}\text{C}$ and saline diatoms from ca. 3000 BP to around 1000 cal. BP indicate a salinity peak (Emeis *et al.* 2002). Sediment cores and dendrochronology indicate that this salinity peak correlates with the Medieval Warm Period (MWP) (ca. 950–850 BP) (Briffa *et al.* 1992; Andrén *et al.* 2000b). The second climate anomaly, the Little Ice Age, occurred toward the end of the Post-Littorina Sea stage and the beginning of the modern Baltic Sea. Andrén *et al.* (2000a) identify changes in sediment cores around ca. 850–700 BP, possibly correlating with the cooling of the Baltic Sea (see also Andrén *et al.* 2000b; Emeis *et al.* 2002).

2.1.3 Baltic Sea (c. 700 BP – Today)

During the last 500 years, the climate, and subsequently the Baltic Sea itself, has seen numerous small-scale changes (i.e., temperature changes, ice coverage and run-off estimates) connected to the unstable weather conditions in the region with high day-to-day variability (Eriksson 2009). Results indicate that

mild/warm periods create lower variability in weather conditions, and cold periods yield periods of high variability (Eriksson 2009). There is a horizontal and vertical salinity and temperature gradient leading to different fauna and flora existing in the different sub-basins within the Baltic Sea. Marine species richness correlates to the salinity gradient, thus the Bornholm basin contains more marine species than the Bothnian Bay (Ojaveer & Kalejs 2005). The trophic levels in the Baltic Sea comprises of four levels, with many of the fish species exploited today belonging to the two highest ones (Andersen *et al.* 2010; ICES 2019).

Salinity influx from the Atlantic Ocean occurs every 30 – 40 years (Snoeijs-Leijonmalm *et al.* 2017), and with the input of freshwater runoffs containing nutrients and pollutants, the Baltic Sea is becoming less saline, whilst eutrophication is increasing and anoxia is spreading (Hansson & Viktorsson 2023). Around the year 1999, a regime shift in the anoxic conditions occurred, and the areas affected and the volume of anoxic water in the Baltic Sea have been constantly increasing (Hansson *et al.* 2011; Almroth *et al.* 2021). With lower salinity and less oxygen many species in the Baltic Sea are struggling (Hansson & Viktorsson 2023). One example is the Baltic Sea cod (*Gadus morhua*) which, with low salinity and oxygen levels, cannot grow or reproduce properly (Plikshs *et al.* 1993; Nissling 1994; Chabot & Dutil 1999; MacKenzie *et al.* 2000; Schmidt *et al.* 2024). The combination of low oxygen and salinity, together with human exploitation has led to a decline in multiple high-trophic-level fishes (e.g., cod). This reduction of high-trophic-level fishes has led to opportunistic population increase in lower trophic level species such as sprat (*Sprattus sprattus*; Andersen *et al.* 2010; Olsson *et al.* 2018). Today the increased sprat extraction this ecological pattern might be changing; and large-scale changes in food web structure, may potentially lead to an altered ecosystem (Österblom *et al.* 2007; Bossier *et al.* 2020). Fishing in the Baltic Sea is regulated at a regional level through the European Union (EU Regulation 2016/1139), and national level (see HaV “Lagstiftning som rör yrkesfisket” and “Lagstiftning som rör fritidsfisket”).

2.2 Fishes

Fishes make up more than half of all known vertebrate taxa on Earth, with more than 33,000 species described today (Nelson *et al.* 2016; Fraser & Thiery 2019; Johanson *et al.* 2019; Manel *et al.* 2020). Fishes vary in size and inhabit almost all aquatic habitats worldwide (Yancey *et al.* 2014). Osteichthyes, or bony fish, represent the largest taxonomic group, with more than 32,000 described species (Nelson *et al.* 2016). They are also the class most likely to be

recovered during archaeological excavations in northern Europe around the Baltic Sea, since Chondrichthyes i.e., cartilaginous fish, are rare in the Baltic Sea (SLU Artdatabanken 2025). Additionally, cartilage preservation in archaeological context is rare (see chapters 3.1, 4.2).

In the Baltic Sea Bony fish are commonly separated into marine and freshwater species. However, species that migrate between saline and freshwater during their lifecycle are not uncommon. Additionally, adaptation to the brackish water conditions in the Baltic Sea have been observed in some marine and freshwater species (Ojaveer & Kalejs 2005), making this classification somewhat crude and potentially problematic for archaeological fishbone studies. Most fish species have specific habitat preferences for spawning, egg deposition, and other life history stages (see Table 1). Skeletal development continues throughout their lives (i.e., growth is not stunted by sexual maturity as other vertebrates) and new bone is built up in a three-dimensional pattern. Fishes in temperate climates exhibit specific growth patterns in their osseous tissue, where yearly cycles, known as annuli, can be observed and recorded. Annuli calculations can be used to determine the age at death of an individual and the likely season of capture (Casteel 1974; Mellars *et al.* 1980; Uzawa 1992; van Neer *et al.* 1999, 2004; Higham & Horn 2000; Polat *et al.* 2004; Limburg *et al.* 2008). Determining the season of catch based on annuli calculations from different osseous tissues e.g., vertebral centra or otoliths are equitable (van Neer *et al.* 1999; Polat *et al.* 2004; Filmalter *et al.* 2009). However, van Neer *et al.* (2004) and Heimbrand (2021) have shown that in modern fish from the Baltic Sea, the method of annuli calculation might not always be reliable. Archaeological studies of annuli on vertebra centra also require the material to be well preserved, as damage to the outer edge of the centra makes the recording of the outermost annuli uncertain (Svensson 2006).

In contrast to mammals, many fish species are polyphyodonts (Herold & Landino 1970; Nakajima *et al.* 1986), meaning that their teeth are replaced throughout their lives. This means that tooth development is not directly linked to the age of the fish, an aspect that has to be considered when interpreting sequential strontium (Sr) isotope analyses (see chapter 4.1.1). Discrepancies between archaeological and modern fish populations, such as variations in growth rates, can cause issues when analysing materials (van Neer *et al.* 2004; Limburg *et al.* 2008). However, these discrepancies can highlight changes in fish populations caused by environmental degradation and/or overexploitation of fish stocks. These methodological biases are also present in the estimation of the total length (TL) of archaeological samples, as past environmental properties could have affected the growth patterns of fish (Limburg *et al.* 2008).

When analysing archaeological fishbone assemblages, the environmental and habitat requirements of the identified species need to be considered when interpreting the water bodies from which they were extracted. For instance, the presence or absence of species can be used as an indicator of paleoenvironmental habitat structures or human selectivity. Spawning site fidelity in some species can influence the presence or absence of certain species in an area, directly influencing the availability of fish for human consumption; fishing during natural agglomeration events (see glossary), such as spawning, can facilitate the capture of large quantities of a single species which dominate archaeological assemblages as a result.

As a result of such factors, aquatic paleohabitat structures and changes within them are difficult to trace, and as a result few studies have used fish as a proxy for understanding such change (Galik *et al.* 2015; Häberle *et al.* 2016). In the context of the Baltic Sea, Holocene environmental change coupled with physiological adaptability in fish species, ensures that the classic classification of oceanodromous, potamodromous, anadromous, and catadromous fish (see glossary) does not present a suitable framework for understanding human fishing practices. For instance, many potamodromous species inhabit the coastal areas of the Baltic Sea today. As such, in this thesis the term euryhaline is used to describe fish species that by any standard classification would be defined as potamodromous. However, such standard terminology in the context of the Baltic Sea is not fully appropriate since it should also include the marine species that have adapted to the brackish waters of the Baltic.

However, since the focal point of papers II and III was to facilitate discussions on the origin of fish usually classified as “freshwater” species (i.e., potamodromous), this terminology was deemed appropriate to apply (see also chapter 8.3.2).

2.2.1 Spawning Season and Habitats

In current waters around Gotland and Åland, many fish species have adapted to the specific conditions of the Baltic. Some of the marine fish species include cod, herring (*Clupea harengus*), smelt (*Osmeridae*), dab (*Limanda limanda*), flounder (*Platichthys flesus*), and eelpout (*Zoarces viviparous*) (Ojaveer & Kalejs 2005). Of these, herring and smelt are less dependent on saltwater influxes from the North Sea, and are therefore considered early immigrant species in the Baltic Sea (Ojaveer & Kalejs 2005). Due to the changing salinity gradient and influxes of saline oxygenated water in different areas of the Baltic Sea, specialisation and adaptation of species is an ongoing and highly active process (Ojaveer & Kalejs 2005: 1496). As a result of the salinity gradient, the southern Bornholm Basin contains more marine species compared to the Bothnian Bay, wherein euryhaline species are more abundant (Ojaveer & Kalejs 2005: 1495). When these adaptations occurred is not fully understood, and many species may have inhabited the waters since the Ancylus Lake stage. This category includes many cyprinid species, as well as pike, perch, and pike-perch (*Sander lucioperca*), all of which can spawn in the low-salinity zones of the Baltic Sea.

The commonly identified species in the archaeological record have different spawning seasons and preferred habitats for spawning. During these natural agglomeration events, large shoals of fish gather at specific locations. In species with high spawning and natal site fidelity, yearly reoccurring events could be utilised by humans to catch large quantities of fish. Table 1 presents an overview of the commonly identified species in the archaeological record from the sites analysed (i.e., papers II-IV), and their current spawning habitat, season, and dispersal/migration patterns.

Table 1. The commonly identified species in the archaeological assemblage (based on data collated in Table A1 in Appendix I), showing the classic classification, spawning habitat, and dispersal/migration of the commonly identified species in the archaeological record.

Species	Classic classification	Spawning habitat	Season	Dispersal/Migration	References
Pike (<i>Esox lucius</i>)	potamodromous	Shallow waters less than 20 cm; vegetation	Mar-Apr	Low	Scott & Crossman 1973; Karaas & Lehtonen 1993; Miller <i>et al.</i> 2001; Skov <i>et al.</i> 2008; Rohltla <i>et al.</i> 2012; Flink <i>et al.</i> 2023
Perch (<i>Perca fluviatilis</i>)	anadromous	Shallow waters; vegetation or coarse sediment	Feb-Jul	Low	Skov <i>et al.</i> 2008
Pikeperch (<i>Lucioperca sander</i>)	potamodromous	Turbid waters 1 - 3 m deep; vegetation or coarse sediment for nest construction	Mar-Jun	Usually move from Brackish to freshwater for spawning	Balon 1975; Mann 1996; Lappalainen <i>et al.</i> 2003; Ložys <i>et al.</i> 2017; Malinovskyi <i>et al.</i> 2018
Bream (<i>Abramis brama</i>)	potamodromous	Shallow waters; vegetation or coarse sediment	Apr-Jun	High individual variability in dispersal	Kennedy & Fitzmaurice 1986; Winter & Fredrich 2003; Geeraerts <i>et al.</i> 2007; De Leeuw & Winter 2008; Kulišková <i>et al.</i> 2009; Gardner <i>et al.</i> 2013; Winter <i>et al.</i> 2021
Ide (<i>Leuciscus idus</i>)	potamodromous	Shallow waters; vegetation or coarse sediment	Mar-Apr	High individual variability in dispersal	Winter & Fredrich, 2003; Geeraerts <i>et al.</i> 2007; De Leeuw & Winter 2008; Kulišková <i>et al.</i> 2009; Gardner <i>et al.</i> 2013; Rohltla <i>et al.</i> 2015; Winter <i>et al.</i> 2021
Roach (<i>Rutilus rutilus</i>)	potamodromous	Shallow waters; vegetation or coarse sediment	Apr-Jun	High individual variability in dispersal	Winter & Fredrich 2003; Geeraerts <i>et al.</i> 2007; De Leeuw & Winter, 2008; Skov <i>et al.</i> 2008; Kulišková <i>et al.</i> 2009; Gardner <i>et al.</i> 2013; Winter <i>et al.</i> 2021

Rudd (<i>Scardinius erythrophthalmus</i>)	potamodromous	Shallow waters; vegetation	May-Jun	High individual variability in dispersal	Pinder 2001; Freyhof & Kottelat 2007; Skov <i>et al.</i> 2008
Tench (<i>Tinca tinca</i>)	potamodromous	Shallow waters; vegetation	July-Sep	High individual variability in dispersal	Kennedy & Fitzmaurice 1970; Alaş & Solak 2004; Freyhof & Kottelat 2007; Ashworth & Johnson 2021; Morissette <i>et al.</i> 2021
Arctic char (<i>Salvelinus alpinus</i>)	anadromous	Turbid waters or slower pools in rivers; coarse sediment for nest construction	Oct	High	Grainger 1953; Melin & Rydberg 2009; Alekseyev <i>et al.</i> 2014
European flounder (<i>Platichthys flesus</i>)	catadromous	Shallow water;	Apr-Jun	High individual variability in dispersal	Ehrenbaum 1909; Molander 1925, 1964; Aro 1989; Nissing <i>et al.</i> 2002; Florin 2005
Turbot (<i>Psetta maxima</i>)	oceanodromous	Shallow waters 10 - 15 m deep;	Apr-Jun	Limited dispersal	Ehrenbaum 1909; Molander 1964; Bagge 1987; Aneer & Westin 1990; Støttrup <i>et al.</i> 2002; Florin & Höglund 2007; Florin & Franzén 2010; Florin 2005
European whitefish (<i>Corengus sp.</i>)	anadromous	Shallow waters; sand or coarse sediment	Oct-Nov	High individual variability in dispersal	Nielsen & Svedberg 2010
Cod (<i>Gadus morhua</i>)	oceanodromous	Open water, 10-270 m depth	Mar-Aug	High	Hinrichsen <i>et al.</i> 2003; Hinrichsen <i>et al.</i> 2009; Schmidt <i>et al.</i> 2024
Burbot (<i>Lota lota</i>)	potamodromous	Shallow waters; sand or coarse sediment	Nov-Mar	High individual variability in dispersal	Freyhof & Kottelat 2007; Rothla <i>et al.</i> 2014; Harrison <i>et al.</i> 2015
Herring (<i>Clupea harengus</i>)	oceanodromous	Open water, 0-140 m depth	Mar-May, Aug-Sep	High	Aneer, 1979; Oulasvirta <i>et al.</i> 1985; Rajasilta, 1992

2.3 Fishing in the Archaeological Record

Fishing identified through the archaeological record of Northern Europe offers vital insights into human-environment relationships, subsistence strategies, and cultural practices over time. Clark (1948) conducted the first comprehensive studies on prehistoric fishing in Europe, combining data on fish remains, tools, and ethnographic research to provide a broad overview of fishing in the past. Due to the absence of herring bones in the archaeological record in earlier periods Clark (1948: 74–79) specifically suggests that deep-sea fisheries did not evolve until the Iron Age. However, later research shows that excavation practices and techniques influenced this interpretation, and emphasized the need for fine sieving to minimize recovery biases in the material (see e.g., Thomas 1969; Payne 1975; Marean 1991; Stahl 1996; O’Connor 2003; Enghoff *et al.* 2007; Olson 2008; Gusick *et al.* 2018; Boethius 2018).

Research on archaeological fishbone assemblages around the Baltic Sea spans from the Mesolithic to the Early Modern period (to mention a few: Lepiksaar 1974; Noe-Nygaard 1983; Jonsson 1986a, b; Enghoff 1987, 1989, 1991, 1994, 1995, 2000, 2007, 2011; Benecke 1996; Lepiksaar & Henrich 2001; Pickard & Bonsall 2004; Enghoff *et al.* 2007; Makowiecki 2008; Olson 2008; Bērziņš 2010; Ritchie 2010; Barrett *et al.* 2011; Orton *et al.* 2011; Terberger *et al.* 2012; Krooks 2013; Nehlich *et al.* 2013; Barrett & Orton 2016; Krooks 2016; Makowiecki *et al.* 2016; Ritchie *et al.* 2016; Schmöcke *et al.* 2016; Lõugas 2017; Boethius 2018; Kivikero 2020a, 2020b; Lõugas & Bläuer 2021). These studies have used bone morphology, anatomical distribution patterns (skeletal part representation), and total length estimation, stable isotopes, and ancientDNA to analyse and identify past fish populations and fishing practices (not limited to: Barrett *et al.* 1999, 2011; Enghoff *et al.* 2007; Orton *et al.* 2011; Krooks 2013; Nehlich *et al.* 2013; Star *et al.* 2017; Kivikero 2020a, 2020b; Atmore *et al.* 2022). The following sections present fishing across the three key periods in this thesis: the Mesolithic, Neolithic, and Medieval period, with a particular focus on the Gotlandic and Baltic Sea region, and introduces how we can identify different scales of interaction, such as catchment area, and post-catch handling of the fish (e.g., butchery, smoking, drying etc.).

2.3.1 Early Fishing Practices

Fishbone assemblages in Europe from the Upper Palaeolithic indicate that fish and fishing was a part of human sustenance strategy from the Gravettian onwards (Hahn 2000; Adán *et al.* 2009; Russ & Jones 2009). Pictographic evidence from the Magdalenian site of Gönnersdof, Germany, suggests that fish

traps and nets were used to catch freshwater fish as early as c. 19.000 - 13.000 BP (Robitaille *et al.* 2024). Furthermore, fishhooks have been identified from the Upper Palaeolithic, indicating that active and passive fishing techniques were employed (Gramsch *et al.* 2013). Since the Scandinavian peninsula was situated beneath the ice sheet of the last Ice Age until c. 16.000 BP, the earliest evidence of fishing stems from the Mesolithic. In the Mesolithic period, fishing was a fundamental component of the subsistence strategies of Hunter-Fisher-Gatherer (HFG) societies in Scandinavia (e.g., Noe-Nygaard 1983; Pickard & Bonsall 2004; Terberger *et al.* 2012; Ritchie *et al.* 2016; Løugas 2017; Boethius 2018).

On Danish, Swedish, Finnish, and Russian sites, fish traps and stationary equipment have been dated to the Mesolithic and Neolithic periods (Petersson & Olausson 1952; Petersen *et al.* 1979; Andersen 1995; Pedersen 1995; Lorenz *et al.* 2012; Hansson 2018; Hansson *et al.* 2018; Koivisto *et al.* 2018, 2024; Piezonka *et al.* 2020). This material together shows that passive fishing has been a significant method of sustenance procurement for millennia. Hansson (2018) and Hansson *et al.* (2018) demonstrated that stationary fishing traps were placed in the shallow lagoon at the Haväng Mesolithic site in Scania, and stationary equipment was likely used to catch large quantities of fish during natural aggregation events, a pattern observed at the site of Norje Sunansund (Boethius *et al.* 2021). Mesolithic sites, situated along the coasts and near freshwater systems, relied heavily on aquatic resources such as fish and seals. In addition to aquatic systems importance for sustenance procurement, other archaeological evidences linked to transportation on snow and ice indicate the importance of water as a way of moving through the environment (Beuker & Nikus 1997; Glørstad 2013; Bjerck 2017; Gjerde 2021).

Areas rich in resources such as coastal and lagoonal areas were likely to be attractive for the early HFG coming to Scandinavia (Bailey & Milner 2002). Dietary studies indicate that aquatic resources are an important part of the diet (Boethius & Ahlström 2018; Robson & Ritchie 2019), and on Gotland freshwater fish made up a large part of the diet (Boethius & Ahlström 2018). On Gotland early Mesolithic sites are located on the Ancylus Lake shoreline whereas sites after the 8.2 ka event are found in the inland regions (see Apel *et al.* 2018, Figure 5). The large lakes on the island's northern part have been seen as a powerful attractor for the early Mesolithic settlers on Gotland (Apel & Storå 2017, 2018, 2020; Boethius *et al.* 2017). Recovered faunal remains have shown the importance of seals (Apel & Storå 2018) and fish (Knape & Eriksson 1988; Lindquist & Possnert 1999; Boethius *et al.* 2017) to the Mesolithic population.

Drawing on ethnographic data, mobility among HFG who focus on aquatic resources is generally lower than amongst groups who target terrestrial game, especially if storage and preservation of aquatic foodstuffs is practised (Rowley-Conwy & Zvelebil 1989). The high percentage of recovered faunal remains at many sites evidence specialisation in resource acquisition, and it is evident that Mesolithic HFG in the Baltic region adapted to the shifting ecological conditions that arose during the Holocene; environmental transitions profoundly influenced the availability and composition of aquatic resources.

2.3.2 Marine Specialisation

The Pitted Ware Culture (PWC) was the last outpost of HFG in Scandinavia, and was penecontemporaneous with the first agricultural societies in the region (Funnel Beaker Culture [FBC]). AncientDNA studies have shown that PWC populations had a genetic profile largely consistent with older Mesolithic Scandinavian groups, but with an admixture of genetic profiles from Neolithic farming groups (Skoglund *et al.* 2012, 2014; Malmström *et al.* 2015, 2019; Günther *et al.* 2018; Fraser *et al.* 2018; Mitnik *et al.* 2018; Allentoft *et al.* 2024; c.f. Coutinho *et al.* 2020). PWC's niche utilisation of marine and brackish coastal habitats enabled them to maintain functioning HFG societies (Artursson *et al.* 2023). This marine and aquatic orientation is evident in the coastal-oriented sites spanning the Scandinavian coastline from Southern Norway the east coast of Denmark to the Gävle area and the islands of Bornholm, Gotland and Åland (Janzon 1974; Österholm 1989; Stenbäck 2003; Pappmehl-Dufay 2006; Nordqvist & Jonsson 2009; Björck, 2011; Klassen 2020). Zooarchaeological assemblages show this strong aquatic dependency on Gotland, with seal and fishbones often dominating faunal assemblages (Lindqvist & Possnert 1997; Storå 2001; Olson 2008; Sjöstrand 2022). Despite this strong marine focus, bones from terrestrial animals and plant seeds in many PWC assemblages also show utilisation of terrestrial resources (Stenberger *et al.* 1943; Ekman 1974; Lepiksaar 1974; Aaris-Sørensen 1978; Edenmo & Heimdahl 2012; Magnell 2019; Vanhanen *et al.* 2019; Sjöstrand 2022).

