When the rivers ran low and the crops turned to dust: Medieval drought ecologies and drought as potential inspiration for the Marine Fish Event Horizon in Central Europe

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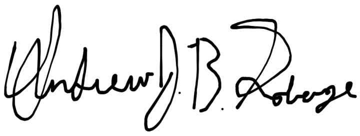
Candidate Declaration of Academic Integrity

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person, except where due reference is made in the text.

Signed: 

Dated: August 29, 2024

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[1] These fish icons are used as page breaks in Dr. Richard Hoffmann's 2023 book *The catch: An environmental history of medieval European fisheries*

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Abbreviation Key

MFEH- Marine Fish Event Horizon	**ONCT -** Organismal Niche Construction Theory
scPDSI- Self-calibrated Palmer Drought Severity Index	**f-** Frequency
HHI- Historic Humidity Index	**N-** Total number
MCA- Medieval Climate Anomaly	**MNI-** Minimum number of individuals
LIA- Little Ice Age	**NISP-** Number of identified species present
OWDA- Old World Drought Atlas	**TPQ-** *Terminus Post Quem*
TAQ- *Terminus Ante Quem*	**LEH-** Linear Enamel Hypoplasia

Note on Report Style

This thesis adheres to the format guidelines detailed in the Australian Archaeology handbook, as well as the style guide provided by Flinders University. However, with the permission of the advisory board and for ease of reading, this thesis uses the "%" symbol rather than the word "percent," and similarly refers to centuries numerically (i.e. "13th century").

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Abstract

Using a multipartite method of analysis, this thesis builds a dynamic body of evidence to suggest recurrent and devastating droughts as a potential inspiration for the AD 900–1540 Marine Fish Event Horizon (MFEH) in Central Europe. By reconstructing pathways of drought harm to freshwater fish ecologies, other human foodways, and general public health in a medieval Central European context, this thesis establishes drought as a pervasive socio-ecological stressor to freshwater fish and the Christianizing Europeans who relied upon them during religious fasts. Drought harm is potentially reflected in archival, osteological, ichthyological, and technological materials, which together provide a body of evidence to compare with reconstructed and archivally evidenced droughts and their fallout. Comparing the temporal proximity of droughts and drought-induced foodway disruptions to specific MFEH events, the development of the Hanseatic League, and technological shipbuilding advancements also suggests drought's role in inspiring human change. Analyzing the medieval climate promises to add a crucial element of the lived experience to previous, purely cultural, MFEH studies. Secondarily, the presented research reveals the pitfalls of epoch-length climate and cultural generalization, emphasizing the need for site and time-specific analysis of multidisciplinary material. Doing so yields specific results that contextualize this complex period of resource revolution and trade while simultaneously complicating notions of simple environmental determinism.

Abstract word count: 211

1 Introduction: A Gap in Marine Fish Event Horizon Considerations

In 2004, Cambridge archaeologists (Barrett et al.) identified a 10th–16th century resource revolution in English zooarchaeological assemblages. Excavations revealed significant dietary introductions of locally sourced and traded Baltic, North Atlantic, and North Sea fish–notably cod and herring–that eclipsed diminishing freshwater fish staples. Barrett et al. (2004) dubbed this phenomenon the "Marine Fish Event Horizon" (MFEH), in tribute to late author Douglas Adams' "Shoe Event Horizon." Subsequent excavations throughout Europe–many of which are recorded in the 2016 anthology *Cod and Herring* (Barrett and Orton)–corroborated these changing exploitation patterns, extended the MFEH scope, and suggested extensive processed marine fish trade networks that penetrated the European interior. Freshwater fish "declined in quantitative importance through time, both in absolute numbers and in relative terms vis-à-vis marine fish" (Barrett 2016:265) across European assemblages, and Marine fish consumption reached a pan-European scale with 14th century Hanseatic trade (Sahrhage and Lundbeck 1992; Hoffmann 1995; 2001; Smith 2010; Orton et al. 2011; Barrett 2016; Holm 2016; Küchelmann 2019). Scholars tout the MFEH as a several-century diffusion and turn to subsistence and surplus economic systems (Lotze 2007). The MFEH encompassed evolving foodways; maritime technologies and cultures; and trade relations, and studying the turn contextualizes the socio-cultural, economic, and ecological conditions that may have inspired its onset and proliferation.