Stable isotope analyses of PWC individuals' dietary patterns ($\delta^{13}\text{C}/\delta^{15}\text{N}$) give further evidence of strong marine dependency (Eriksson 2004; Eriksson & Lidén 2013; Fornander *et al.* 2008; Howcroft *et al.* 2014). More recent studies on enamel $\delta^{13}\text{C}$ have shown input of terrestrial food stuffs in the diet of the PWC (Ahlström & Price 2021).

On Gotland, PWC sites are spread across the island, with settlement and burial sites occupying slightly different areas in the landscape. The large settlements were placed in sheltered areas along the coastline and the burial sites are often found in more exposed areas visible from the water (Österholm

1989). This visibility of burial grounds has been suggested to be a sign of territorial ownership of the landscape by different groups (Saxe 1970; Goldstein 1981; Grøn 2015; Rowley-Conwy & Piper 2016; Conolly 2018). Ethnographic foraging data indicate that aquatic-dependent foraging societies, with seasonally-abundance resources, often display more pronounced territoriality (Binford 2001; Rowley-Conwy & Piper 2016). PWC territories on Gotland have been analysed and discussed by Österholm (1989) and by Wallin and Martinsson-Wallin (1992). Intrapersonal violence identified on PWC individuals, and the placement of burial grounds could indicate some territorial practices, as suggested by Ahlström and Molnar (2012). Additional indications of different population groups can be found in the zoo- and anthropomorphic clay figurines recovered at PWC sites (Lindström 2024, Figure 28) which suggest localised material cultural identities. Strontium isotope data ($^{87}\text{Sr}/^{86}\text{Sr}$) of humans and dogs from Åland indicates that mobility between different areas occurred (Boethius *et al.* 2024).

What is known about Neolithic fisheries on Gotland stems primarily from Olson (2008), where zooarchaeological assemblages, fishing equipment such as net sinkers, birch floaters, and fish hooks indicate diverse practises. It is also likely that fish traps were likely used on Gotland during this time, but no archaeological evidence has been found supporting this. While clubbing of fish through the ice in winter could also have been practiced, this is difficult to confirm based solely on material culture.

These tools, alongside the presence of large fishbones in the archaeological record, illustrate a growing specialization in marine resource exploitation, which likely had important social and economic implications. The emphasis on marine resources in the PWC reflects the adaptability of these communities to the dynamic environmental conditions of the Baltic Sea, which continued to evolve from a freshwater lake to a brackish sea during the Holocene (as presented in chapter 2.1).

2.3.3 Shift Toward Commercial Fisheries

After the Stone Age, and especially in the Bronze Age, there seems to be a decline in the use of fish as a main substance resource but by the Medieval period fish consumption in Northern Europe increased. Medieval fishing had become more specialized and economically significant, particularly in the Baltic Sea region. The rise of the herring fisheries, especially during the MWP, marked a pivotal shift in the economic importance of marine fishing (Barrett & Orton 2016, Holm 2016). Zooarchaeological studies of English fishbone assemblages have indicated an increased reliance on marine species, particularly herring and *gadids* (Barrett *et al.* 2004a, b). This shift, referred to as the

“Fish Event Horizon” (950 bp), is associated with changes in sea temperatures and productivity, which influenced fish populations in the Baltic and North Sea (Barrett *et al.* 2004b), whilst Perdikaris and colleagues (2007) propose that the Norse settler’s food culture could be an additional driving force behind this increase in cod consumption.

The increase in cod consumption was not uniform across the countries bordering the Baltic Sea. Makowiecki *et al.* (2016) note that cod bones are rare in fishbone assemblages from Polish sites until around 750 bp and thereafter becomes more common. Between c. 750 and 850 bp, cod consumption at many sites focused on imported fish, sourced from areas in the North Sea and Atlantic Ocean (Barrett *et al.* 2008, 2011; Orton *et al.* 2011; Krooks 2013; Nehlich *et al.* 2013). A shift toward more local fisheries in the Baltic Sea occurred around 850 bp (Orton *et al.* 2011; Holm 2016), and historical sources indicate the emergence of an eastern Baltic industry of dried cod [*Rundfisch*] and pike (Hoffmann 2009).

It is evident that the growing reliance on herring, cod and other marine fish during the Medieval period is likely attributed to a combination of ecological, economic, social, and technological factors. Advances in fishing technology and increasing urbanisation were crucial to the development of commercial fisheries, particularly in the Baltic Sea, where fish became a major commodity in regional trade networks (see Holm 2016). In the Baltic Sea, the first regulated large-scale fisheries were the Medieval Scania herring fisheries (Sahrhage & Lundbeck 1992; Holm 2016). Much of the information on these large-scale fisheries presented above stems from written records of taxation. From Central and Southern Europe, written sources from also contain information on fishing regulations, including the designation of protected areas, fishing bans during certain periods, and restrictions on gear usage (Hoffmann 2020; Zeheter 2020). According to Holm (2016), the development of industrialised fishing in the Baltic Sea began with large-scale herring catches, followed by a gradual increase in the size and scale of cod catches. The expansion of these fisheries is often linked to a rising demand for fish from mainland Europe during Lent. The Hanseatic League is also considered a driving force behind the early industrialisation of fisheries and trade in the Baltic Sea and Atlantic Ocean, contributing to the creation of quality-controlled fish products (Sahrhage & Lundbeck 1992).

On Gotland the role of fish in the Middle Ages, compared to the earlier periods is under-explored, despite some recovered assemblages (paper I). What is known about fishing is based on written sources, spatial landscape studies and some test pit excavations (d’Agnan 2009, 2010a). In England, fishermen have been argued to have had a strong connection to Christianity, as

fishers they were working at the mercy of the sea at God's dispensation (Fox 2009). Many small fishing villages had chapels and churches despite their limited size. Fox (2009) argues that fishermen, sailors, and their families had strong beliefs since they made a living and lived near the ever-changing sea. It is reasonable to assume that there might have been similar connections in Sweden during the Middle Ages. Medieval seasonal fishing villages [sv. *Fiskeläge*] on Gotland are often located on peninsulas (Carlsson 2008a, b; d'Agnan 2010a), and around ten fishing villages with ecclesiastical presents, such as chapters and churches have been identified on Gotland (d'Agnan 2009, 2010b).

Evidence of tolls on herring and cod fisheries on the island dates to the Danish period (589-305 bp), and were enforced by the harbour bailiffs of the eight districts on the island (Steffen 1945). The written records from Wisborg Castle contain information on the castle and island economy, and give some indications on the fishes consumed and taxed (Tott 1991; Norby 2003; Johansson 2008). Written sources from the Middle Ages reveal that access to freshwater bodies was regulated in many parts of Europe, with restrictions often aimed at controlling who could access these waters and what equipment could be used (Hoffmann 2020, 2023; Zeheter 2020). In Sweden, these regulations were linked to land ownership, with the right to fish in freshwater bodies granted to landowners and those whose land bordered freshwater resources (paper IV). On Gotland, land ownership seems to have played a similar role in restricting access to freshwater fishing in certain streams. During the Early Modern Period, legal disputes were common in some of the streams in Bogevisken (Steffen 1945). Fishers (landowners or leaseholders) fishing in these streams were required to pay a tenth of their catch to the church and a fifth to the crown (Steffen 1945). Similar fishing rights structures can be found in two other streams on Gotland, where landowners or leaseholders held exclusive fishing rights (Steffen 1945). From Tingstäde Träsk, parts of stationary fishing equipment from the Early Modern Period have been documented (d'Agnan 2022). In written sources, such as *Historia de gentibus septentrionalibus* (Magnus 1555), several fishing techniques are described. These techniques include passive fishing with various types of nets and traps, active fishing with hook and line, clubbing through the ice, spearing fish, and others (see Figure 2), showcasing the diverse fishing methods employed.



Figure 2. Depiction of salmon fishing and different methods of preserving fish after catchment, from Magnus 1555, (book 20, chapter 3).

2.3.4 Handling the Catch

Processing large quantities of fish requires both sufficient manpower and knowledge of preservation methods and storage facilities to prevent spoilage before consumption (Ingold 1982; 1983; Testart 1982; Cunningham 2011). In Mesolithic Scandinavia smoking, drying, and fermenting were likely used as preservation techniques (Woodman 1985; Molin *et al.* 2017; Boethius 2016; Damm 2022). It is likely that these practices were known and used on Gotland in prehistory despite lack of direct archaeological evidence. Archaeological contexts from later periods have been tentatively suggested to stem from fish processing. On Västergarn several clay bottoms [*Sv. Lerbottnar*] (clay-lined pits, often rectangular with rounded corners) have been excavated (Norderäng 2009b; Norderäng *et al.* 2010), these features have previously been found in Denmark, Blekinge, Scania and Öland (e.g., Rydbeck 1935; Liljegren 1981; Stenholm 1981; Tesch 1981, 2014; Ersgård 1988, 2006; Cardell 2005; Wallebom 2006; Svedberg 2013; Axrud 2016). The majority of these features have been found in Scania with a close spatial relation to the large herring fisheries from the Middle Ages c. 850 – 650 bp. Several explanations for the function of the features have been brought forward (Rydbeck 1935; Liljegren 1981; Stenholm 1981; Tesch 1981, 2014; Wallin 1981; Ersgård 1988, 2006; Cardell 2005; Wallebom 2006; Svedberg 2013) based on multiple lines of evidence.

Zooarchaeological analyses of bone materials recovered in the clay bottoms indicate that herring was likely stored within them (Cardell 2005).

Stockfish, dried fish (often cod) left to air-dry in cold climates, have been identified in archaeological sites from northern Europe, in Iron Age and medieval contexts (to mention a few Barrett *et al.* 2008; Krooks 2013; Nehlich *et al.* 2013, Lõugas & Bläuer 2021, Figenschow 2022). The widespread distribution of stockfish across Europe highlights its role as a major trade commodity during the medieval period. Identification of this type of product in archaeological fishbone assemblages can be done in three main ways; distribution of elements, size estimation, and isotope analyses. These are not limited to identifying the traded products but also the local fisheries and the access to different aquatic habitats, and using them requires knowledge on the taphonomic processes likely to impact the analyses (see chapters 3 and 4.2).

Magnus (1555), mentions salting, drying, and smoking fish as conservation methods of fish in Scandinavia (see Figure 2), and in a royal decree from 1535 (Kongl. Maj:ts Nådige Förordning 1735) dried pike is prohibited from being sold with its head attached, as customers were charged by weight, and the head lack culinary use. Additional evidence for later practices can be found in Carl Linnés (1741) travels in Öland and Gotland, wherein he describes flounder and herring smoking pits dug into the earth at Fårösund, Gotland.

2.3.5 Fishing as a Dynamic and Multifaceted Practice

The archaeological record of fishing in Northern Europe, particularly in the Baltic Sea region, indicates a dynamic relationship between humans and their aquatic environments over millennia. From the fishing practices of the Mesolithic HFG to the economically significant fishing of the Medieval period, the archaeological evidence highlights the adaptability and innovation of past societies in a region with shifting waterscapes (as presented in chapter 2.1). Fishing in the Baltic Sea was not only a subsistence activity but also a central part of social, cultural, culinary, and economic life. The study of fishbones, fishing tools, written sources, and settlement patterns can provide a nuanced understanding of how human communities interacted with their environment, adapted to ecological changes, and developed increasingly sophisticated methods for exploiting aquatic resources. Despite the richness of potential source materials for studying these long-term changes, and their relevance in understanding the pattern that led us to the current situation, there is a lack of general knowledge about this.

Since the 1960s the amount of fish caught for human consumption have decreased, however, the total catch volume have not declined at the same rate (Sundblad *et al.* 2020). Today only c. 17 % of the total aquatic species caught

and farmed in Sweden ends up as human consumables, with the majority of catches ending up as animal fodder (Sundblad *et al.* 2020). By integrating the evidence of these past practises within contemporary evaluations of the impact of large-scale fisheries effects on the marine food ecosystem, such as shifting baselines, cascading effects, and fishing down the food web (Pauly *et al.* 1998; Valtyrsson and Pauly 2003; Andersen *et al.*, 2010; IOC-UNESCO and UNEP 2016; Korpinen *et al.* 2022), we can highlight the possibilities of changing practises for more sustainable fishing and aquatic ecosystems.

Despite the importance of the fishing practices in the past, in order to understanding the impact of fishing in the Baltic Sea in relation to shifting conditions, few studies have utilised a long enough temporal perspective (see Poulsen *et al.* 2007; Holm *et al.* 2022 and c.f. Ammar 2021). Here two highly interlinked reasons are likely influencing this. Firstly, a lack of awareness of the potential for archaeological fishbone to inform studies on sustainable fisheries, marine protected areas, and the impact of human driven and natural processes in the Baltic Sea. Secondly, modern monitoring data is easily accessible and understood in contemporary perspective, but is not directly comparable with archaeological fishbone analyses. This makes temporal variability easier to study but might not showcase the long-term trends linked to past climatic shifts (chapter 2.1). This is compounded by the fact that some species and areas have received more attention than others leading to an imbalance in our knowledge (see discussion on Cod and Herring fisheries in chapter 2.3.3).

In this study I aim to showcase the potential of using archaeological fishbones to understand long-term interactions and thereby shift the perceived value of the material. To this end five archaeological sites from two islands in the Baltic Sea are used.

2.4 Sites

Two islands in the Baltic Sea were selected as the starting points, Gotland in the Baltic Sea Proper and the Åland isles on the border between the Baltic Proper and Bothnian Sea (Figure 3). The islands differ in several ways, with land to water ratio the most pronounced. Gotland comprises a main island composed of sedimentary limestones and marls, whilst Åland is made up of 6757 islands and skerries of ingenious batholith. The sites, though rarely the main subject of the studies, serve as entry points to discuss broader ecological and cultural processes. This chapter gives a brief summary of the archaeological record of the islands, followed by presentations of the sites.

The first human occupation of Gotland dates to 9200 BP (Lindquist & Possnert 1999), and throughout time humans made deliberate alterations to the

environment by introducing new species, including hare, hedgehog, bovids, and boars (Ahlgren 2011; Fraser *et al.* 2018; Martinsson-Wallin *et al.* 2011; Rowley-Conway *et al.* 2012). Mesolithic zooarchaeological material suggests that the island was seasonally used to primarily extract aquatic resources (Apel & Storå 2017; 2018; Apel *et al.* 2015; Boethius *et al.* 2017). Freshwater fish were identified as a significant part of the HFG subsistence strategy in the late Mesolithic on Gotland (Boethius *et al.* 2017). The FBC, genetically linked to groups from the southwest and associated with a megalithic tradition, settled on Gotland during the Early Neolithic, bringing agriculture and animal husbandry (Frazer 2018; Martinsson-Wallin *et al.* 2011). With the advent of farming, forested areas were cleared for crops. However, the agricultural methods of the FBC eventually faltered, leading to a shift back to a more marine-focussed diet.

In the mid-Neolithic, the PWC peoples settled along the coasts of Gotland. Archaeogenetic studies show that the people of the FBC and PWC traditions were genetically distinct, with different subsistence patterns, potentially living penecontemporaneous for a few hundred years (Frazer 2018; Iversen *et al.* 2021). However, PWC sites contain some terrestrial domesticates, suggesting contact with farming societies (Edenmo & Heimdahl 2012; Vanhanen *et al.* 2019). The Mid-Neolithic also saw significant environmental changes during the Littorina Sea phases (see chapter 2.2), which impacted the animal species on and around Gotland. These changes likely influenced the subsistence strategies and lifestyle of the island's inhabitants.

By the Bronze Age, agriculture and a pastoral lifestyle became dominant on Gotland (Runesson 2014). There is limited archaeological and material cultural evidence of fishing during this period, though a depiction on a picture stone shows two men fishing with a harpoon in a boat, suggesting the practice was known (Nylén, 1978). During the Iron Age, the pre-urban organization of villages, followed by the development of the medieval city of Visby, placed increased pressure on sustenance needs due to growing populations on Gotland and throughout Europe. Iron Age settlement patterns on Gotland indicate that farming and animal husbandry were increasingly important (Östergren 1989). Stone foundations of houses and stone walls from the Early Iron Age are associated with landscape utilisation near deciduous forests (Östergren 1989). Less is known about the Late Iron Age and Early Medieval settlement structure, but Östergren (1989) and Carlsson (1981, 1983) suggest that the Late Iron Age and Medieval farms were likely situated beneath remnants of the historic agricultural landscape.

By 730 bp, the laws of the Gotlanders (*sv. Gutalagen*, GL) was the legal framework for governance the island (Peel 2009). The GL did not mention a

king, and the Visby town law likely developed to meet the city's needs (Peel 2009; Sarnowsky 2015). The GL has been argued to be designed for a self-governing farming community, aiming to maintain viable estate sizes (Peel 2009). The law indicates that Gotland did not have large manor estates with leaseholders but instead consisted of farmsteads of varying sizes (Peel 2009; Siltberg 2013; 2019). Despite the appearance of a unstratified society, the medieval Gotlandic society did have power structures with individuals holding more power than others (Peel 2009; Siltberg 2019; Lingström 2025). A major reason for this stratification was the Hanseatic Leagues integration of Visby in its trading network, after the civil war in 662 bp, the town monopolised the Islands trade with Lübeck (Cramer 1949, Christensen 1957; Eimer 1966; Hammel-Kiesow 2015; Sarnowsky 2015). Around 750 bp Visby has become an integrated part of the League, with all Baltic Sea trading routes being channelled through the town (Eimer 1966; Schmidt, 1966; Sarnowsky 2015). Following the plague (c. 650 bp) and Danish invasion (589 bp) Visby's role as a trading port declined, and in 425 bp following a time of piracy and warfare, the invasion of an army from Lübeck, the city's position as a major trading hub was over (Harreld 2015; Sarnowsky 2015). These major societal shifts, such as increased centralisation, likely changed the mobility of people and trading goods on the island.

Freshwater fishing during the Middle Ages was often tied to landownership (see discussion in papers III and IV), latter written sources from Gotland indicating that fishing in freshwater streams was highly regulated, and fishing rights disputes were not uncommon (Steffen 1945). In modernity the freshwater systems on Gotland, have been heavily modified through drainage, peat extraction and damming (Sernander 1941; Björkander 2012; Martinsson-Wallin 2022; Mels 2023), making their past utilisation and habitat structures largely unknown. To explore the past usage of freshwater resources on Gotland and the changes these systems underwent over time, four sites on the island with recovered euryhaline fishbones were selected (Figure 3) (papers II and III). Visby was excluded as case study, since only a few recovered and sporadically documented fishbone assemblages exist (see paper I). However, written sources from Visby will be as comparative material for discussion in this thesis.

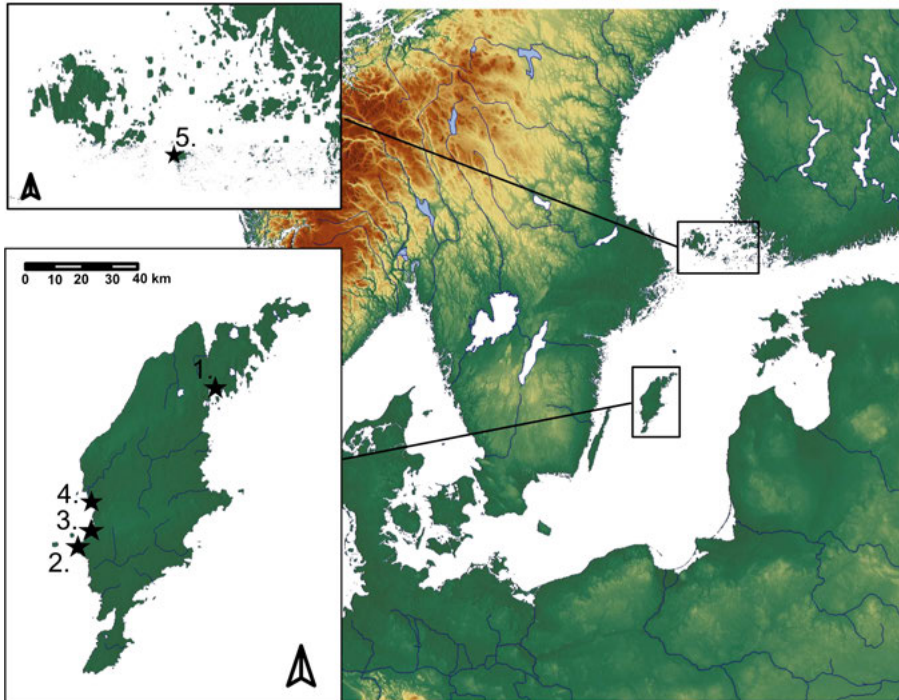


Figure 3. Location of the sites used in the case studies marked with numbered stars in chronological order based on archaeological phases. 1. Gisslause, Paper III; 2. Ajvide, Papers II and III; 3. Fröjel, Paper III; 4. Västergarn, Paper III; 5. Kökar, Paper IV

The Åland isles have similar trends of human occupation as Gotland, with some of the islands has been inhabited since the Neolithic (Stenbäck 2003; Strömberg & Anderberg 2010). During the earliest settlement phase influences from the East, Comb Ceramic Culture, and West PWC have been identified (Martinsson 1985; Stenbäck 2003). From the Bronze Age, the settlement of Otterböte on the island of Kökar, nine round huts have been excavated (Drejer 1947, Meinander 1954; Gustavsson 1997 b). Artifacts recovered include pottery, stone tools, and bones (Drejer 1947, Meinander 1954, Gustavsson 1997, Nunez *et al.* 1997). Large quantities of bones from grey seal suggest the site served as a sealer dwelling, the inclusion of domesticates indicates that the site was possibly used beyond peak sealing seasons (Nunez *et al.* 1997). There appears to be no permanent settlement on Kökar between ca. 1300 -750 BP, but small-scale and seasonal usage likely occurred (Nunez *et al.* 1997). Iron Age Åland had a population influx during this period (see Larson *et al.*, 2023). From the central island [*sv. Fasta Åland*], written records from Kastelholm castle have shown insight into the economy of the Åland islands during the Middle Ages (Kivikero 2020a). Around 500 bp, a

Franciscan friary was established on Kökar in the outer archipelago and remained active until the reformation. To understand the Friary's connection to the local fisheries and the contemporary Kastelholm castle, Paper IV focused on the medieval fishbone assemblage recovered at Kökar (Figure 3) and discusses the zooarchaeological material in relation to Kastelholm and written sources.

2.4.1 Gisslause

The Mesolithic site of Gisslause is located on the northeast side of Gotland (Figure 3), and was discovered through gravel extraction in 1928 (Munthe & Hansson 1930). Excavations were carried out in 1929, 1982 and 2010 (Munthe & Hansson 1930; Seving 1986; Apel & Vala 2013). From the 1929 excavation, some soil samples have been sieved however the mesh size is unknown. Recovered material includes seals, terrestrial mammals, fish, and molluscs, as well as flint artefacts (Munthe & Hansson 1930). Site stratigraphy, with the main cultural layer covered by a marine transgression, indicates that the site was likely abandoned around the 8.2 ka event (Munthe & Hansson 1930; Apel & Vala 2013; Boethius *et al.* 2017).

Recovered faunal remains contain a large amount of seal bones, with ringed and grey seals present (Apel & Vala 2013; Boethius *et al.* 2017). Age distribution of the seal bones indicates that the Mesolithic HFG peoples at Gisslause targeted juvenile and subadult individuals (Boethius *et al.* 2017). The recovered fishbone material from the 2010 excavation is the best recovered Mesolithic faunal assemblage on Gotland today due to the sieving protocol for recovery of faunal evidence (Apel & Vala 2013). Freshwater and some migratory species are present in the material, with cyprinid sp. and burbot dominating the identified material (Boethius *et al.* 2017). Based on the species distribution, the likely fishing grounds are interpreted as deriving from shallow lakes/streams (Boethius *et al.* 2017). The high amount of burbot has been interpreted as utilisation of natural agglomeration events during winter when the burbot gathered in the shallows to spawn (see Table 1, for information on spawning) (Boethius *et al.* 2017). From Gisslause two cyprinid pharyngeal teeth (See Table A2 Appendix I), were used to investigate the likely catchment area of these fishes, and discuss the habitat structures needed to sustain these fish populations (paper III).

2.4.2 Ajvide

The PWC site of Ajvide, Eksta parish, is located on Gotland's southwestern shore (Figure 3). The site was first identified in 1922, and test excavations began in 1923, and subsequent work occurred intermittently until 2017 (Österholm 1989, 2002, 2008; Norderäng 2001a, 2001b, 2003, 2004, 2006a, 2006b, 2007a, 2008a, 2009a, 2010; Sjöstrand & Wallin 2017). The settlement is subdivided into four areas (A, B, C, D), with the main PWC activity located in area D (Österholm 2002). Ajvide's PWC chronology covers 1800 years of diverse use, shaped by environmental and cultural shifts (Sjöstrand 2022). Cultural layers from pre- and post-Littorina maximum differ (c. 5000 BP): earlier layers lack inhumations, which appear only after the transgression, suggesting a change in site function (Palmgren & Martinsson-Wallin 2015; Wallin & Martinsson-Wallin 2016; Sjöstrand 2022).

The vast amount of zooarchaeological material from the site highlights a predominantly marine-based diet, supplemented by boars and wild birds (Rowley-Conwy & Storå 1997; Storå 2001, 2002; Storå & Ericson 2001; Mannermaa & Storå 2006; Olson & Walther 2007; Mannermaa 2008a, 2008b; Olson 2008; Österholm 2008; Sjöstrand 2022). However, isotope analysis of buried individuals indicates little evidence of regular boar consumption, as $\delta^{13}\text{C}$ values reflect a diet focused on marine sources (Lindqvist and Possnert 1997; Wallin and Martinsson-Wallin 2016). Seasonal patterns in boar slaughter, primarily in autumn, suggest links to ritualised feasting or cultural events (Rowley-Conwy & Storå 1997; Wallin & Martinsson-Wallin 2016). The bird assemblage once again highlights the aquatic orientation of the PWC, wherein ducks and auks are the most identified in the zooarchaeological bird assemblage (Mannermaa & Storå 2006). These families could be hunted in the vicinity of the settlement, but at different locations and seasons (Mannermaa & Storå 2006).

Fishbones, despite dominating the recovered material from almost all areas of the site (e.g., Sjöstrand 2022 Figure 4.122), have sadly not been analysed to the same extent as other recovered osseous materials. One exception is a sample from area D-Upper where marine and euryhaline species are present (Olson & Walther 2007; Olson 2008). The fish assemblage supports the marine-oriented practices of the PWC with cod and herring being the most identified species (Olson 2008). The total length estimation (TL) of cod indicates that larger adult fish between 45-50 cm were the primary target. Otolith annuli data (Limburg *et al.* 2008) and the TL estimates (Olson & Walther 2007) indicate hook and line fishing in deeper waters during the autumn. Herring showed two distinct size classes, likely reflecting fishing in the nearshore habitat preferred by juveniles and deeper waters for adult fish (Olson & Walther

2007). The euryhaline fish in the assemblage have received less attention and are interpreted as bycatch or fishing in the nearshore area of the site (Olson 2008; Sjöstrand 2022). To increase the understanding of euryhaline fish exploration at Ajvide, five pike teeth and 18 cyprinid pharyngeal teeth from three different areas were selected for strontium analysis in paper II (see Table A2 in Appendix I). These results were also incorporated in to paper III, to discuss the habitat structure in the aquatic systems likely utilised by the PWC.

2.4.3 Fröjel

On the southwestern coast of Gotland (Figure 3), the site of Fröjel contains two main areas: the Viking Age harbour and trading port, and the medieval and early modern harbour. Excavation at the site was carried out between 1987 and 2006 (Fischer 1998; Carlsson 1999; Dahlström & Eriksson 2002; Dahlström 2003, 2004, 2005; Eriksson 2003; Carlsson & Wideström 2007). Stratigraphic data from the 2003 excavation of the northern burial field indicate a two-phase chronology, with older Viking Age burials covered by a slightly later cultural layer (Dahlström 2004). The excavation reports do not indicate the mesh size used during the excavation, and much of the spatial data only ties the zooarchaeological assemblage to excavation square and spit level. From the excavation in 2003, trenches 2 and 4 contained a combination of burials and later accumulated cultural layers, the other 4 trenches contained a combination of postholes, refuse pits, hearths, and cultural layers. Layers 1 and 2 showed signs of later agricultural activities on the site, where traces of ploughing and bioturbation were identified in all trenches in the first 20 cm of depth.

Isotope analyses of human burials from the Viking Age and Medieval occupational phases of the site show no change in food practices over time (Kosiba *et al.* 2007). Bulk Sr analyses of 60 Viking Age burials from the site indicate that individuals buried at the site predominantly come from the island or multiple regions with similar Sr ranges as Gotland (Peschel 2014; Peschel *et al.* 2017).

Recovered zooarchaeological material from the site is inconsistently reported; fishbones are treated as one generic category reported by weight, but there are inconsistencies in how bone count and weight are reported (see paper I). What is known about fish consumption based on zooarchaeological materials from the site stems from a few unpublished non-peer reviewed student reports (Björk 2001; Bech-Hanssen 2007; Andersson & Franzén 2010; Gustavsson & Karlsson 2010; Landström & Foglemark 2010; Rönngrén & Jakobsson 2010; Strand & Fridén-Rolstadaas 2010; Sjöstrand & Gustavsson 2010) and stable isotope analysis of cod vertebra (Krooks 2013). The

$\delta^{13}\text{C}/\delta^{15}\text{N}$ ratios of the cod vertebra indicate that imported Atlantic cod was consumed at the site (Krooks 2013).

For paper III, one pike tooth and nine cyprinid pharyngeal teeth were selected for Sr analysis (see Table A2 in Appendix I and paper III). During the sampling for paper III, a large species richness in the fishbone record was noted and further studies into the fishbone assemblage could highlight new aspects of the site.

2.4.4 Västergarn

Västergarn, located on the western shore of Gotland (Figure 3), comprises a large area enclosed by an extensive earthwork boundary wall. Excavations conducted since 2005 have revealed long-term usage of the site, with the earliest radiocarbon date around 1000 BP (Norderäng 2006c, 2007b, 2008b, 2009b; Norderäng *et al.* 2010; Söderström 2013; Kilger *et al.* 2014; Kilger & Söderström 2017; Kilger *et al.* 2022, 2023). The enclosed area contains house foundations, wells, burials, and two churches. The houses at Västergarn have a uniform layout with two rooms and corner stoves or smoking ovens (Kilger *et al.* 2022, 2023). From the recovered materials Kilger & Söderström (2017) argue for a reduced trading activity of around 600 bp, and links this to the increasing importance of Visby. Additional arguments for the reduced activity are the shallowing of the bay, linked to the isostatic rebound. Spatial analyses of material culture indicate that around 2,5 m above sea level, corresponding with the estimated shoreline around 600 bp, traces of occupation expansion disappear (Holmbäck 2017).

A limited number of studies into the faunal assemblage at the site have been conducted by students at Campus Gotland, these have mainly focused on terrestrial domesticates (Forsberg 2009; Hammarsten 2013; Peterson 2023; Renmarker 2024), and rodents (Zetterström 2023). Despite fishbones making up 16% of the identified material from Trench 23 (Forsberg 2009), no special studies into the fishbones recovered at the site have been conducted. Based on the few identified fishbones, cod is common. However, the standard sieves with a 4 mm mesh size and lack of knowledge of fishbones have created a bias towards the recovery of large marine species and suggests that the fish material at the site is far more diverse (see Kilger *et al.* 2022). Large cod vertebrae recovered in Trench 56 (dated to c. 970 - 695 BP (Forsberg 2009), have $\delta^{13}\text{C}/\delta^{15}\text{N}$ ratios correlating to cod from the Atlantic Ocean (Krooks 2013), indicating that the site was connected to the larger trading networks. This is further supported by the clay bottoms excavated at the site (see chapter 2.3.4 and Norderäng 2009b; Norderäng *et al.* 2010).

During the excavations in 2021 and 2022, several large cod vertebrae in anatomical articulation were recorded around four houses dated to 810 – 730 BP (Kilger *et al.* 2022, 2023), further studies into them could highlight the trading network and connections of the site. For paper III, one pikeperch tooth, two pike teeth and nine cyprinid pharyngeal teeth were chosen for Sr analysis (see Table A2 in Appendix I and paper III).

2.5.5 Kökar

The name Kökar [*Thiycækarl*] first appears in the Danish itinerary and is subsequently mentioned in Franciscan sources and five times in muniments (Gallen 1993). The friars were active in nearby parishes, and by the Reformation (ca. 420 bp), the friary owned significant lands, including parts of Hamnö, Överboda, Finnö, and several smaller islands, as well as fishing rights (Gustavsson 1986; Gallen 1993). The friary's earliest medieval structure, the Southern House, dates to ca. 750 bp and consisted of the foundation of a two-room house [*sv. Parstuga*]. This structure is interpreted as temporary housing or living quarters during construction of the friary (Gustavsson 1986, 1990; Sundberg 1996). The friary complex was built north of the church, where ¹⁴C dated burials and stratigraphic data show that the existing parish church was incorporated into the friary. In the refectory and kitchen, parts of a hypocaust system have been identified - dating of mortar from the hypocaust suggests activity as early as the c. 650 BP (Gustavsson 1995). However, coins found during excavations place the Franciscan activity to c. 500-420 bp (Gustavsson 1995; Sundberg 1996).

During the Franciscan period, a western tower was added to the church. Its foundation walls partly cover older burials, and ¹⁴C dating places its construction to around 500 BP (Gustavsson 1995; Sundberg 1996). After the Reformation, the friary buildings were repurposed as chaplain's residences, with artefacts in a nearby midden showing a continuous use until ca. 250 bp (Gustavsson 1995). Several studies have analysed the Kökar archaeological material, focusing on mammals (Storå 1990; Fisher 1996), fish (Krooks 2016), and birds (Kivikero & Eriksson 2024). For paper IV, three areas associated with Franciscan activity, with recovered zooarchaeological material were selected for analysis.

2.5 Materials

In paper I, the reported fishbone assemblages on Gotland from the years 2000-2024 were synthesised and used as a discussive point to highlight the discrepancies in available materials for analysis. In total 66173 bones (excluding scales) were identified in the material, of which 34 % have been determined to species level.

Based on this information a total of 42 fish teeth from four sites where euryhaline species could be identified were sampled and analysed in papers II and III (see Table A2 in Appendix I). Sample selection was based on availability within the material; if possible, samples from the earliest and latest occupational phases on the site were selected. Spatially different squares, layers or contextual units were chosen to avoid double sampling the same fish (See paper II for information about Ajvide sampling). Material from spit 1 and 2 at Fröjel was excluded since the excavation report indicated later historical agricultural influences. For Västergarn, the focus was on material excavated in 2021 – 2022 (Kilger *et al.* 2022, 2023), from contexts with ¹⁴C dated material. The sampled materials cover a timespan from ca. 9800 to 600 BP (see paper III SI, for Bayesian chronological models), this means that shifts in practices and habitational origin of fish species can be identified. Since the sites correlate to some of the bigger shifts in climate and water properties as presented in chapter 2.1. the data can also be correlated with these events.

Since there was a lack of available excavated materials from the Late Middle Ages – Early Modern Period on Gotland, the material from the Franciscan friary on Kökar with a rich fishbone assemblage was selected as a comparative site. Here the potential for identifying the taxational shift on cod fisheries from Kökar to Kastelholm, implied by written sources (Kivikero 2020b), made the material of high interest to facilitate discussions on using multiple sources to understand past practises (i.e., research question 3). Since the site lacks official excavation reports, and there are only a few publications available on the stratigraphy of the site, analysis and publication of materials from the site is important for preserving synthetic information for future research.

To facilitate a discussion of aquatic resource utilisation in the past (chapter 8.3), data on the presence of fish species in the zooarchaeological and written archives for the case studies were recorded. By collating this with modern monitoring data of fish species in the Baltic Sea and on Gotland and Åland (Table A1), this information was used to create table 1 (chapter 2.2.2) and Figure 9 (chapter 8.1). Chapter 8.3 utilises the information in Table A1 (Appendix I) to discuss aspects of past fishing practices in a larger contextual setting.

3. Theoretical Framework

This thesis explores different fishscapes based on human-fish interactions through (zoo)archaeological materials. The core principle behind using zooarchaeology to interpret fishing and animal-human interactions rests in the interdisciplinarity embedded in zooarchaeology (Wheeler & Jones 1989; Lyman 1994; Reitz & Wing 1999). Interpreting any zooarchaeological assemblage requires understanding of biological processes within an animal's body during its life, and how interactions with the world around it can influence growth rates, and health. It also requires understanding on how human interactions (killing, butchering, consuming) and post-depositional environments effect the bone material. Many biotic and abiotic aspects are not linked to human interaction but can be influenced by human activity (see Lyman 1994). To understand how environmental factors influence the presence or absence of animals in the zooarchaeological record, it also requires knowledge on paleo-habitat and niche structures likely to exist within the region of study, to contextualise the data in ecological context. Since zooarchaeology primarily focuses on human created assemblages, interpretive models also rest in theories on how, why and to what extent humans have interacted, used, and modified the world around them.

3.1 Social Zooarchaeology and Ethnoichthyology

Zooarchaeological theoretical perspectives are highly interlinked with the overarching archaeological theorems, however one key theoretical aspect of zooarchaeology is taphonomy (Efremov 1940; Lyman 1994; 2010; Behrensmeyer *et al.* 2018). Originally defined as 'the study of the transition (in all its details) of animal remains from the biosphere into the lithosphere' (Efremov 1940: 85), this concept has been adapted by some archaeologist to describe post-depositional processes affecting non-biological entities (for discussion on this see Lyman 2010; Behrensmeyer *et al.* 2018). Taphonomy in this thesis refers to the processes of interactions from deciding to catch a fish in the past to writing the conclusion of the habitational origin of the fish based on the analytical results (Medlock 1975; Fernandez-Jalvo & Marin-Monfort 2008).

Much of the taphonomic research within social zooarchaeology focuses on reconstructing the relationship between biological and cultural processes in the past (Bar-Oz & Munro 2004; Marciniak 2001, 2005a, 2005b; Orton 2010). However, the separation between reconstruction (quantification) and interpretation within zooarchaeology is entangled (Orton 2012). During the post-mortem processes bones physical properties are altered by human actions such as butchering and cooking, and post-depositional replacement of organic collagen with inorganics from the depositional environment through diagenesis (see Lyman 1994, 2010; Behrensmeyer *et al.* 2018). The loss of information is inevitable since a vast majority of interactions of humans with the world around them do not leave behind traces (material culture), confounded by the fact that preservation and recovery influence the source material available (Perreault 2019). Understanding of animals' roles in ecological systems are a prerequisite for zooarchaeological interpretations (see Wheeler & Jones 1989; Lyman 1994; Reitz & Wing 1999).

Social zooarchaeology follows the path of where materiality leads, and as within the paradigm of new materialism accepts that there are knowledge gaps and factors of under-determination (Witmore 2014; Perreault 2019). Moving beyond taphonomic aspects, other researchers have emphasised the need for more diverse interpretations of zooarchaeological assemblages (Gifford-Gonzalez 1991; Russel 2011; Overton & Hamilakis 2013; Hamilakis 2014; Armstrong-Oma 2017; 2020; Macãne, 2022; Hussain & Brusgaard, 2024). Following the notions of new materialism and posthumanism, they encourage us to move beyond faunal remains as only an expression of human consumption and resource utilisation and seeing them as individuals or actors within their ecosystem.

Interestingly, despite the inclusive aim of social zooarchaeology, fish is often not given the same attention as terrestrial mammals (c.f. Hussain & Brusgaard 2024). One example where fish is given more attention as an active participant is the ethnoichthyology framework presented by Svanberg & Locker (2020), wherein they showcase the range and potential of research and knowledge gain when adopting a more inclusive framework which draws on archaeological, ethnographic and socio-anthropological sources. The lack of research on fish as active participants in their environment, I would argue, is an expression of the ascribed low value generally applied to fishbone materials (paper I), and the adaptability and variety of fish (as discussed in chapter 2.2), making inclusive interpretations far more complex than for domesticated terrestrials. Despite this, it is necessary to give the same attention to this material as others if we are to understand the complex relationships of humans, fish, and environments in the past.

3.2 Negative Space

The concept of negative and positive space revolves around our perception and how we value things and relationships, many interactions are often taken for granted as unconscious norms and assumptions. These concepts tie to the formation of fishscapes as shaped by scales, values and practices as discussed in paper 1 and used as a model in this thesis. The initial shaping, or the decision to engage with something in a particular way, requires critical questioning and contextualization. Rubin's (1915) work exemplifies the psychological foundation of what can be defined as negative space. When two fields share a border, one is perceived as the figure and the other as the (back)ground. This perceptual experience is shaped by the common boundary, which influences one field more strongly than the other (Rubin, 1915). In art, this phenomenon is described in terms of positive and negative space within the artist's "work area" or "canvas" (Stevko, 2018). Stevko (2018) defines positive space as the area that represents the subject, while negative space refers to the area that does not represent the subject.

The perceived figure or subject discussed by Rubin (1915) and Stevko (2018) is always defined in relation to the (back)ground, not the subject itself. The two are interchangeable, with the boundary or subject shifting depending on the observer. These distinctions naturally create perceptions of importance, with the subject typically being ascribed a higher hierarchical position. This interchangeability and fluidity in perception suggest that negative and positive space cannot be strictly polarized (see also Merleau-Ponty 1968, on visibility and subject).

A notable example of negative space in archaeology is found in "negative features," such as the outer edges or borders left by soil removal. Inside these negative spaces, positive features often emerge, like backfills, layers, constructions, or deposits (Harris, 1975). These positive features contain material culture, from which artifacts are recovered and analysed. However, the positive feature's existence in its current form would not be possible without the negative feature. Because positive features are typically perceived as more informative, they are often given higher value.

The concept of negative and positive space is also embedded in symmetrical archaeology, where avoiding polarized distinctions enriches our understanding of the past. As Di Blasi (2014) notes, *when we create distinctions, we deal with asymmetrical differences* (Di Blasi, 2014: 72). In symmetrical archaeology, the perspective of the observing participants shapes their interpretation. Symmetry in this context refers to treating all entities, human or non-human, as having equal ontological value in the analysis of archaeological evidence (Witmore 2019). This approach challenges the traditional

hierarchical distinction between human agents and passive objects, suggesting that objects—such as fish-bones—have their agency and are active participants in shaping human history (Olsen 2010). When aware of the interplay between negative and positive spaces, individuals can shift their focus from the initially perceived subject to other subjects within the negative space. This helps us recognize the complex interactions and interconnectedness of both spaces. *A comprehensive understanding of the past is less about matching our archaeological findings to an idealized past and more about a personal and collective achievement* (Shanks 2007: 589-590). By engaging with these asymmetrical spaces, we acknowledge how our present values and notions influence the interpretations of past data. An “archaeological event” exists within multiple positive and negative spaces, containing information about the past, present, and future.

This interplay between negative and positive space becomes even more pronounced when viewed through the lens of new materialism perspectives in archaeology. New materialism challenges the traditional dichotomy between culture and nature, asserting that material objects, artifacts, and environments are active agents in shaping human experience and social realities (Witmore 2014). It emphasizes the agency of materials themselves—not just as passive objects, but as entities that interact and influence human actions and relationships. Witmore (2014:213) argues that new materialism starts with engaging with the actual entities (Things) and not the processes, and the *past is an emerging product of work done with things*. Synergies to the entangled reconstruction – interpretation relationship in zooarchaeology (Orton 2012) can be drawn, where the starting point is the bone itself. Through the lens of new materialism, archaeology is not just the study of artifacts as inert objects; instead, it is the dynamic relationship between people, objects, and the environment as a co-creational process (Hodder 2012; 2014; Witmore 2014; Hodder & Mol 2016). Interestingly, the example of *fellow creatures memories* given by Witmore (2014: 215), the focus is not on the marginalised and in (zoo)archaeology often forgotten animals (i.e., fish, birds, molluscs) but the terrestrial domesticates.

In archaeological analysis, these spaces are both distinct and interconnected. Our perception of what to study, interpret, or write about is shaped by how the materials are related to one another. The scales of value we assign to these spaces influence how we interpret them. Moving between these spaces is only possible when we recognize that the negative space holds valuable information. It's crucial to highlight that shifting between these spaces can yield new insights and interpretations of the materials. Through the framework of new materialism, these shifts become not just interpretative but also onto-

logical, highlighting how materials themselves can open new lines of inquiry. Negative and positive spaces are not static but dynamic, as the materiality of both the artifacts and the surrounding environment shapes and is shaped by the observer's perspective. To shift perspectives and find the materiality hidden in the negative space rests in the acknowledgment of the observer that their perceived value of materials will have a shaping effect on the interpretations.

3.3 Scales

Scales can mean several things, here it is the relation between things (in space, time and value). In the relational relationship between the positive and negative space and the materiality of fishbones, several analytical and value scales are present. The concept of scales has been used in several disciplines to discuss interactions between different actors and interpretations, there are different definitions of what scales are and how they affect the interpretations (Gibson *et al.* 2000). The concept of scales as theoretical and analytical frameworks, I argue is fundamental for the interpretations of archaeological materials (Lock & Molyneaux 2006). Spatial scale is easiest to contextualise within archaeology, we can relate a single object (thing) to a feature, found at a specific site, which can be related to a country and then to a larger region. However, as is exemplified by Yarrow (2006) the removal of the surrounding soil from a thing during excavation fundamentally changes the relationship of the thing to us. Returning back to the negative space, the thing excavated, existed in this space before excavation, but we could not see it. The removal of soil and the identification of the thing as an archaeological object, needed to be documented was created by the perception of the thing as important when contrasted with the background (soil) (Yarrow 2006).

We instinctively organise the value of the thing to the background based on perceived values, these are not arbitrary but rather sustained by normative practices. As discussed in relation to fishbone recovery rates and fine mesh sieving (see chapter 4.2), there is a discrepancy between the value ascribed to the material and the actual interpretive power contained within it. I would also argue that the normative archaeological value scale, despite the move towards more diverse perspectives, is still often driven by hierarchical anthropocentric standpoint. We will instinctively place a human burial at a higher hierarchical position than a deposit of faunal remains, this can create anthropocentric narrative of our past.

Working with time is a central part in any archaeological endeavour (Gosden & Kirsanow 2006), we are obsessed with time, both chronological time periods and lifetimes of individuals. In the words of Gosden & Kirsanow

(2016: 27); - *temporal scales are hard to make sense of, being not one thing but many; each set of archaeological evidence contains nested within it a number of different forms of duration and means of measurement.* The tasks carried out daily can generate spatial patterns wherein a singular individual activity can be hard to observe (Gosden & Kirsanow 2006). Moving between the long chronological timeframes and the shorter individual ones means that, just as with the spatial one, relationships between the thing we observe changes and in the case of bones the material properties changes. However, temporality is also linked to our perception, when I started this work, my research group at Uppsala University (comprised of colleges from the Department of Archaeology, Ancient History and Conservation and Department of Earth Sciences; Natural Resources and Sustainable Development) struggled to define the terms old and long-time perspective. Old is relational to the temporality of different scientific disciplines, to define old means that we have to decide what is not old.

This work, in the temporal viewpoint of Scandinavian archaeological time, have a long-term perspective spanning c. 9000 years. It also encompasses the temporal scales of the individual sites, where some have been used for thousand years and others for a hundred, meaning that the temporality of the assemblages or samples analysed are situated at different temporal scales. There are also individual life-time scales of the fish whose teeth were analysed, where the age of the fish is unknown. However, using the temporality of tooth mineralisation, the spatial origin where the fish likely lived at the time of mineralisation is observable. As discussed in the previous section taphonomy aims to understand the changes in properties of bones in relationship to spatial and temporal variables as the individual, i.e., fish, is transformed through interactions (Efremov 1940; Lyman 1994; 2010; Behrensmeyer *et al.* 2018). Here I would like to return to some points touched upon above, the creation of background when excavating and of the concept of old. Both of these are also influenced by social and value driven scales, we ascribe value to things differently depending on how we perceive them. We value things in different contexts differently. The individual and societal value of *things* can be vastly different. This is exemplified in this work with my perception of fishbones as material remains carrying information on immaterial interactions and relationships.

In this thesis a multi-scale approach is used to discuss local and regional changes in functional relationships made visible through the analyses of archaeological fishbone assemblages. Each scale is to some extent interlinked in the analytical discourse but not always explicitly stated. In paper I, scales are used to discuss how adopting multisource perspectives can highlight

human-fish interactions beyond the zooarchaeological assemblages. Paper II, intra-site spatial-temporal fish teeth samples are used to discuss mobility patterns of fish and humans in the Mid-Neolithic. Paper III expands the spatial-temporal scope and discusses fish mobility and human resource utilisation in relation to climatic change and cultural shifts based on fish teeth. Paper IV uses a narrow temporal scale to discuss site specific patterns and relating them to bigger regional trends. In chapter 8 these aspects are interwoven to highlight the importance of the value ascribed to materials in facilitating discussions of past fishscapes.

3.4 Scapes

The concept of space in archaeology has a long history and similarly to taphonomy it has been adapted in various ways (see discussions in Wylie 2007; David & Thomas 2016). The concept of -scapes as both spatial and social phenomena co-created by interaction has been adapted in archaeology to discuss different scapes (Arnold 2024; Müller 2020). Scapes are the entwinement of materialities and symbolism, of the tangible and intangible. As David & Thomas states (2016: 38): *Landscape archaeology is an archaeology of how people visualized the world and how they engaged with one another across space, how they chose to manipulate their surroundings or how they were subliminally affected to do things by way of their local circumstances*. This ties in to the concept of habitus (Bourdieu 1977) and Ingold's taskscapes (1993), and the new materialism perspective of things as assemblages, participants, and things (Witmore 2014). Fish are entangled and disentangled from us, interactions with fish in their habitat requires us to modify our behaviour or use equipment (holding our breath to look under the water, or using things such as diving gear, remote operated vehicles etc.). We are, when interacting with fish, regardless of the method creating fishscapes, and as discussed in chapter 3.1 (and papers I - IV) many of these interactions are not preserved in the archaeological record since they are immaterial.

It is within this concept of scapes this thesis is situated; fishbones are assemblages of interactions at various scales (see paper I). I argue that when perceiving fishscapes as interactions, they can be both temporally and spatially fixed and fluid at the same time. They are evidence of the practices of everyday life and of expressions of the values ascribed to them as fish, and products for consumption. They contain information of natural fluctuations and responses to them (by all entities). Therefore, by moving fishbones and fishes from the negative spaces, the values, interactions, and co-creations of fishscapes can be sought and discussed. I suggest that; archaeological studies

of fishbone assemblages are an active part of creating and sustaining fishscapes, and how interactions with materiality shape the archaeological record and the interpretations of them, and that the fishscapes are expressions of multigenerational multisource interactions at various temporal, spatial, social, environmental, and scales.

4. Methods

All source material was chosen to create a wide perspective fish and fisheries in the Baltic Sea over time. Narrower windows focus on specific sites or practices related to the research questions. An initial literature review of the reported fishbone assemblages from Gotland became the foundation for paper I, where some sites featured materials suited for further studies. Fishbones pose a unique category in the zooarchaeological record, with morphological, chemical, and mechanical properties highly diverse from mammal and bird bones. Due to the diversity of fish species and the continued skeletal growth (as presented in chapter 2.2), two aspects were chosen as the main focal points; bone chemical analyses (Papers II and III) and quantification (Paper IV). The following sections present the methods used in the case studies; thus, this work uses analytical mixing; *the resolution of the archaeological record is not just a function of cultural and natural site formation processes – it is also a function of the way archaeologist analyze it* (Perrault 2019: 56).

4.1 Isotope Analysis

Chemical analyses of fishbones can help mitigate quantification biases, although they depend on preservation and recovery standards (see chapter 3 and paper I). These methods can enable the study of legacy collections with limited contextual data and align with modern ecological research. By modifying cleaning protocols and combining annuli calculations with chemical analysis, habitat, pollution, and mobility can be inferred (Barrett *et al.* 2008, 2011; Limburg *et al.* 2008; Krooks 2013; Nehlich *et al.* 2013). While sub-fossilized bones require specific extraction and validation methods, comparisons between archaeological and modern materials remain possible.

4.1.1 Strontium

Strontium (Sr) isotope analysis has been integral to archaeology since the 1980s. The method relies on the geological composition of the bedrock and the stable ratio of $^{87}\text{Sr}/^{86}\text{Sr}$ within an archaeological timeframe (Faure & Mensing 2005). This ratio, absorbed into organisms through soil, water, and

food webs, helps trace provenance and mobility (Ericson 1985; Balasse 2002; Holt *et al.* 2021). However, diagenetic alterations in archaeological bones can complicate analysis, therefore enamel rather than bone is preferred. Where diagenetic Sr from the depositional environment is less likely to occur (Snoeck *et al.* 2015). Various methods have been proposed to facilitate the removal of diagenetic Sr, but they can affect elemental values (Lambert *et al.* 1985, 1989; Price *et al.* 1992). To avoid contamination, burnt bone or enamel (including fish enameloid tissue (see glossary)) is preferred due to its higher resistance to post-depositional changes (Snoeck *et al.* 2015).

When Sr is absorbed through food consumption, its concentrations are significantly reduced along the food chain. But not all food sources contribute equally to the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios. Plants have higher Sr concentrations compared to herbivores, and herbivores have higher Sr concentrations than carnivores. Therefore, if an animal consumes a diet based on a mix of plants and mammal flesh, the Sr ratios in the consumed plants will contribute most of the Sr ratios in the end consumer (Bentley 2006). Fishes Sr uptake differs from mammals, as it is absorbed primarily through the gills rather than through diet (Schiffman 1961; Walther & Thorrold 2006), this means that fish can have Sr concentrations equal to (or even surpassing) those in plants (Boethius *et al.* 2024). The Sr ratios in archaeological fish teeth should therefore reflect the Sr ratio in the water body wherein the fish lived during enameloid mineralisation, thus serving as a direct proxy for water Sr ratios during tooth formation.

Since marine environments are homogenised in Sr content (Mokadem *et al.* 2015), this method is best suited for euryhaline species from lakes and streams, but has also been applied to marine species (Glykou *et al.* 2021). However, two main aspects are necessary to consider: The properties of fish teeth themselves (as presented in chapter 2.2), additionally due to the small size of fish teeth the enameloid cover is thin, and inconsistencies in enameloid coverage can occur (Boethius *et al.* 2021). The second aspect that must be considered is the contextualisation of the fish enameloid Sr, to interpret the data a reference dataset of bioavailable Sr is necessary. Since Sr in fish teeth are reflective of the habitat during mineralisation water samples from the likely catchment areas are best way of creating a regional bioavailable Sr baseline for contextualising the results.

By the application of laser-ablation multi-collector inductively-coupled-plasma mass-spectrometry (LA-MC-ICP-MS), high-resolution Sr analysis have enabled the identification of mobility and habitational origin of euryhaline fish (Boethius *et al.* 2021). Papers II and III applied LA-MC-ICP-MS to investigate Gotland's freshwater fisheries using Sr isotope analysis to explore past fish mobility, habitat structures, and human interactions (see Figure 4).

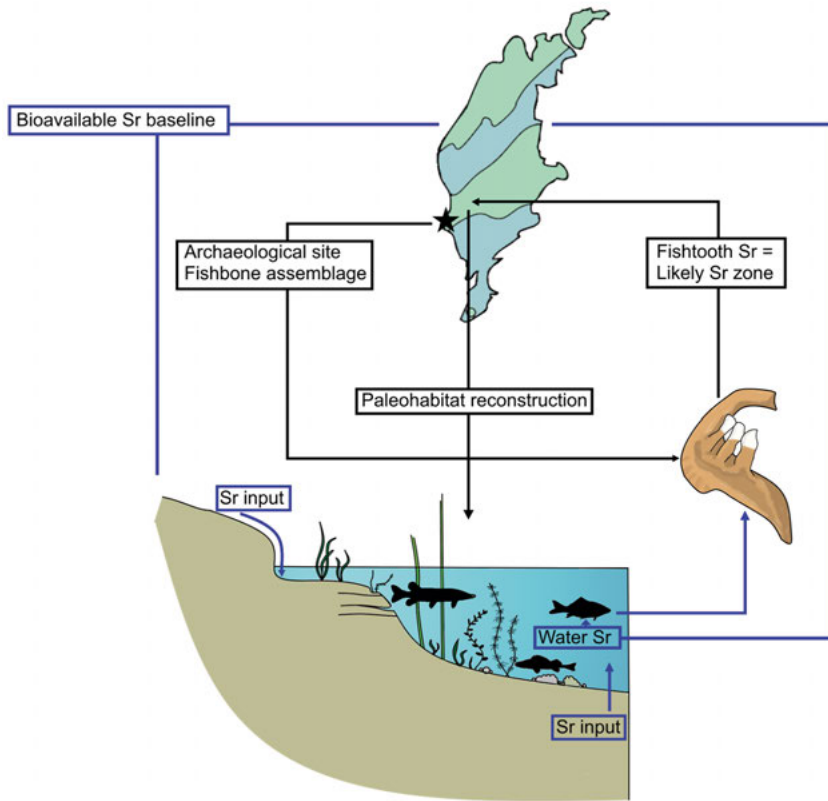


Figure 4. Simplified schematic of the analytical model used for Papers II and III. Blue lines and boxes represent the Sr pathways into the biological system. Black lines and boxes represent the interpretative and analytical pathways for the archaeological discussions and reconstruction paths for paleohabitat structures.

4.1.2 Fish teeth

Sr isotope ratios from 42 archaeological fish teeth from Gisslaue, Ajvide, Fröjel and Västergarn were analysed (papers II and III). The fish teeth chosen for analysis were identified to the lowest taxonomical unit possible using the comparative osteological collections at Uppsala University and the Osteoarchaeological Research Laboratory, Stockholm University. All samples were cleaned using the cleaning protocols described in Boethius *et al.* (2022a) and analysed using LA-MC-ICP-MS at Vegacenter, Natural History Museum Stockholm. On each tooth between 6 to 12 sequential ablations starting at the tip of the tooth down to the Enameloid Dentine Junction (EDJ) were made. After the sequential laser ablations, the teeth and data were proofed for dentine and enameloid contaminations. This was done by ocular assessment of each

ablation (see Figure 5) and in observing diverging elemental values in the dataset (as presented in papers II and III).

4.1.3 Bioavailable Baseline

To establish the bioavailable Sr baseline for freshwater systems on Gotland (used in papers II and III), water samples were collected from 14 freshwater bodies and one sample from the Baltic Sea between April and June 2021 (see Methods in paper II for more details). Given that the bedrock of Gotland is largely homogeneous (see chapter 2.4), the resolution of the bioavailable baseline was expected to be low. However, considering this baseline alongside other archaeological and ethnographic data on mobility, and the fishes relatively low dispersal patterns (Table 1) the expected resolution was deemed sufficient for the studies. In addition to these water samples, published Sr data from the island and the Baltic Sea were incorporated (see paper III).



Figure 5. Ablated cyprinid tooth, with the EDJ, indicated with a dotted line. Ablations from left to right; first two targeting only enameloid, with valid Sr ratios; the third located on the EDJ, with Sr ratios reflecting a mixture of enameloid and dentine Sr ratios. The fourth to eight ablations targeting dentine only, Sr values reflecting a mixture of the Sr ratios of the dentine with an unknown admixture of depositional environmental Sr ratios. Photo B. Krooks

4.2 Quantification

Numerous pre- and post-depositional factors influence the preservation of materials, and aspects of these taphonomic processes can be identified in the recovered bone material (see also chapter 3.1). Fishbones cannot withstand as much mechanical impact as mammalian bones (Wheeler & Jones 1989), leading to higher fragmentation rates. Due to the small size of fishbones, fine mesh sieving is necessary for recovery (to mention a few Thomas 1965; Wheeler & Jones 1989; Marean 1991; Butler & Chatters 1994; Nicholson 1996; Stahl 1996; Reitz & Wing 1999; O'Connor 2003; Olson & Walther 2007; Enghoff *et al.* 2007; Olson 2008; Szpak 2011; Boethius 2018; Gusick *et al.* 2018). Consumption of fish have been shown to impact the archaeological materials (Jones 1986; Nicholson 1993, 1996; Butler & Schroeder 1998), with herring bones being highly impacted by mastication, where up to 90% of the skeletal tissue can be destroyed (Jones 1986). Thus, finding evidence of herring consumption is highly dependent on appropriate recovery protocols. When recovered properly, fishbones can be identified to species and element to a much higher degree than fragments of most small sized mammalian or avian bones.

Fishbones are commonly quantified using NISP (Number of Identified Specimens) and NSP (Number of Specimens). There are disadvantages to using NISP for fishbones, as fish with large and robust bones are often overrepresented (see Colley 1990; Wheeler & Jones 1989, and discussion above on sieving). Some recording standards are commonly used, one is the separation of the fish body into skeletal regions: cranial, and appendicular elements, abdominal (pre-caudal) and caudal vertebrae (see e.g., Barrett *et al.* 1999; Orton *et al.* 2014, Kivikero 2020b). By applying this registration standard, distinction between so-called “primary production sites” and “secondary consumption sites”, i.e., areas where fish was transformed to a product or areas where they were consumed and discarded, becomes possible. This method is not perfect, fish brought whole to a site and butchered, cooked, consumed and discarded, or small fish dried whole, might not be identified (see Butler & Chatters 1994; Matson & Coupland 1995; Hoffman *et al.* 2000; Partlow 2006; Lubinski & Partlow 2012). Building on this quantitative issue, methods to remove fragmentation, such as MNE (Minimum Number of Elements) and MNI (Minimum Number of Individuals) are generally more difficult to apply to fishbones. Wheeler and Jones (1989), following the standards of mammalian quantification, suggest that using only non-paired bones, such as the vomer, basioccipital, or first vertebra, will facilitate the most accurate MNI or MNE. In materials with low number of such elements paired lateral cranial bones can be used with discretion, however, using vertebra centres are discouraged due to the low morphological differentiation and high size variability in the spinal

column of fish. For mammals, the use of zonation i.e., dividing the bone in units (e.g., Outram 2001) can facilitate the usage of MNI and MNE. There is however no standardised zonation method for fishbones, likely due to the high species diversity of fish (chapter 2.2), and low intra-family morphological differentiation.

4.2.1 An Attempt to Develop Zonation for Fish

Inconsistencies in registration and analysis of fishbones in archaeological records presents challenges when conducting intersite comparisons (see paper I). Given the significant variety of fish species and intra-species size variability (as discussed above and chapter 2.1), quantification and zonation methods must account for this diversity. To address this, the method developed by Krooks (2016) was re-evaluated and refined. Krooks's (2016) method considers interspecies size variation and fragmentation when quantifying fishbone material. Each element is assigned to a size class ranging from 5mm to over 80mm (see paper IV). Additionally, element completeness is recorded using three categories: complete, almost complete, or fragment (paper IV). During the re-evaluation of the original dataset, inconclusive data points were excluded from the analysis. The cleaned datasets facilitated the identification of spatial variability in species and size distribution (paper IV). The full potential of adopting this method was in paper IV not fully explored, but could potentially facilitate intra- and intersite comparison of relative fish size in materials where total length estimation is not possible.

4.2.2 Size Estimation

Zooarchaeological size estimations rely on the relationship between bone size and body size of a “standard” animal, often modern specimens, therefore using size estimations we assume that the archaeological population had identical relative proportions (Reitz & Wing 2003; Orton 2014). However, the representability of the archaeological record (as discussed in chapters 3.1 and 3.3) is known to only represent an estimation of the past. In paper IV, measurements were taken in accordance with Morales & Roslund (1979) were used for total length (TL) estimations using regression formulas from Enghoff (1994 Appendix 2). Since the origin of the modern marine specimens used to create the regression formulas is unknown using the formula on Baltic Sea cod might be sub-optimal due to the adaptation of the species to the Baltic Sea conditions (see chapter 2.2).

In paper IV the focus for the TL was on the three most identified species: pike, perch, and cod. The element chosen for the TL was based on the availability

of measurable elements in the material. For pike and perch the anterior height of the dentary (D), and for cod, the maximal width of the posterior facet of the first vertebral (W) was used. The TL estimates were used to discuss inter- and intrasite variation, where size differences of pike, perch and cod between the different analysed areas were used to highlight temporal variability. In addition, the published dataset contains measurements for additional species, enabling future research on the material.

4.3 Written Sources

To understand what fishes were utilised the Middle Ages and Early Modern Period on Gotland, where limited archaeological fishbone assemblages could be identified, transcribed accountancy books from Wisborg Castle (Tott 1991; Norby 2003; Johansson 2008) were used. In both Tott (1991) and Norby (2003), the original manuscript pages and the transcriptions of the text are presented on opposite pages, with the Medieval text transcribed letter by letter. Abbreviations in the original manuscripts are written out and marked in italics, and illegible words or those with several plausible interpretations are marked with footnotes. Johansson (2008) presents a translated and interpreted account of several manuscripts from 350 to 305 bp. Access to the original manuscripts was at the time of data collection limited, due to the COVID-19 pandemic. Since the manuscripts were used to identify fish species and fish products (and no quantitative analyses were conducted), the transcripts and translations were deemed sufficient for the studies.

The rationale behind this was that the texts, as normative sources, highlight which species of fish were worth mentioning by name in the records and were likely seen as more valuable (see paper I). Additionally, a translation of the *Historia de gentibus septentrionalibus* (Magnus 1555) was used to discuss both fishing practices and processing of fish. Since analyses of material culture tied to fishing on Gotland are not within the main scope of this thesis, Magnus (1555) and some archaeological evidence of fishing practices were used to broaden the discussion (see chapter 2.3). Furthermore, to explore the legislation of fishing, the law of the Gotlanders [GL] as translated by Peel (2009) and Steffen's (1945) interpretations of several letters pertaining to conflicts over fishing rights were used as a basis for discussion.

5. Results and Summary of Paper I

To understand how our preconceived notions of material value impact the recovery and interpretations of fishbone assemblages, paper I investigated and collated the reported fishbone assemblages from Gotland between the years 2000 and 2024. Based on the data, the paper identified four scales where different analytical approaches can be used to circumvent inadequate recovered fishbone assemblages to understand past human-fish interactions. Furthermore, by adopting the theoretical perspective of negative space in combination with the analytical scales, the paper highlights how these concepts can be used to discuss immaterial interactions in the past.

5.1 Scales of analyses

Based on the irregularities in the reported fishbone materials from Gotland the four scales facilitated discussions on past fishing practices and human-fish interactions. The first scale focused on examining the methodological “challenges” in studying fishbones, emphasizing how excavation, recovery protocols, and analytical traditions have shaped our understanding of human-fish interactions in the past. Here the concept of negative space (as presented in chapter 3.2), was exemplified using the collated materials reported from excavations. The key factor identified was the impact of recording standards, in many cases the materials were registered in NISP or NSP but weighing 0,0g, thus making comparative analysis impossible. Additionally, a small fraction of the materials has been identified to species, but in many cases no attempt to identify species have been conducted. Creating a gap in our knowledge of fishing on Gotland in the past.

Building on this, the second scale investigates the fish as a consumable, identified through stable isotope analysis of human remains. Palaeodietary pattern are used to discuss changes in human-fish relationships from the Island in a diachronic perspective. This scale also underscores the changing role of fish in societies, i.e., the values and roles, as a source of subsistence, a trading good, and touches on the broader shift from HFG to agricultural and urban lifestyles and their impact on fish consumption.

Moving away from the first two human-centred perspectives in scale one and two, scale three discusses fish-environment interactions. This scale argues that by integrating zooarchaeological data with modern ecological knowledge, the potential of habitat reconstructions of past aquatic environments becomes possible. Many fishes are dependent on specific structures to spawn and have high fidelity, making it possible to discuss the ecosystems they originate from. Furthermore, the reconstructions of paleohabitat structures can give insight into human interactions, since different aquatic systems can impact the gear use to fish. Highlighting how the environment shapes interactions between humans and fish.

Lastly the fourth scale provides a different perspective of fish as symbolic and ritual significant entities. Fishbones in burial practices and depictions on various material culture objects indicates that they hold symbolic and possibly religious significance. In burial context, the presence of fishbones, such as the pectoral fin rays associated with two PWC burials suggests they were not just food but played a role in social identity. The study draws comparative analogies with traditional fishing communities, where fish carry multiple layers of meaning beyond sustenance. By acknowledging the symbolic roles of fish and fish depictions, we can better understand how human-fish interactions shaped economic and spiritual spheres.

5.2 Summary

Paper I ultimately call for rethinking the value of fishbones in archaeological research and integrating new analytical frameworks that recognise fishes as co-creators of history. This approach can re-shape how archaeologists interpret past aquatic ecosystems and human subsistence strategies, offering a richer and more nuanced understanding of our shared history with fish. Facilitating discourse on how to incorporate knowledge of our shared past into contemporary issues on fishing practices and legislation. Paper I, informed the selection of sites and methods for papers II-IV, which were designed to showcase how the implementation of this framework can facilitate nuanced understanding of past human-fish-environment interactions.

6. Results and Summary Papers II and III

By using LA-MC-ICP-MS facilitated Sr analyses, papers II and III investigated fishing of euryhaline species in a long-term perspective. In total 42 archaeological fish teeth from four sites were analysed. Implementing the same methodological approach allowed the samples in paper II to be seamlessly incorporated into the dataset for paper III. This approach also facilitates a discussion on how interdisciplinary approaches can give us better insight into past fish-human relationships.

6.1 Bioavailable Strontium Baseline

To contextualise the fish teeth data, paper II expanded the bioavailable Sr baseline for Gotland with 14 water samples. By projecting the Sr data on the island's geological map, five Sr zones were identified on the island. The North, Central and Southern-impediment are located on bioherm limestone and marl from the Wenlock Formation and the Central-North and Central-South Marl of the Ludlow Formation (see Figure 6). In paper III, to facilitate the interpretation of the Gisslause sample the bioavailable baseline was expanded to include circum-Baltic Sr values.

6.2 Fish Teeth Data

In papers II and III different stratigraphical units at the sites were sampled (see table A2, Appendix I), since the sites were excavated using different techniques intra-site comparisons were only carried out for Ajvide. Here the number of samples from different spatial units and previously published ^{14}C dates enabled some intra-site comparison based on the temporal diversity using Bayesian chronological modelling (see paper II and supplementary information therein). From the other sites, ^{14}C data could not always be tied to the same context as the sampled fish teeth (see paper III and supplementary information therein). Therefore, care was taken to sample layers, or squares with associated ^{14}C dates. Despite these uncertainties, the sample selection, based on the long-term perspective of this work was deemed having sufficient

resolution to allow for discussion of temporal shifts. Despite a high number of failed measurements (see papers II and III and SI therein for excluded data), interesting patterns of the origin of euryhaline fishes on Gotland were observed (see Figure 7).

Between c. 9800 and 4000 BP the analysed cyprinids were exclusively from freshwater habitats, whereas the later samples only showed Sr values correlating to the Baltic Sea constant. Indicating a shift in fishing practises, in papers II and III we used interquartile ranges of the Sr zones and the fish teeth Sr to discuss the likely origin of these freshwater systems on the island. Since the Sr zones have some overlap, ethnographic foraging data, historical sources and modern ecological knowledge was used to discuss the likely mobility patterns of fish and humans in the past.

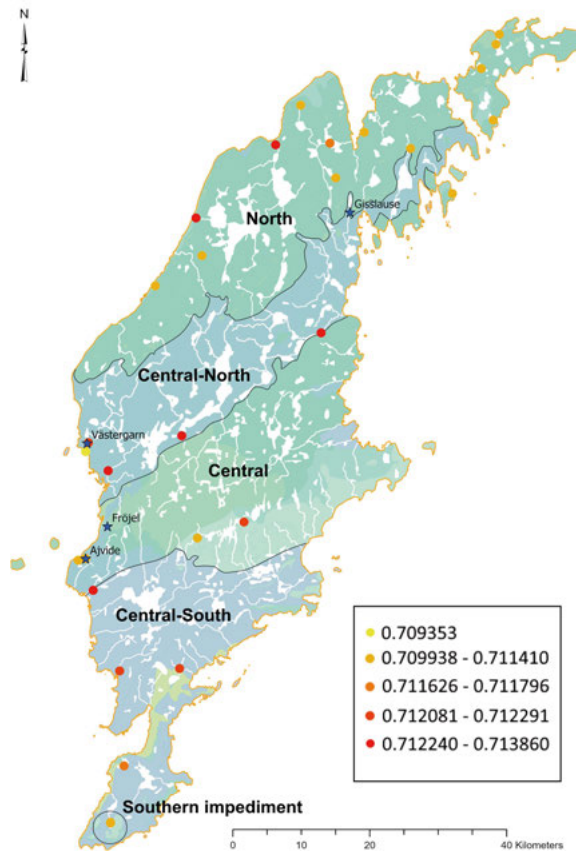


Figure 6. The bioavailable Sr baseline for Gotland developed in Paper II. The zones correlate to the bedrock of the island, areas with the same bedrock; North, Central and Southern impediment with bioherm limestone and the Central-South and Central-North consisting of Marl, show overlapping values. Indicative of the possibility to use the baseline to determine the likely origin of fish to the different zones but not to a specific area.

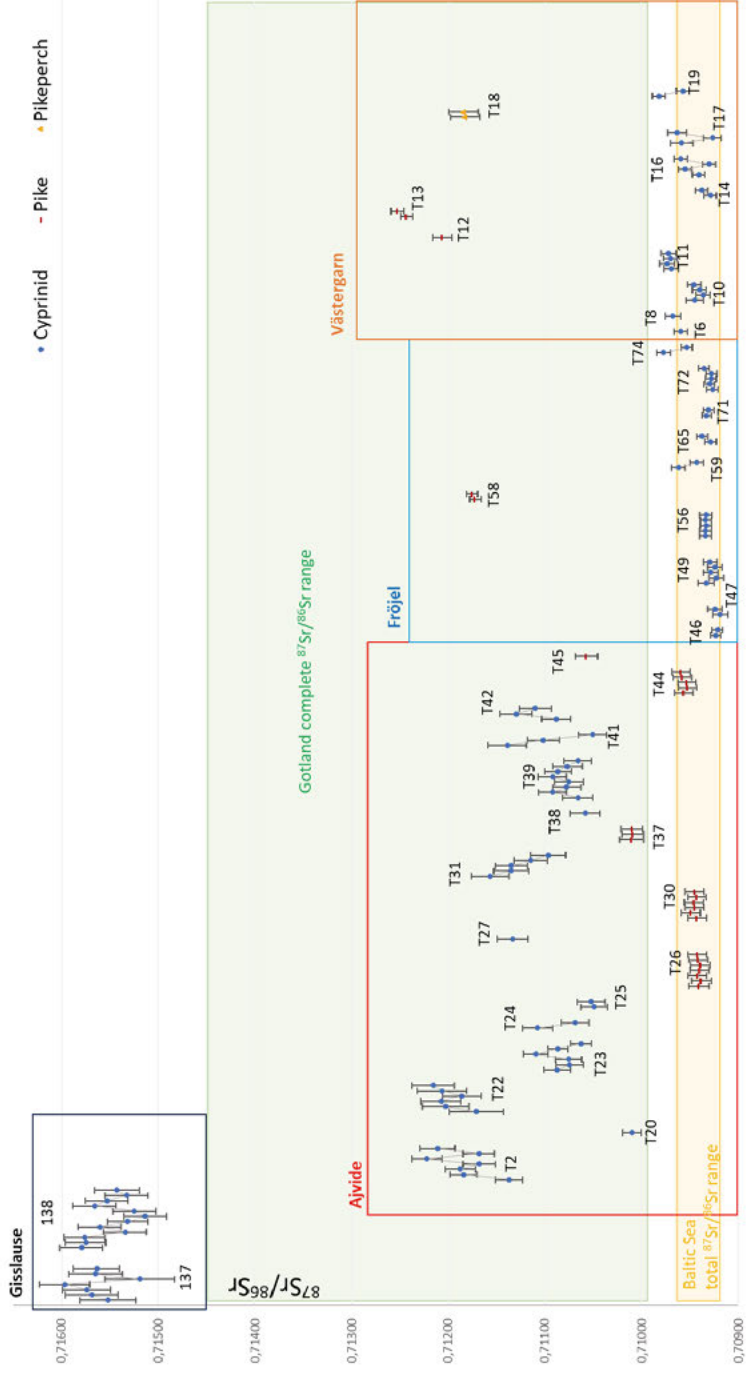


Figure 7. All successful ablations were plotted against the complete Sr range for Gotland (Green) and the total range of the Baltic Sea (Yellow) (data from Papers II and III). Sites are presented chronologically based on the Bayesian chronological model (see Paper III).

6.2.1 Water Body Alignment

To explore the minimum number of water bodies utilised, papers II and III applied the concept of Water Body Alignment (WBA). By correlating the non-overlapping intra-individual specific average Sr ratios with added standard deviation from the fishes to the bioavailable Sr from Gotland and the Baltic Sea, illustrating the minimum number of waterbodies utilised. In papers II and III these were used, with discretion, to discuss the mobility of people and fish in the landscape (see paper II, Figure 9, and paper III, Figure 8).

The WBA and Sr fish data were compared to the modern ecological knowledge of the analysed species, to showcase similarities in fish mobility and provenance over time.

6.2.2 Habitat Reconstruction

By combining the data from the bioavailable baseline, fish teeth data, modelled freshwater and shoreline displacement maps (see paper III, Figure 2), and the preferred spawning habitats (see Table 1) of the analysed fish one goal of paper III was to attempt to reconstruct the aquatic freshwater habitats. However, since cyprinids in the Mesolithic and Middle Ages were identified as stemming from the Ancylus Lake/ Baltic Sea, the reconstructions were expanded to include both waters on and around the island. Regardless of the origin, i.e., fresh, marine or brackish, and the period, the waterbodies would have had shallow vegetated areas to allow for spawning. In chapter 8.1 these reconstructions are expanded to include other species recovered at the sites but not analysed using LA-MC-ICP-MS.

6.3 Summary

Papers II and III showcase that the application of laser-ablated facilitated Strontium isotope analysis, despite a high number of failed ablations, can be used to trace the habitational origin of euryhaline fish. Enabling a better understanding of fishing practises in the past. Paper II diversifies the interpretation of fishing at the PWC site of Ajvide, by the identification of freshwater cyprinid fishing. In paper II, we tentatively propose that terrestrial mobility of the PWC for fishing increases over time, and this might be due to reduced territorial pressure as the partly contemporary FBC disappeared. Paper III reconstructed the aquatic paleoenvironments on and around Gotland between 9000 – 600 BP, using archaeological fish teeth Sr data and scientific ecological knowledge of fish habitat. In addition, Paper III identified a potential shift in the bioavailable Sr values during the Ancylus Lake – Littorina Sea transgression.

7. Results and Summary of Paper IV

In order to better understand fish-human relationships, by using combinations of standardised zoological analysis and historical sources, paper IV analysed the Medieval fishbone assemblage from Kökar. A total of 6,173 fishbones were analysed, with 4,442 identified to species or family level. The bones were categorized into anatomical groups, including cranial, vertebral, and pectoral elements, and to assess processing and consumption patterns, the level of bone fragmentation was recoded (see method section in paper IV). Total length estimation (TL) of cod, pike, and perch were used to discuss the practices and human selection.

7.1 Fish at Kökar

The analysis of fishbones from three pre-Reformation areas at Kökar revealed distinct patterns that challenged previous assumptions based on the historical sources. Fish species richness between c. 500 – 420 bp, indicate that various fishing practices were utilised. While taxation records from Kastelholm suggested that cod likely constituted the primary fish consumed at the friary, the zooarchaeological record did not support this interpretation. Instead, perch and pike were the dominant species in the materials, with anatomical distribution patterns indicating that whole fish were transported to the friary.

Spatial and chronological patterns in the fishbone distribution provided insight into the use of different buildings at the friary. The southern house and the refectory showed high resemblance in species and anatomical distribution of elements, supporting the interpretation of the southern house being used as the initial housing of the friars. The low number of cod bones in the southern house, suggests that the taxation rights of the Mörskär fishery was not yet established. Whereas the large cod recovered in the refectory were interpreted as stemming from the Mörskär fisheries as tenth or tax paid to the friars.

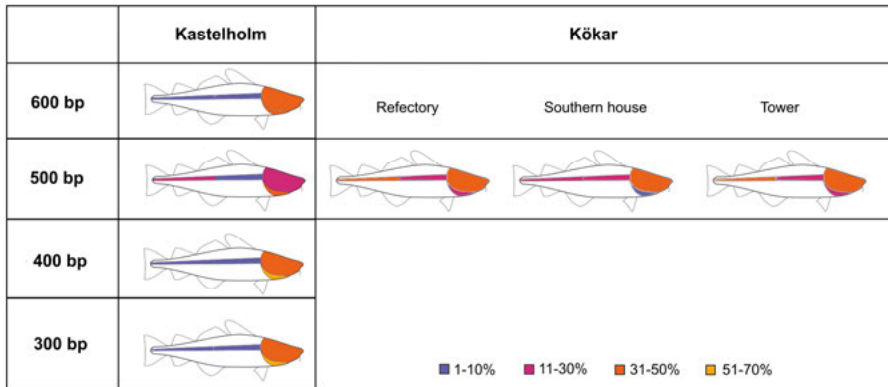


Figure 8. Comparison of element distribution between Kastelholm and Kökar, based on paper IV, Fig 6. Where the shift in element distribution in Kastelholm seems to correlate to the active phase of the Kökar friary.

7.2 Transporting Cod on Åland

To situate the Kökar friary within the broader Åland fish economy, comparative analysis with the fishbone assemblages from Kastelholm Castle indicated shifting practises during the friary's active period. Historical records indicate that Kastelholm acquired the taxation rights to the Mörskär cod fishery after the Reformation. This was supported by a shift in the anatomical distribution pattern of cod bones between the two sites (see Figure 8). By comparing written sources on Kastelholm's economy with anatomical distribution patterns at both Kökar and Kastelholm, the study identified a shift in how cod was transported. However, the exact form in which cod arrived at the friary remains unclear. The study discusses the possibility that some locally caught cod was processed as spitfish [*Sv. Spitfisk*], a fish product where the cod is dried on sticks with the head attached.

7.3 Summary

Paper IV showcases the role of fishing in medieval monastic life, illustrating how this religious institution managed their fish resources. It also sheds light on the economic and cultural factors influencing food consumption at the friary. The results indicate that medieval fish consumption was shaped not only by resource availability but also by institutional control over fisheries and regional dietary traditions. Combining zooarchaeological evidence with historical records, provided a more nuanced understanding of how this medieval religious

community sustained itself. The findings partly challenged the emphasis on cod and demonstrate the significance of locally caught euryhaline fish in the diet of the friars at Kökar. The results also highlight the importance of incorporating various sources to understand the past human-fish relationships.

8. Long-term perspectives of fishing in the Baltic Sea

This chapter synthesises the results of papers I-IV into three broader discussions related to the research questions (chapter 1.1). Firstly, using the results in papers II and III, changes in aquascape utilisation, fish mobility and shifts in habitat structure on Gotland are discussed using relevant analogies. To give insight into the questions on how we can get in-depth knowledge on fish mobility, paleohabitat structures and human interactions with them and how we can better understand past human-fish relationships when using a wider range of source materials (research questions 2 and 3). Secondly, fish as a commodity is discussed using papers I and IV as a starting point. Combining the zooarchaeological results, and historical and ethnographic records a discussion of fish as products is carried out. This gives insight into past perceptions of the value of fish as commodities (research question 1). Finally, using papers I-V, a discussion on if and how the knowledge of past fishscapes can be used in contemporary discussions on sustainable fishing, conservation, and protective legislation (research question 4).

8.1 Fishy Information

To understand the fishing on Gotland in a long-term perspective, this chapter utilises the Sr isotope studies (paper II and III) in combination with zooarchaeological and ecological data on modern fish populations. Figure 9 shows the modern spawning seasons for the species commonly identified in the zooarchaeological record materials and is used to discuss the likely seasonal usage of natural agglomeration events. On Gotland freshwater fishing in the shallow lakes on the island's northern part has been suggested as an important factor for Mesolithic HFG coming to the island (Boethius *et al.* 2017). This has been supported by a freshwater reservoir effect identified in the ^{14}C dating of human remains and Bayesian mixed modelling of zooarchaeological and isotopic dietary data (Boethius *et al.* 2017; Boethius & Ahlström 2018). In addition, the commonly identified faunal remains at Mesolithic sites are seals and fish, and on Gisslause (c. 9000- 8000 BP) most of the fishbones identified are

euryhaline species (Boethius *et al.* 2017). Since Gisslausa was likely abandoned before the 8.2ka event (Munthe & Hansson 1930; Apel and Vala 2013; Boethius *et al.* 2017 and paper III), the freshwater Ancylus lake coastal waters would not contain any marine species (see chapter 2.1 and Andrén *et al.* 2000b). Surprisingly the Sr data in paper III, did not indicate cyprinid fishing in the lakes on Gotland, but rather in the freshwater Ancylus lake. However due to the small sample size, it is likely that both freshwater bodies on the island and the coastal areas was utilised for fishing.

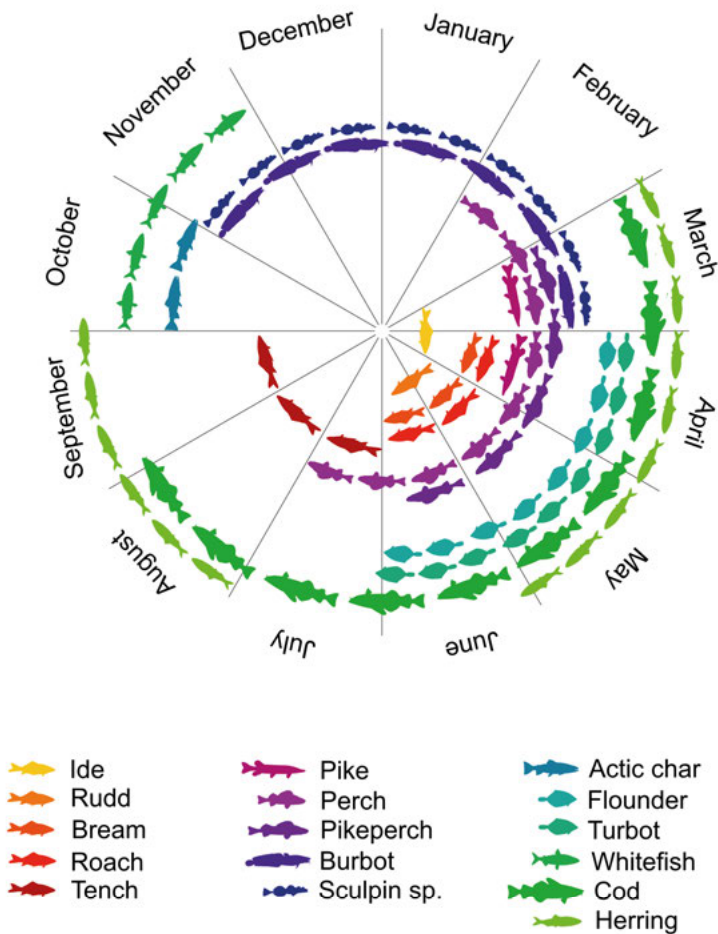


Figure 9. Spawning season of the most common species in the archaeological materials, based on Table 1 and Table A1 appendix I.

During the Mid-Neolithic (c. 5200- 3900 BP), PWC marine fish species dominate the Gotlandic materials (Olson 2008) and dietary data ($\delta^{13}\text{C}/\delta^{15}\text{N}$) indicate a marine-dominated diet (Eriksson 2004; Eriksson & Lidén 2013; Fornander *et al.* 2008; Howcroft *et al.* 2014), this has led to euryhaline species receiving less attention. This lack of attention, despite the presence of euryhaline fish in most of the recovered assemblages (i.e., Nihlén 1923, 1927; Ekman 1974; Wallin 1984; Österholm 1989; Bägerfeldt 1992; Rundkvist *et al.* 2004; Olson 2008; Lidström 2012), have caused a gap in knowledge of PWC freshwater fishing. However, some data indicate that freshwater fish was included in the diet from the PWC site Västerbjers (Boethius *et al.* 2022c). In paper II, this gap is partly bridged, identifying targeted cyprinid and pike fishing in freshwater bodies.

From Fröjel and Västergarn (c. 1350 – 600 BP) less information on the fish species richness of the recovered materials is present. Much of the identified material at Västergarn consists of large cod vertebrae (Forsberg 2009), but there is a clear recovery bias in the material due to the mesh size used for sieving (Kilger *et al.* 2022). In this material, imported Atlantic cod, further problematises the interpretations (Krooks 2013). The Sr data in paper III from both sites indicate that fishing for cyprinids was likely occurring in the coastal zone and might be linked to natural agglomeration events.

8.1.1 Mesolithic

Expanding on previous interpretations of Mesolithic cyprinid fishing on Gotland, which focused on freshwater bodies, to include the Ancyclus Lake (paper III) demonstrates the Mesolithic hunter-fisher-gatherer (HFG) adaptation to their local environment. The lack of correlation between cyprinid teeth Sr and the bioavailable baseline for Gotland, and the limited overlap with the extended baseline (paper III), suggest two possible explanations. First, the samples might originate from another region, implying the presence of knowledge regarding long-term fish preservation and transportation (chapter 2.3.4 and paper III). However, Mesolithic HFG populations with an aquatic focus typically exhibit high niche specialization within their local ecosystems and limited mobility (Kelly 2013). Second, temporal variations in Sr ratios within the Ancyclus Lake, reflecting glacial meltwater and freshwater drainage, could explain the discrepancy. The proposed shift in Sr between the Ancyclus Lake and the Littorina Sea (paper III), necessitates careful consideration when conducting Sr isotope analyses on archaeological materials predating the Littorina Sea phase. This broadens previous interpretations, highlighting how the island's combined freshwater and coastal systems provided year-round aquatic resources.

Considering the species composition and cyprinid Sr data from Gisslaue, Mesolithic HFG on Gotland likely utilised natural fish aggregation events in the coastal zone (Boethius *et al.* 2017, paper III). Given the high spawning and natal site fidelity of many species (Table 1), the Gisslaue population likely understood optimal seasons and areas for targeting different fishes. While fishing occurred year-round, certain periods likely saw intensified activity, mirroring patterns observed at other Scandinavian Mesolithic sites (Boethius *et al.* 2021, 2022b). The recovery of Mesolithic fish hooks from Gotland suggests active fishing, though passive techniques were likely employed during natural aggregation events. Historically, fyke nets were used in Gotland's streams during cyprinid spawning seasons to catch ide (Steffen 1945). While Mesolithic fish traps have not been found on Gotland, they have been discovered at other Mesolithic sites (Petersson & Olausson 1952; Petersen *et al.* 1979; Andersen 1995; Pedersen 1995; Lorenz *et al.* 2012; Hansson *et al.* 2018; Koivisto *et al.* 2018; Piezonka *et al.* 2020).

Given the association of sealing with winter months (Boethius *et al.* 2017), a likely yearly subsistence cycle can be inferred. In spring, perch, pike, and cyprinids congregate in shallows to spawn (Figure 9), pike are dependent on vegetation for egg deposition whereas cyprinids can utilise coarse sediments as well. Indicating that fishing at various locations with suitable habitats could yield substantial catches. The staggered spawning peaks of different species likely ensured a high abundance of fish in shallows until mid-summer (see Figure 9). From mid-summer to autumn, fishing was likely carried out, though fish would not shoal near the shore. October marks the start of the autumn spawning season, Arctic char, burbot, and European whitefish likely gathered in shoals. These species have different habitat preferences during spawning: Arctic char favours turbid waters or pools with coarse substrate for nest construction, while burbot and European whitefish spawns in shallows with sandy or coarse sediment bottoms (Table 1). This suggests autumn and winter fishing in two distinct aquatic systems: one with turbid water and another with a more stationary water column. Further strontium analyses of Mesolithic euryhaline fish could enhance our understanding of past fishing practices on Gotland.

8.1.2 Neolithic

Fishing in the Neolithic on Gotland is highly marine oriented as identified in the zooarchaeological assemblage (Olson 2008; Sjöstrand 2022) and human dietary data (Lindqvist & Possnert 1997; Eriksson 2004; Eriksson & Lidén 2013; Fornander *et al.* 2008; Howcroft *et al.* 2014 Wallin & Martinsson-Wallin 2016). However, some limited input of terrestrial food stuff has also been identified (Ahlström & Price 2021). Based on paper II the discussion on

PWC fishing is diversified with 14 of the 17 samples from euryhaline fish clearly showing correlation to the bioavailable Sr baseline of the island (see Figure 7 and Paper II). By correlating this data with the bioavailable baseline, reconstructions of the coastline and marine HFG mobility patterns (Binford 2001; Kelly 2013), the area utilised for fishing both marine and freshwater was likely around 15 km from the site. There are some chronological shifts in the utilisation of freshwater bodies, as exemplified by the WBA in paper II. Where it appears that inland movement might become more common in the later phases. This could correlate to a reduced reliance on aquatic foods, on Ajvide there is a reduction of fish in the later areas on the site (Sjöstrand 2022). However, this pattern could also be caused by a shift in where the material was deposited, i.e., changes in site utilisation pattern, or a decline in fish populations (see 8.3.1), could create similar patterns.

The lakes around Ajvide likely contained shallow vegetated waters sustaining populations of cyprinids and pike (see paper III). In contrast to the Mesolithic, cyprinid fishing was not conducted in the coastal area (Figure 7). This could be explained by the high salinity estimate for the Littorina Sea, at double the modern salinity (Westman *et al.* 1999). Furthermore, the Sr data indicate that the Littorina Sea contained habitats that sustained the pike population, indicating the presence of shallow vegetated waters. Mobility was low for regardless of the Sr indicating fresh or Littorina Sea origin, fitting in with the modern mobility patterns (see Table 1).

Seals were hunted throughout the year but intensified during the breeding and pup season (Storå 2001). During the autumn and winter months, cod was extensively fished, with 45 % of cod otolith annuli indicating the season of catch to be during the colder phase of the year (Limburg *et al.* 2008). Additionally, TL estimations indicate that mature individuals were targeted. Interestingly the season of catch based on annuli, does not correlate to the modern spawning time of cod. It is possible that the Neolithic cod spawned at a later time in the year compared to the modern Baltic Sea cod population, and that this reflects a targeted fishery during the spawning season.

Herring catches at Ajvide have been proposed to take place in the spring and late summer during spawning events in the coastal waters (Olson & Walther 2007). During this time the main fowling season occurred, based on the bone material, with Auks and ducks commonly identified as showing an aquatic orientation (Mannermaa & Storå 2006). The Auks were likely hunted at Stora Karlsö directly after the main fishing and sealing season in the spring. Some birds are associated with terrestrial habitats but are similar to the euryhaline fish species in low numbers.

Compared to PWC sites on mainland Sweden the fishbone assemblage at Ajvide (and other PWC sites on Gotland and Åland) shows a clear preference for marine species such as cod and herring (Olson 2008), whereas the mainland sites despite their coastal location often have high amounts of euryhaline fish (Segerberg 1999; Olson 2008; Sönnergren 2008; Vajking 2021). Since the Holocene temperature optimum and the Littorina Sea maximum (5000 BP), likely led to favourable conditions for marine species in the Littorina Sea (Emise *et al.* 2002), freshwater fishing might have been more time consuming.

Limited freshwater fishing, as is evident in the fishbone assemblage could be an expression of several interlinking factors, limitations in territory (i.e., a higher risk of intrapersonal violence) (Ahlström & Molnar 2012), the overlapping spawning season of herring, cod and cyprinids (see Figure 9), and the low water levels in lakes (Negendank 2002; Seppä *et al.* 2005). If freshwater systems on Gotland had unfavourable habitats conditions, i.e., less fish, optimal utilisation of the marine species in the Littorina Sea would likely be favoured by the PWC population at Ajvide. This optimisation and adaptability of the PWC to utilise local available resource has been demonstrated at various sites (see Stenberger *et al.* 1943; Ekman 1974; Lepiksaar 1974; Aaris-Sørensen 1978; Lindqvist & Possnert 1997; Storå 2001; Olson 2008; Edenmo & Heimdahl 2012; Magnell 2019; Vanhanen *et al.* 2019), the marine specialisation at Ajvide could indicate that in the islands freshwater systems fish was not as abundant as in the Littorina Sea. However, freshwater, and migratory fish seems to have been incorporated into the symbolic world, with some burials at Ajvide containing fin rays from percids and sturgeon scales (Österholm 2008 and paper I).

8.1.3 Middle Ages and Beyond

The Middle Ages witnessed significant shifts in human-fish interactions due to centralisation, cultural changes, and technological advancements. In Europe, freshwater fishing appears to have declined during this period in favour of marine species (Barrett *et al.* 2004a, 2004b). Excavations at Västergarn have yielded large, articulated pieces of cod vertebrae (Kilger *et al.* 2022, 2023), and cod from the Atlantic Ocean has been identified on both Fröjel and Västergarn (Krooks 2013). However, the prevalence of cod bones, amongst the recovered fish species remains uncertain, as a comprehensive fishbone analysis has not been conducted for either of the sites. Coupled with a preliminary report of the implementing a 2mm mesh size at Västergarn increases the species richness in the recovered material (Kilger *et al.* 2022), it is clear that additional analyses of the materials are necessary.

However, the Sr data from Fröjel and Västergarn suggests a reduction in freshwater fishing occurs during this time (paper III). A shift in fishing locations is evident, with pike exclusively fished in freshwater and cyprinids in brackish habitats, likely the coastal area. Notably, the MWP (chapter 2.1.2) likely influenced both the Baltic Sea and Gotland's freshwater systems. Compared to today, the higher salinity favoured marine species (Andrén *et al.* 2000b; Emise *et al.* 2002), while increased peat formation in the wetland likely reduced accessible freshwater habitats for fishes. The observed decrease in freshwater fishing, may reflect an increased marine orientation in fisheries, coupled with centralisation and societal shifts in land ownership and religious food taboos.

The clay bottoms excavated at Västergarn (Norderäng 2009b; Norderäng *et al.* 2010) support the interpretation of intensified marine fish utilisation and Gotland's integration within the broader Baltic Sea trading networks. A decline in clay bottoms at sites in Scania is estimated to have occurred around the same time as activities at Västergarn declines (Axrud 2015). Despite taxation on cod and herring catches, these marine fish were likely more profitable. In England, the MWP, Christianity, land ownership, and centralisation have been proposed as drivers of this shift in fishing practices. While the Fröjel and Västergarn samples are small, precluding definitive conclusions, they raise compelling points for discussion in regards to the Medieval fishing practices on the island. The GL mentions fish only once: "*One has permission to ride to the marketplace with prepared food, cheese and butter and all dairy produce, fish, fowl and those beasts that one is to sell on the market square*" (GL 6:18). This section, which regulates work on holy days, indicates that bringing fish to market for sale was permitted. Peel (2009) notes that the GL appears more liberal than other contemporary legislation regarding permitted work on holy days.

Christianity's influence on food culture, such as the practice of Lent, which, while abstaining from meat, did not exclude fish consumption (Leviticus 11:9, KJB) could be a driver for the marine fish extraction. Attempts to trace the impact of Lent using $\delta^{13}\text{C}/\delta^{15}\text{N}$ on Gotlandic populations shown no significant increase in fish intake in coastal populations with a pre-Christian marine diet (Kosiba *et al.* 2007). However, some archaeological evidence suggests Christianity altered fish consumption, most notably through the emergence of aquaculture, exemplified by the three fish ponds at the Cistercian abbey in Roma. While the abbey was founded in 786 bp (Lagerlöf 1973), the establishment date of the fish ponds remains unknown. However, their layout aligns with the Medieval aquaculture system described by Hoffmann (2023). Cistercian abbeys, though often rural, were connected to travel routes (Kerr 2009). Roma monastery's central location on Gotland meant that travellers likely passed by.

This mirrors the Kökar friary, situated on the main waterway between Stockholm and the Eastern Baltic countries (paper IV). The Kökar material indicates that the friary's fish consumption included euryhaline species, such as perch and pike, likely caught by friars or laymen. Cod was also present at the site, and was likely transported from the Mörskär fishery as tithes or taxes. While marine species like cod and herring were likely dietary staples at Roma, no supporting analysis is currently available. Further analysis of Medieval assemblages from ecclesiastical sites on Gotland and comparative sites are necessary to explore patterns of changing fish consumption.

With the legal disputes over fishing rights in streams on the island (Steffen 1945) it is apparent that freshwater fish, had value as consumables for the Gotlanders. The large-scale draining of Gotland's wetlands in the 20th century, facilitated larger agricultural areas it also eliminated many habitats for euryhaline species. Ethnographic sources indicate that cyprinid, particularly ide, fishing was a crucial part of the subsistence strategy for many island farmers (Klintberg 1983).

8.2 Fishy Business

From the earlier periods within this thesis, i.e., the Meso- and Neolithic, we have little evidence to the way fish was treated after being caught. There are clear indications that species caught at different periods of the year, were treated in different ways. The utilisation of fermentation (Boethius 2016), as a preservatory technique indicate the necessity to create a product which could be consumed over a longer time span. Since the techniques for preserving fish appears to be well known in the past, it is likely that these were also practised during the Meso- and Neolithic on Gotland, however there is no archaeological evidence supporting this. The clearest evidence for the “commodification” of fish is seen in the Medieval fishbone assemblages from Kökar that have been investigated in tandem with written sources. This subchapter mainly focusses the discussion on the results from the Mediaeval fishing in the Baltic Sea context.

From Gotland, few written sources regarding fishing are preserved (Tott 1991; Norby 2003; Johansson 2008), and only limited analyses of faunal assemblages have been identified, many of which lack NISP (see paper I). To facilitate discussion on how fish might have been transformed into a more commodified product, material from Kökar, Åland, was analysed (paper IV). In contrast, fish consumption and fish products are much more explored on Åland and southern Finland (Kivikero 2020a, 2020b; Löugas & Bläuer 2021). Despite the limited written record available from Gotland, some information

on the structure of how fishing was regulated can be understood. Furthermore, the value of different fish species as a product or consumable can be seen. Some indications of fish consumption can be seen in $\delta^{13}\text{C}/\delta^{15}\text{N}$ dietary data from two cemeteries in Visby (Lindkvist 2007) and Gotland (Klevnäs *et al.* 2024; Peschel 2014), which indicates a mixed diet with individual variation in the amount of marine fish consumption.

8.2.1 Fish Products in the Past

Identifying the commercialisation of fish requires a combination of source materials, products can be recognised in written records. However, the written sources do not always allow us to identify the fish species used for to create a product. In paper IV the pathways of cod from the Mörskär fishery were traced over time using the zooarchaeological assemblage and written records, and indications of a shift of cod transportation could be identified. On Gotland due to the limited fishbone assemblages no such studies could be conducted, there are however compelling comparisons between Åland and Gotland. The written records from Wisborg Castle identify 21 categories of fish or fish products (Tott 1991; Norby 2003; Johansson 2008). These are sometimes processed products of a specific species and sometimes just recorded as fresh or food fish. Food fish should according to Steffen (1945) be fjällfisk [scaly-fish]. Fjällfisk is the name used for all fishes, excluding herring, cod and European flounder, caught in either fresh- or saline waters (e.g., euryhaline species) (Steffen 1945).

On Åland and Gotland the differentiation between fjäll- and skinfisk [skin-fish] seems to be linked to the fish's economic value as a trading good. Skin-fisk is the most economically valued fish, with regulations on the season of catch and the amount of tax paid to the crown. From the 465 bp Wisborg records Bergefisk, a dried cod product from Bergen in Norway is an indication of the interconnectedness of the island (Tott 1991). Further products indicating the trading of fish can be seen in the mention of Este Strömligh [*Estonian herring*] in the following year (Tott 1991). In the 350- 340 bp for records, Bergefisk is still part of the castle economy (Johansson 2008). Herring appears to have been of high economic value, the clay bottoms (discussed in chapter 8.1.3) can be seen as an indicator for the function of Västergarn as a node in a larger trading network. Tension between the merchants in Visby and the Gotlanders were hostile, and c. 662 bp the town merchants excluded the Gotlanders from trading with Lübeck and Riga (Harreld 2015). All these aspects make a plausible interpretation that due to the societal shifts, Västergarn lost its role as a trading centre and the fishery became more focused on fishing for the household's subsistence. Within the scope of this work, exploring the potential

monetary value of these products and the trading routes was not possible, however research into the zooarchaeological material, the content of the clay bottoms, and written sources could shed light into Västergarn's role in the larger Medieval trading network. Since there are clear indications of fish products being brought to the site (Krooks 2013), understanding the relation of imports and locally caught fishes could give insight into the role of Västergarn as shifts in the islands societal, cultural and aquatic environments occurred. In addition, this could further highlight the different values ascribed to the different species.

8.2.2 Regional Patterns of Fish Products

As previously mentioned, comparing species and anatomical distribution patterns of fishbone assemblages can be used to understand local and regional patterns. On Åland, spitfisk has been identified as a dried cod product with a diverging anatomical distribution of elements to the imported stockfish from the Atlantic Ocean (paper IV). Stockfish typically has the head removed at the production site as the fish is dried, before exporting the products (See Barrett *et al.* 1999 and chapter 2.3.4). However, on the Åland Isles cod appears to be dried with the head still attached to the body. Spitfisk might in this context be the same type of product as the *rundfisch* described by Hoffmann (2009), i.e., a dried cod with the head still attached.

Interestingly when spitfisk appears in the written record on Gotland it has been interpreted in two different ways; as a dried fish product made from fjällfisk, usually freshwater species (Steffen 1945) or smaller cod dried on a stick, as described in a Danish quittance: small wind-dried cod [*smaa winndthørchede thorsch*] (Johansson 2008). When related to the circum-Baltic fish products in written sources, Steffen's (1945) interpretation of spitfish as any fish dried on a skewer shows high resemblance with *Strekfusz* (Hoffmann 2009). According to Hoffmann (2009: 120) the Prussians used the word *strekfusz* to a variety of fish species stretched out and dried, and the consumers likely only knew the product name rather than the actual fish species.

Indicating that written sources might not be useful in discussing the species composition at a site, but as an indicator of the preservative method, or the fish products brought to a site. Paper IV and the Gotlandic written sources in combination with the European evidence, indicates that preservative methods used in the past appear to be relatively uniform in the Baltic Sea area. In Magnus (1555), depictions of fishing, dried fish and drying of fish can be seen and in one picture whole fish are laid out, crania attached to dry (see also Figure 2). On the Norwegian coast in the *Carta Marina* (Magnus 1539), two types of fish products are depicted (Figure 10). Bigger cod-like fish are depicted with

detached heads, likely stockfish, and smaller fish are depicted whole in bundles, this could be a depiction of rundfisch (Hoffmann 2009). Spitfisk or strekfusz in the Baltic Sea context should maybe be seen as a method of preserving fish. Further studies into distribution patterns of fjällfisk bones from archaeological sites on Gotland could potentially be used to identify this practice. This could also shed light on the species of fish classified as food and fresh fish in the written sources.

Additional information on uniform patterns of handling of fish can be seen in pikes. Pike in the Baltic Sea region from the Middle Ages appears to have uniform patterns in anatomical distribution and cutmarks on the dentary (see paper IV, Jonsson 1986a, Hoffmann 2009). Pike dentary's from Kökar and Kastelholm (Krooks 2016; Kivikero 2020b), have cutmarks following the pattern presented by Jonsson (1986a). Paper IV, concludes that it is likely that both dried and fresh pike were sold with the crania before 215 bp thus the anatomical distribution of pike bones might not indicate the way pike was brought to a site. If the preparation of pike on Gotland follows this pattern is currently unknown. But both fresh and dried pike appear in the written records from the island (Tott 1991; Norby 2003; Johansson 2008).

Based on this data it is clear that different species of fish have been used for different products, and some appears to have been more financially important. Dried cod is still a staple food in many countries today.

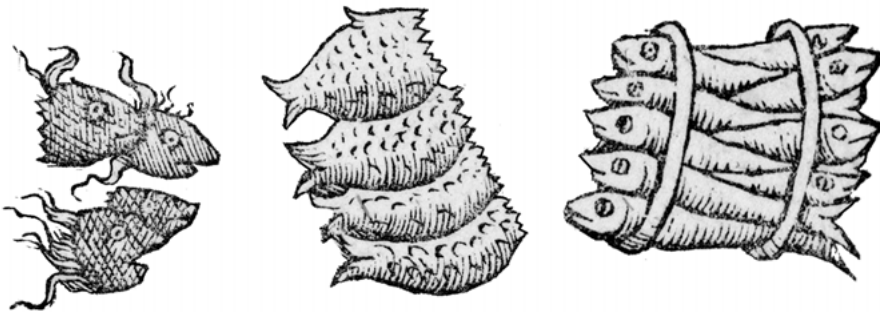


Figure 10. Depictions of Norwegian fish products from *Carta marina* (Magnus 1539), (Public Domain Mark 1.0.) Modified by the author

8.3 Swimming with the Fishes

The previous chapters 8.1 and 8.2 have focused on the archaeological aspects of the research questions. The present chapter applies the concept of “fishing down the food web” on the archaeological record and discusses potential ways of integrating archaeological fishbone data to inform contemporary policies, and finally presents the benefits of a fishier archaeology. The discussion is based on the fish species collated in Table A1 (Appendix I) based on the reported zooarchaeological assemblages and written sources from the case studies.

8.3.1 Fishing Down or Up the Food Web

One proposed way to estimate human impact on the ecosystem is the concept of fishing down the food web (FDFW), where overexploitation of high-trophic-species becomes a driver for extraction of lower-trophic-species (Pauly *et al.* 1998). The utilisation of FDFW as a driver for the large-scale changes seen in modernity have been questioned, Caddy *et al.* (1998) argues that the observed ecological patterns, i.e., FDFW, could be created by a shift in market demand rather than a decline in high-trophic-level species. Where the smaller, low-trophic-level species are extracted for animal fodder. Despite this potential caveat, the fishing down the food web scenario, when applied to modern observable fish stocks and food webs, have been successful in identifying Anthropocene impacts on marine ecosystems (see for example Pauly *et al.* 1998; Valtyrsson & Pauly 2003; Andersen *et al.* 2010; IOC-UNESCO and UNEP 2016; Korpinen *et al.* 2022).

When applying FDFW to the archaeological record, consideration must be given to the changes utilisation of the fish caught, today only 17 % of fish caught is in Sweden allocated for human consumption (Sundblad *et al.* 2020). We do not know the total biomass extracted in the past, or how much of this was used for human consumption. However, in the comprehensive study of North Atlantic cod and herring fisheries in the Early Modern Period Holm *et al.* (2022, 65) concludes that: *North Atlantic fisheries for cod and herring were of an order of magnitude comparable to industrial fisheries for several centuries before the Industrial Revolution took off. This is a finding that challenges notions of relatively unimpacted marine ecosystems before the Industrial Age.*

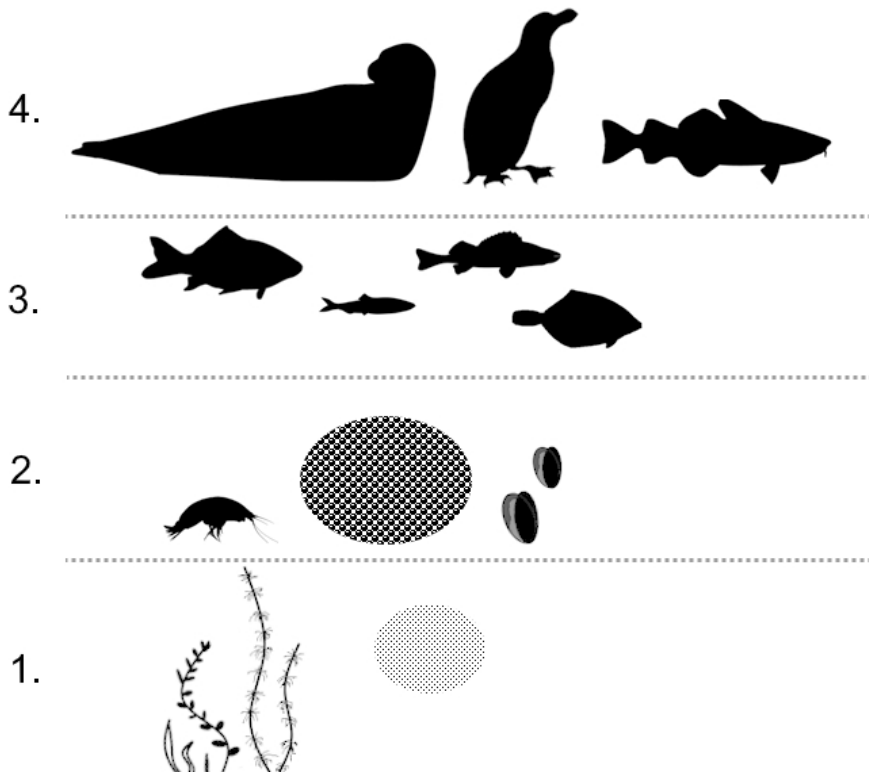


Figure 11. Simplified schematic of the Baltic Sea trophic levels. 1. Phytoplankton, benthic algae, and Vascular plants; 2. Zooplankton and Zoobenthos; 3. Small fish such as perch, cyprinids, and herring; 4. Large fish i.e., cod, seals, and waterfowls.

This indicates that fishing, pre-dating the industrial revolution, could have significant impact on past ecosystems. There are some archaeological studies that have showcased the potential in using FDFW to discuss temporal trends in archaeological fisheries (Erlandson *et al.* 2009; Pestle 2013). In applying FDFW on archaeological fishbone materials from the Baltic Sea, the large changes (as presented in chapter 2.1) must be kept in mind, since they could potentially create similar ecological patterns as a FSFW scenario.

The trophic levels in the Baltic Sea today consists of four levels (Andersen *et al.* 2010). The past food web structures are unknown, but based on the zoo-archaeological materials (Table A1) it likely followed a similar structure as today with piscivore species (aquatic mammals, birds, fish and humans) at the highest trophic level. The archaeological record indicates that fishing primarily targeted species from today's high-trophic-levels (see Figure 11 and Table A1 in Appendix I).

Mesolithic dietary reconstructions using Bayesian mixing models have indicated that seals and mid-trophic fish was the primary protein intake on Gotland, this differs from the Mesolithic site of Norje Sunnansund where cypriids and terrestrial herbivores and omnivores makes up a larger part of the diet (See Boethius & Ahlström 2018, Figure 4). The extraction of fish during natural agglomeration events (chapter 8.1.3) could potentially impact localised fish populations. Whereby the total impact of Mesolithic fisheries on the food web was likely highly localised and did not lead to large scale cascading effects.

The Ancylus Lake- Littorina Sea transgression (c. 8300 BP) is likely the most critical change in the past for the aquatic habitat in the coastal zone around Gotland. Rising salinity and the arrival of new species (see chapter 2.1.2) reshaped trophic levels and food webs within the ecosystem. The reduced fishing in the Early- to Mid-Neolithic, is therefore potentially a combination of the agricultural practised of the FBC groups on the island (Fraser *et al.* 2018), and instable fish populations in the initial Littorina Sea. If freshwater fish was consumed is unclear, since the identification of freshwater fish consumption, regardless of trophic level is difficult (Hedges & Reynard 2007). Lakes can have a wide range of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values and variations within the same waterbody can occur (Katzenberg 1989; Wheeler and Jones 1989; Cohen 1994; Hecky & Hesslein 1995; Katzenberg & Weber, 1999; Grey *et al.* 2000; Katzenberg *et al.* 2009; Milner *et al.* 2004).

During the Mid-Neolithic the ecosystem in the Littorina Sea likely stabilised, with high saline conditions favourable for the new marine species, such as cod and herring. This was utilised by the PWC groups on Gotland and Åland, who primarily targeted the two highest aquatic trophy levels i.e., 3 and 4 (Figure 11). It is possible that the targeted high-trophic-level exploitation could have led to a depletion of cod and herring in the coastal areas around Gotland leading to a cascading effect in the ecosystem. This means that the reduced fish consumption in the Bronze Age could be linked to the overexploitation of high-trophic-level species and the cultural shift towards an agricultural societal structure. However, due to the lack of zooarchaeological material and human isotope data from the Bronze Age no conclusive interpretations can be drawn.

Discussions on FDFW in the Middle Ages are caseous, since the materials available for analyses are limited. Based on papers I, III and IV high-trophic-level species were likely the preferred species for consumption. During this time the Christian belief system could influent food consumption; low-trophy-level species such as bivalves lack scales or fins, and should therefore not be consumed during Lent (Leviticus 11:9-10, KJB). However, bivalves also rely

on specific ecosystem properties to thrive. A lack of them in the archaeological record could therefore be caused by several factors, such as inadequate recovery protocols, unsuitable habitats in the area, or that they were not consumed based on taboos (see below for a synthesising discussion on bivalves).

At Västergarn, the presence of clay bottoms (see chapters 2.3.4 and 8.1.3) implies that herring were caught and processed at the site, and the presents of seal bones in the zooarchaeological material indicate that high-trophic-level species were regularly exploited (Kilger *et al* 2022; 2023). This pattern is also seen in the later written sources from Gotland wherein cod, herring and seals are commonly mentioned (Tott 1991, Norby 2003). Further studies into fishbone assemblages from the Medieval period on Gotland are necessary to investigate fishing practices. However, the recovery bias and low numbers of fishbone assemblages from this period needs to be mitigated (paper I).

By using Kökar (paper IV) as a comparative dataset, the Medieval fishbones from the site primarily stems from the high to mid-trophic range species. Since the cod at the site likely reflects the income of the friary from the Mörskär fishery the total cod catches were likely more substantial than indicated by the fishbone assemblage alone. When compared to the contemporary Franciscan friary Rauma and Bridgettine Abbey of Naantali, Finland (Löugas & Bläuer 2021), the amount of cod bones to other species, size and anatomical distribution pattern differs. On Kökar no large cod vertebral indicating import of stockfish has been identified, and the anatomical distribution pattern indicates a that fish was brought whole to the site (see paper IV). In the Naantali fishbone assemblage, only large vertebral have been identified, fitting with the pattern of imported stockfish (Löugas & Bläuer 2021). At Rauma, larger cod vertebra indicates the presence of stockfish, but there are also smaller cod bones in the assemblage (Löugas & Bläuer 2021), with anatomical distributions pattern similar to the one identified at Kökar (paper IV).

One aspect of FDFW not possible to explore in this thesis is the utilisation of bivalves, since they are rarely represented in the archaeological record from Gotland. Today bivalves in the Baltic Sea around Gotland are small and rarely seen as a human consumable. The utilisation of bivalves has in Mesolithic assemblages from France been showed to include two distinct groups, bigger species used for consumption and smaller once for ornaments (Dupont 2019). Erterbølle shell middens in Denmark consists of substantial amounts of bivalves, indicating that they were a part of the foodstuff in Mesolithic Denmark (Andersen 2000, 2008). There are a few finds of bivalves from Gotlandic PWC burials, such as cockles, tooth shells, Baltic macoma (*Limecola balthica*) and mother of pearl ornaments (Österholm 2008; Wallin, P. personal communication 2025.03.22). This indicates that the PWC did utilises bivalves

as grave goods, and smaller bivalves could have been boiled as taste enhancement. As previously mentioned, the lack of bivalves in the Middle Ages could be an expression of the taboo of consuming meat, and things without scales during days of Lent, thus a lack of bivalves might be an indicator of shifting dietary practices. This can at this stage not be evaluated since the recovery of bivalves is not standardised, and therefore, they are almost completely absent in the archaeological record of Gotland. Modern day data clearly shows the impact of changes in the food web when high-trophic-level fish is overexploited (Andersen *et al.* 2010) and with more zooarchaeological fishbone data further evidence of Anthropocene impact on past ecosystems can be discerned.

Today we know that fish, just as any other entity on the planet is finite and that our utilisation and overexploitation of them can have unforeseen consequences. Consumption and utilisation of resources are deeply rooted in cultural practices, and changes requires active engagement and knowledge. In the case studies some indications of shifting food practices have been exemplified, these were likely driven by a combination of natural environmental shifts and cultural preferences (papers II-III) and economic and cultural values (papers I and IV).

8.3.2 Integrating Knowledge of Past Practice for a Better Tomorrow

One of the aims of this thesis, is to situate and discuss archaeological fishbones in the wider context of aquatic conservation and sustainable use of blue food. In recent years inter- and transdisciplinary research have used archaeological fishbone materials to discuss sustainable fisheries and fish stocks (Barrett 2019; Rick *et al.* 2013; Lambrides & Weisler 2016, Holm *et al.* 2022). Shifts in species assemblages within archaeological records, i.e., biogeography, can be used as a proxy for understanding natural shifts in climate and habitat structures, as well as human-driven change.

In Paper III, the Sr isotope analysis highlights long-term shifts in the water bodies used for cyprinid fishing, these were likely influenced by the environmental changes in the Baltic Sea, and cultural preferences. Papers II and III clearly shows that the categorisation of fish, based on conventional classifications, i.e., oceanodromous, potamodromous, anadromous, and catadromous cannot be applied with a high certainty for many of the species in the archaeological record. The term euryhaline is more applicable but still only gives a crude differentiation, and if applied consistently to all fish would also include many of the marine species post the Littorina Sea phase when the salinity dropped below marine conditions. Furthermore, as the discussion above highlights, utilising various archaeological, historical and ecological source

materials and methods can facilitate deeper understanding of the fishscapes in the past.

I would argue that a key factor of using fishbones to inform contemporary legislation and regulations, with a goal to restore ecosystems we need to understand how past interactions shaped the present situation. The continuum of shifting baselines in the Baltic Sea makes the classification of native species difficult to define. Cod was during the Ancylus Lake – Littorina Sea transgression able to survive in the increasingly saline waters, and have evolved to a genetically diverse sub-population endemic to the Baltic Sea. With the Baltic Sea becoming increasingly fresh with a low influx of saline oxygen-rich waters and anthropogenic-induced eutrophication, the conditions for the marine species in the Sea are deteriorating (Andersen *et al.* 2010; Olsson *et al.* 2018). We have also introduced new species to the Baltic Sea through ballast water, these invasive species can potentially lead to further changes in the food web.

Fish resource management in Europe is not a modern invention (see e.g., Hoffmann 2020, Zeheter 2020). Past conservation and management actions were carried out to protect the breeding fish stock from overexploitation. According to Hoffmann (2020), preserving breeding stocks was the most common reason given for legislative action. By regulating the fishing season, gear and areas open for fishing, attempts to create sustainable freshwater fishing in medieval Europe were conducted. These actions show the importance of local ecological knowledge of past societies since the legislation protected fish and their habitats during spawning season (Hoffmann 2020). There were actions to improve habitat structures, such as banning bottom trawling and seine fishing or improving habitats by refilling lake shores with branches to protect overwintering fish (Hoffmann 2020). Several other protective legislative actions across Medieval Europe protected fish stocks and habitats. Many of these legislations are adapted to the specific conditions in the area, showing the importance of understanding the local ecological premises when creating legislations that regulate fisheries. Interestingly there was no legislation on the number of fish allowed to be caught, which can reflect the importance of fish as sustenance for the populations or the belief that fish was an infinite resource.

Fishing today is highly regulated both for industry and recreational fishing, based on scientific estimates of population regrowth, areas are protected from bottom trawling and regulations to prevent chemical runoffs are in place. Despite this, the degradation of the Baltic Sea ecosystems is continuing, and industrial fishing is allowed above what many experts consider sustainable quotas (Hamrén 2023 c.f., EU Regulation 2016/1139). In Sweden many rivers and streams are modified to facilitate hydroelectric powerplants and other Anthropocene activities, blocking migration paths and destroying habitats, most of

the restoration efforts are done by organisations such as SportFiskarna and Hushållningssällskap (“Sveriges Sportfiske- och Fiskevårdsförbund | Sportfiskarna,”; “Vatten,” Hushållningssällskapet). In striving towards the sustainability goals (Muller-Karger 2024), we must incorporate more than human actors, and ask for whom should it be sustainable and why. Since only 17 % of the aquatic resources caught and farmed in Sweden are being consumed by humans today (Sundblad *et al.* 2020), we rarely see the fish. Reducing our impact on the aquatic food web should maybe start with the question: is it sustainable to fish to feed livestock? Because “modern” fishing practices, such as bottom trawling, was identified in the Middle Ages as destructive to the habitat and fish populations within them.

With the rapid climate changes today, shifts in the Baltic Sea food web can lead to cascading effects impacting the entire ecosystem, but this would not be the first time this would have happened in what we today define as the Baltic Sea. However, in the case of marine species i.e., cod and herring, that since the Neolithic has been highly valuable sources for human sustenance and economic products, thus making it a priority for humans to preserve them. In the past, adaption to consume locally available species might not have been rapid, localised overfishing likely occurred, and cultural, ecological and technical aspects would have influenced the fish species utilised. Drawing on past practices we need to challenge our perceived values of what type of fish is a “good” consumable, what are we actually doing with the fish we catch, and for whom are we really trying to restore and save ecosystems.

9. Fishscapes

By using the concept of fishscapes, this work has employed traditional zooarchaeological and novel approaches in four case studies focusing on fishing in a long-term perspective on two islands in the Baltic Sea. The results from the case studies formed the base for an expanded discussion and interpretations on human-fish interactions in a long-term perspective. The following section reflects on these methodologies and results and relates them to the overall aims: understand and highlight informative properties of fishbone assemblages and show changes in habitat structure, and human aquatic utilisation and relate this to the bigger climatic and cultural shifts in the past.

Improving how archaeological fishbones are perceived and interacted with starts with recognising the potential of knowledge stored with them. With the integration of scientific ecological knowledge, Sr isotope analysis and historical records, new previously hidden interactions have been brought to light. The interpretations of paleohabitat structures, fish mobility and human utilisation of aquatic resources have in this thesis been showed to be more diverse than previously assumed. Furthermore, this work has demonstrated that by combining standard zooarchaeological methods and historical records, the interactions between human and fish as a commodity can be discussed.

On Gotland, over the roughly 9000 years explored, it is evident that waterbodies on and around the island have been important, and that they have sustained populations of fishes and humans throughout large-scale climatic changes. Human interactions with fish, in the past and the present is influenced by normative, preconceived notions of importance (paper I). When we approach the archaeological record from new perspectives, previously underexplored interactions can be identified.

Starting from the first human occupation of the island, paper III diversified the interpretation of lakes as important parts of the factors attracting Mesolithic settlers to the island. Despite the limited sample from the Mesolithic site Gisslaue, insight into the habitat structures on the Gotlandic coastline before the *Littorina* transgression has been attained. During the Middle Neolithic marine species were the most important for humans in the coastal community groups the sub-Neolithic PWC, however freshwater fishing was also carried out. Papers II and III highlight the PWC adaptability in aquascape utilisation.

Additionally, paper III identifies and discusses the habitat structures in the Littorina Sea and the island's freshwater systems. The distinct change of cyprinid fishing between the Meso- and Neolithic is likely an expression of the high saline properties of the Littorina Sea, leading to a reduction of cyprinids in the coastal area. This appears to have changed during the Middle Ages when cyprinid fishing was exclusively carried out in the Baltic Sea, this might be the start of the cyprinid fishing carried out in streams and lakes on Gotland into modernity. Aquaculture s during this time a new emerging fishscapes, this fishscape was limited to the friars and laymen at the Roma estate. Import of fish also crated new fishscapes, the Visby merchant's monopoly of trade and the Hanseatic leagues dominance in trade shaped the fish trade.

The materials studied at the Franciscan friary on Kökar (paper IV), exemplifies how interactions creates an economic fishscape, where the transportation of cod shifts during the active phase of the friary (Paper IV). The role of ecclesiastic centralised power on fishing can be seen in the taxation rights of the local Mörskär fishery, which during the reformation were transferred to Kastelholm castle. This economic fishscape was interlinked with the regional economic sphere of fish trade. The transformation of fish into a recorded product produces a fishscapes wherein the fish becomes immaterial. The written sources give insight into the economic value ascribed to different species and products, however, as discussed in chapter 8.2.2 this commodification can complicate interpretations of written sources. To understand which species were used to create the fish products in the Middle Ages on Gotland, further studies into fishbone assemblages is necessary. These studies need to be related to the larger context of the Baltic Sea fisheries and fish products.

The four papers and the discussion on FDFW in chapter 8.3 indicate a dynamic relationship between humans-fish and the environment. Where natural fluctuations and human induced changes in the aquascape reshapes the interactions of fish and humans alike. Cultural preferences are also co-creators of fishscapes, where the preferred fish, culinary or economical will define the archaeological source material. Humans are also the co-creators of the archaeological fishscapes, our engagement with fishbone materials, defines the knowledge we can attain of past fishscapes.

9.1 A Fishier Archaeology

Implementing a “fishier” archaeology does not mean that we should only focus on fish, but rather utilise the materials we recover to their full potential. There will seldom be optimal recovery strategies, limiting factors beyond our control will be present. Despite these caveats, if aware of the concept of negative space, we can strive for more holistic knowledge of past practices, fishes,

and their habitat structures. Integrating various source materials and methods, these fishscapes becomes more diverse. Highlighting the value of fishbones as a material in archaeological research we reduce the knowledge gaps and inform contemporary discourse on sustainable fisheries. In doing so we also gain insight into how fish is and was valued as part of the world we share, as foodstuff for humans and actors within their aquascapes. Reanalysing legacy collections, as shown in papers II, III and IV using standardised and novel methods will lead to reinterpretations and reduce the knowledge gaps. Finding new ways of seeing past interactions and relationships, and how they are interlinked with us. When we start to focus on materials that have for a long time been neglected, our understanding of past societies and habitat structures will improve.

Limitations should not discourage us from seeking new ways forward, trying new methods and integrating knowledge from other academic fields and modern scientific and local ecological knowledge. Achieving this type of transdisciplinary research needs a firm foundation to stand on, it requires us explore new scapes, and highlight what is hidden in the negative space.

Starting a new journey is always based on previous experiences, so we need to enable the initial perception of archaeological fishbones to be positive, to evoke interest. Informing how fishbones give insight into aspects of the past that can be used to discuss ways forward today (as discussed in chapter 8), to students and other archaeologists, we can start to bring the fish out from the negative space. These fishscapes, just as Edgeworth (2011) defines water-scapes, are neither natural nor cultural but entanglements of both. They are spatial, temporal, and non-temporal, they are sustained by interactions of humans, fish, environmental shifts.

9.2 Final thoughts

This work is not a complete synthesis of all fishbone assemblages on Gotland or Åland nor all methods possible to use, but a solid starting point for further exploration. Research into site-specific patterns such as the articulated cod vertebra at Västergarn and diachronic multisite perspectives are necessary to continue to build on the knowledge generated in this work. Using of the concept of fishscapes is a way of bridging gaps between disciplines wherein diverse archaeological, ethnographic and ecological materials and methods can be synthesised to understand the world around us, in this case the one in the intersection of land and water, human and fish.

Continued research into archaeological fishbone assemblages can create a solid foundation for the next generation of researchers to create knowledge about the diachronic human-fish relationships and at the same time provide

insights for current day legislators in striving towards reaching the sustainability goals and to protect fish and habitats for sustainable fishing practices in the future.

Populärvetenskaplig Sammanfattning

Denna avhandling är skriven som en del av det interdisciplinära projektet *fiske och kustzons utveckling i ett långtidsperspektiv, dåtid, nutid och framtid* i forskarskolan GRASS på Uppsala universitet, Campus Gotland. Genom att utforska arkeologiska fiskben och skriftliga källor i ett långtidsperspektiv, är målsättningen med denna avhandling att visa på mängden information i dessa källmaterial. I dagens Östersjön, med klimatförändringar, övergödning och överfiske är risken för storskaliga förändringar i ekosystemet stor. Utifrån ett arkeologiskt perspektiv är förändringar i det akvatiska systemet inte obekant, sedan den senaste istiden har den vattenmassa vi idag kallar Östersjön genomgått flertalet storskaliga förändringar. Fokus lades på två öar, Gotland och Åland, och tre tidsperioder Mesolitikum, Neolitikum och Medeltiden.

När de första människorna nådde Gotland under mesolitikum (ca. 7200 f.v.t) var kustvattnet färskt och inga av de saltvattenarter, så som torsk och sill/strömning, som finns i Östersjön idag var tillgängliga. För att förstå vart man fiskade har denna avhandling jämfört strontiumvärden i arkeologiska karpfisk tänder från Gisslause (ca. 7000 – 6200 f.v.t) med biologiskt tillgängligt strontium på Gotland. Resultaten visar att människorna under denna tid fiskade både i kustzonerna och i de många sjöar som fanns på ön. Karpfisk och lake är de vanligaste arterna i arkeologiska materialet och fisket skedde troligen under de olika leksäsongerna.

Ungefär 2000 år senare kollapsar Laurentide glaciären i Nordamerika och stora mängder färskvatten från de tidigare uppdämmande sjöarna släpps ut i Atlanten. Detta leder till ett kallare klimat och att havsnivån ökar och saltvattnen når in i Östersjön. Nu kan torks, sill/strömning och andra saltvattenarter överleva och föröka sig, på Gotland utnyttjas dessa arter av människorna under neolitikum på den groppkeramiska boplatsen Ajvide (ca 3100 – 1800 f.v.t). Stora mängder marina fiskben har tillvaratagits vid utgrävningar, med en tidigare utforskad aspekt är de få färskvattenarterna i materialet. Genom att använda samma analyssteknik som på de mesolitiska karpfisktänderna har ett bredare resursutnyttjande kunna identifieras.

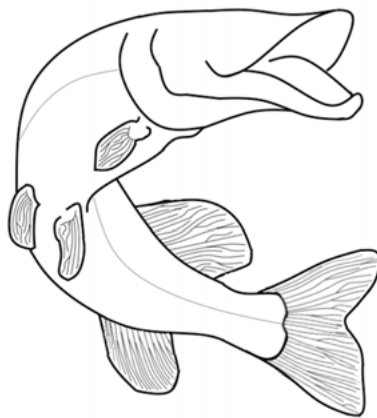
Under medeltiden blir Gotland en viktig knutpunkt i Östersjön, den ökade centralisationen, kristnandet, teknologiska utvecklingar, pest och krig förändrar förutsättningarna för fiske. I kontrast till de tidigare perioderna utforskade

finns det mindre arkeologiska fiskbensmaterial tillgängliga. Två platser med fiskben valdes som studieobjekt, Fröjel (ca. 600 - 1300 v.t) och Västergarn (900 - 1350 v.t). Båda dessa platser visar kontinuitet från vikingatiden och tidigare studier har visat att torkad torsk från Atlanten importerats. Även här användes strontiumvärlden från fisktänder för att förstå vart människor fiskade. Resultaten indikerar att fiske av karpfisk skedde i kustzonen, denna praktik var vanlig på Gotland ända in i modern tid.

För att förstå hur en ökad centralisering och reglering av fiske kan uttryckas i det arkeologiska materialet användes Kökars konvent på Åland som en utgångspunkt. Detta konvent grundades ca. 1450 v.t. och utnyttjades av franciskanerorden fram till reformationen 1523 v.t. Skriftliga källor indikerade att konventet hade skatterätt på det lokala torskfisket vid Mörskär, en rätt som övertogs av Kastelholms slott efter upplösningen av konventet. Genom att analysera fiskbenen kunde ett troligt skifte i hur torsk från Mörskär transporterades på Åland i och med konventets grundande och upplösande identifieras.

Genom att diskutera resultatet från dessa platser i relation till andra arkeologiska och historiska källmaterial samt moderna metoder för att förstå mänsklig inverkan på akvatiska ekosystem, visar denna avhandling hur viktigt fiske och fisk har vart för människor på Gotland. Resultaten ökar vår förståelse för interaktioner mellan människor, fiskar och miljö över tid. Detta kan användas för att skapa förutsättningar för ett hållbart lokalt fiske och hälsosamma akvatiska ekosystem.

Genom att lyfta fram potentialen i arkeologiska fiskben har denna avhandling som målsättning att inspirera framtida arkeologer och forskare att fortsätta utforska våran och fiskarnas gemensamma historia.



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Appendix I

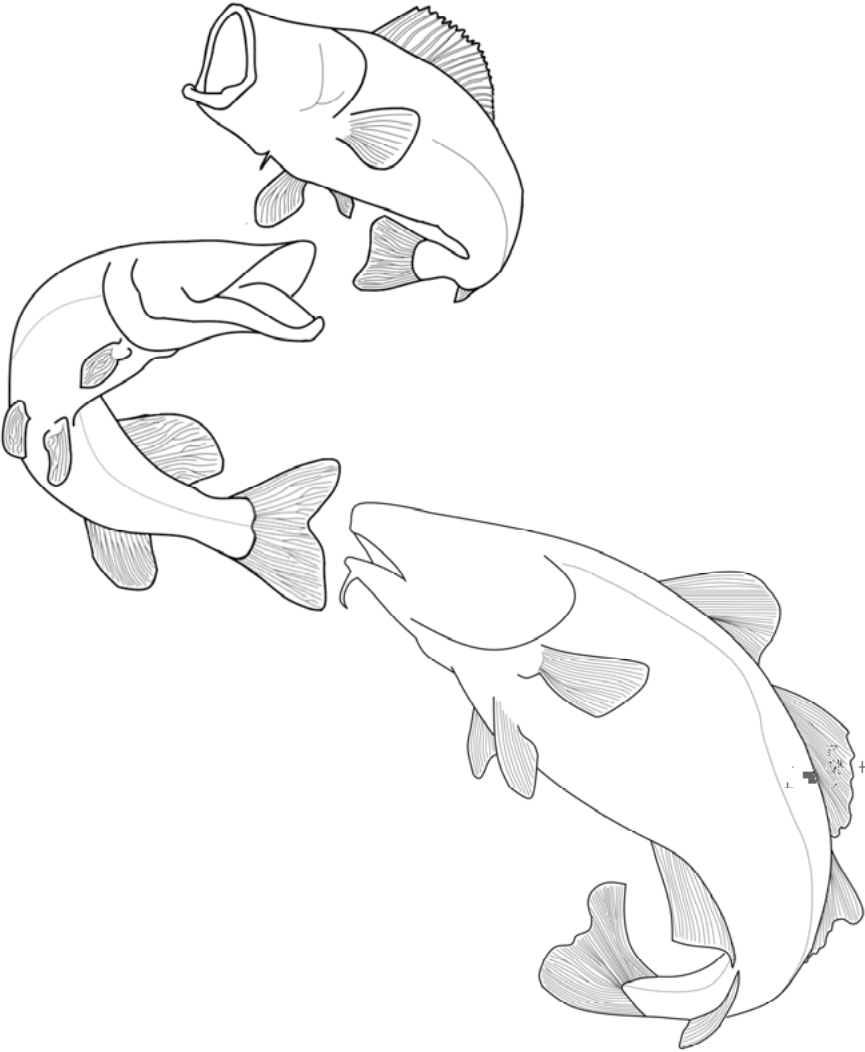


Table A1. Fish species in the Baltic Sea and on Gotland and Åland today, and the species identified in the Archaeological record. Modern fish data from; Noréhn 1984, Adjers 2021, SLU Artdatabanken 2024, 2025, and Archaeological and historical data from; Tott 1991, Björk 2001; Norby 2003, Bech-Hanssen 2007, Johansson 2008, Österholm 2008; Landsröm and Foglemark 2010, Hammarsten 2013, Boethius et al 2017, Kivikero 2020a, b, Kilger et al. 2022, 2023, Papers II, III and IV.

	<i>Gotland</i>					<i>Åland</i>		
	349-318 bp	427-426 bp	465-463 bp	1350-600 BP	5200-3900 BP	9000-8000 BP	570-350 bp	500-427 bp
<i>Moden data</i>								
1984-2024								
Percidae sp.				X				
Perch (<i>Perca fluviatilis</i>)	X		X	X	X	X	X	X
Pikeperch (<i>Sander lucioperca</i>)				X	X	X	X	X
Pike (<i>Esox lucius</i>)	X	X	X	X	X	X	X	X
Cyprinid sp.					X	X	X	X
Crucian carp (<i>Carassius carassius</i>)			X					
Tench (<i>Tinca tinca</i>)					X			
Roach (<i>Rutilus rutilus</i>)				X	X	X	X	
Ide (<i>Leuciscus idus</i>)				X			X	X

Rudd (<i>Scardinius erythrophthalmus</i>)	X	
Bleak (<i>Alburnus alburnus</i>)		
White bream (<i>Blicca bjoerkna</i>)		
Bream (<i>Abramis Brama</i>)	X	X
Common carp (<i>Cyprinus carpio</i>)		
Prussian carp (<i>Carassius gibelio</i>)		
Goldfish (<i>Carassius auratus</i>)		
Grass carp (<i>Ctenopharyngodon idella</i>)		
Sichel (<i>Pelecus cultratus</i>)		
Common minnow (<i>Phoxinus phoxinus</i>)		
Ruffe (<i>Gymnocephalus cernua</i>)		
Three-spined stickleback (<i>Gasterosteus aculeatus</i>)		
Ninespine stickleback (<i>Pungitius pungitius</i>)		

Swordfish (<i>Xiphias gladius</i>)	
Black goby (<i>Gobius niger</i>)	
Sand goby (<i>Pomatoschistus minutus</i>)	
Round goby (<i>Neogobius melanostomus</i>)	
Common goby (<i>Pomatoschistus microps</i>)	
Two-spotted goby (<i>Pomatoschistus flavescens</i>)	
Alpine bullhead (<i>Alpinocottus poecilopus</i>)	
Sea-snail (<i>Liparis barbatus</i>)	
Common seasnail (<i>Liparis liparis</i>)	
Snakeblenny (<i>Lumpenus lampretaeformis</i>)	
Rock gunnel (<i>Pholis gunnellus</i>)	

Broadnosed pipefish (<i>Syngnathus typhle</i>)										
Straightnose pipefish (<i>Nerophis ophidion</i>)										
European Eel (<i>Anguilla anguilla</i>)	X	X	X	X	X	X	X	X	X	X
Salmonidae sp.	X	X	X	X	X	X	X	X	X	X
Atlantic salmon (<i>Salmo salar</i>)										X
Sea Trout (<i>Salmo trutta</i>)										
River trout (<i>Salmo trutta fario</i>)										
Brook trout (<i>Salvelinus fontinalis</i>)										
European whitefish (<i>Coregonus lavaretus</i>)									X	X
Maraena whitefish (<i>Coregonus maraena</i>)										
Rainbow trout (<i>Oncorhynchus mykiss</i>)										
Arctic char (<i>Salvelinus alpinus</i>)									X	

Eelpout (<i>Zoarces viviparus</i>)						
Great sandeel (<i>Hyperoplus lanceolatus</i>)						
Small sandeel (<i>Ammodytes tobianus</i>)						
Northern sand lance (<i>Ammodytes dubius</i>)						
European sturgeon (<i>Acipenser sturio</i>)	X	X	X	X		X
Atlantic sturgeon (<i>Acipenser oxyrinchus</i>)						
European river lamprey (<i>Lampetra fluviatilis</i>)						
European smelt (<i>Osmerus eperlanus</i>)					X	
Batomorphi sp.						X

Table A2. Additional contextual information for the fish teeth analysed in papers II and III.

ID	DNR	SITE	TRENCH	SQUARE	LAYER	SPECIES	ELEMENT	PAPER
T137		Gisslause		103/199	5c	Roach (<i>Rutilus rutilus</i>)	Pharyngeal	III
T138		Gisslause		100/200	2c	Cyprinid (cyprinidae indet.)	Tooth	III
T2	220-1825-93	Ajvide	Dark Area 2	- 7 / -167	3	Cyprinid (cyprinidae indet.)	pharyngeal	II, III
T4	220-1825-93	Ajvide	Posthole area	-21 / - 132	3	Pike (<i>Esox lucius</i>)	Tooth	II
T20	220-1825-93	Ajvide	Posthole area	- 23 / - 133	6	Bream (<i>Abramis brama</i>)	pharyngeal	II, III
T22	20-1825-93	Ajvide	Dark Area 1	- 4 / - 133	6	Cyprinid (cyprinidae indet.)	pharyngeal	II, III
T23	220-1825-93	Ajvide	Posthole Area	- 22 / - 124	5	Bream (<i>Abramis brama</i>)	pharyngeal	II, III
T24	220-1825-93	Ajvide	Posthole Area	- 23 / - 124	5	Rudd (<i>Scardinius erythrophthalmus</i>)	pharyngeal	II, III
T25	220-1825-93	Ajvide	Posthole Area	- 22 / - 128	5	Bream (<i>Abramis brama</i>)	pharyngeal	II, III
T26	220-1825-93	Ajvide	Dark Area 1	- 9 / - 133	6	Pike (<i>Esox lucius</i>)	Tooth	II, III
T27	220-1825-93	Ajvide	Dark Area 2	- 9 / - 165	3	Roach (<i>Rutilus rutilus</i>)	pharyngeal	II, III
T30	220-1825-93	Ajvide	Posthole Area	- 20 / - 127	2	Pike (<i>Esox lucius</i>)	Tooth	II, III
T31	11.391-168-83	Ajvide	Dark Area 1	- 3 / - 125	4	Tench (<i>Tinca tinca</i>)	pharyngeal	II, III
T37	11.391-168-83	Ajvide	Dark Area 1	- 3 / - 124	2	Pike (<i>Esox lucius</i>)	Tooth	II, III
T38	11.391-168-83	Ajvide	Dark Area 1	- 1 / - 125	4	Roach (<i>Rutilus rutilus</i>)	pharyngeal	II, III
T39	11.391-168-83	Ajvide	Dark Area 1	- 3 / - 125	4	Tench (<i>Tinca tinca</i>)	pharyngeal	II, III
T41	220-2029-98	Ajvide	Posthole Area	- 17 / - 138	3	Roach (<i>Rutilus rutilus</i>)	pharyngeal	II, III
T42	220-2029-98	Ajvide	Posthole Area	- 17 / - 139	4	Roach (<i>Rutilus rutilus</i>)	pharyngeal	II, III
T44	220-2727-01	Ajvide	Dark Area 2	- 10 / -168	4	Pike (<i>Esox lucius</i>)	Tooth	II, III

	220-2727-01	Ajvide	Dark Area 2	- 11 / - 167	3	Pike (<i>Esox lucius</i>)	tooth	II, III
T45	431-2867-03	Fröjel	2	161 / 123	5	Ide (<i>Leuciscus idus</i>)	pharyngeal	III
T46	431-2867-03	Fröjel	3	157 / 124	6	Roach (<i>Rutilus rutilus</i>)	pharyngeal	III
T47	431-2867-03	Fröjel	2	161 / 132	5	Cyprinid (cyprinidae indet.)	pharyngeal	III
T49	431-2867-03	Fröjel	3	156 / 124	5	Bream (<i>Abramis brama</i>)	pharyngeal	III
T56	431-2867-03	Fröjel	3	156 / 124	5	Pike (<i>Esox lucius</i>)	tooth	III
T58	431-2867-03	Fröjel	3	157 / 124	5	Bream (<i>Abramis brama</i>)	pharyngeal	III
T59	431-2867-03	Fröjel	3	157 / 126	6	Bream (<i>Abramis brama</i>)	pharyngeal	III
T65	431-2867-03	Fröjel	1	161 / 125	4	Ide (<i>Leuciscus idus</i>)	pharyngeal	III
T71	431-2867-03	Fröjel	1	161 / 125	4	Roach (<i>Rutilus rutilus</i>)	pharyngeal	III
T72	431-2867-03	Fröjel	3	155 / 124	4	Bream (<i>Abramis brama</i>)	pharyngeal	III
T74	431-243-2020	Västergarn	67	4	NA	Cyprinidae sp.	pharyngeal	III
T5	431-243-2020	Västergarn	67	17	NA	Ide (<i>Leuciscus idus</i>)	pharyngeal	III
T6	431-243-2020	Västergarn	PG2	14	NA	Ide (<i>Leuciscus idus</i>)	pharyngeal	III
T8	431-243-	Västergarn	71	20	NA	Roach (<i>Rutilus rutilus</i>)	pharyngeal	III
T10	431-243-	Västergarn	67	46	NA	Ide (<i>Leuciscus idus</i>)	pharyngeal	III
T11	431-243-2020	Västergarn	67	48	NA	Pike (<i>Esox lucius</i>)	tooth	III
T12	431-243-2020	Västergarn	67	64	NA	Pike (<i>Esox lucius</i>)	tooth	III
T13	431-243-	Västergarn	73	96	NA	Ide (<i>Leuciscus idus</i>)	pharyngeal	III
T14	431-243-	Västergarn	71	17	NA	Roach (<i>Rutilus rutilus</i>)	Pharyngeal	III
T16	431-243-	Västergarn	71	17	NA	Roach (<i>Rutilus rutilus</i>)	Pharyngeal	III
T17	431-243-	Västergarn	70	NA	NA	Pikeperch (<i>Sander lucioperca</i>)	Tooth	III
T18	431-243-	Västergarn	71	13	NA	Ide (<i>Leuciscus idus</i>)	Pharyngeal	III
T19	431-243-	Västergarn	71					

Appendix II