To date, published explanations for the MFEH (Hoffmann 1995; 1996; 2001; 2005; 2023abcd; Barrett et al. 2004; Barrett et al. 2011; Olsen 2013; Barrett 2016; Häberle et al. 2016; Drtikolová Kaupová et al. 2018; Jílková et al. 2019; Häberle and Plogmann 2019; Živaljević et al. 2019) have been socio-cultural in nature. As 9th–11th century birth rates and life expectancies improved, Europe's population burgeoned (Barrett et al. 2004). Fronteiring Europeans settled trade routes and river crossings; proximally to pilgrimage, resource, and ecclesiastic sites; and in locations fortifiable against potential aggressors (Zečević and Ziemann 2022). New cities exploited fertile river and coastal wetlands (Zhang et al. 2021), and increased nutritional demand required mass cropland clearing, poldering, industrial food processing and milling development, and dam and dike building to control water levels. Immigrants united by similar Romance, Germanic, and Slavic languages– and by spreading Christianity and trade– settled many prosperous cities. Concurrently, the widespread adoption of St. Benedict's Rule (Barrett et al. 2004), which forbade quadruped meat consumption for up to 182 days of the year, left freshwater (often pike, perch, eel, catfish) and spawn-migrating (often salmon, sturgeon) fish (Delatouche 1966; Dyer 1988; Hoffmann 2004) as some of few substantial protein sources (Hoffmann 1996; Reitsema et al. 2010). Larger populations and specific Christian demand for fish invigorated freshwater fishing and weir-trapping efforts, and the non-isolable products of industrial milling and expansion antagonized medieval ecologies and economic systems. Encroaching humans also directly polluted waterways, and the combined results of urban growth depleted freshwater stocks, inflated fish prices, and fueled the desire for cheaper, more sustainable marine alternatives (Hoffmann 1995; 1996; 2001; 2005; 2023a,b,c,d; Barrett et al. 2004; Barrett et al. 2011; Orton et al. 2011; Van de Noort 2011; Barrett 2016, Häberle et al. 2016; Holm 2016; Hufthammer 2016; Lõugas 2016; Makowiecki et al. 2016; Nedkvitne 2016; Van Neer and Ervynck 2016; Živaljević et al. 2019; Kyselý et al. 2022). Over a few centuries, "low-value, high-bulk" (Barrett et al. 2004:618) marine fish– many processed and traded from Iceland, Denmark, Sweden, and Norway– entered mainland markets to satisfy Christian demand.

The accepted MFEH research has discussed only anthropogenic factors for the turn, omitting or discrediting nature's volatile impacts on fish, cropping, and public health as potential factors. Recognizing this gap and noting archival accounts of hyper-variable climate-induced stress, the contributors to *Cod and Herring* (Barrett 2016) purport a missing meteorological-ecological key to better understanding the turn's multi-impetus origins (Orton et al. 2011). The following analysis extends MFEH research to address that gap in understanding, and examines drought as a complex stressor.

1.1 *Written on the Rocks: Climatological, Geographic, and Temporal Focus*

Climate reconstructions and archives document frequent and devastating 10th–16th century European droughts. Though many volatile medieval weather events are known, drought records are bolstered by physical remembrances known as hunger stones. Typically submerged rocks only visible during extreme riverine lowstands, hunger stones feature human-made carvings that chronicle droughts and their societal impacts (Figure 1, 7). Carvings– sometimes just a date, sometimes pictographic or with epigraphic inscriptions– span 900 years and are crucial components of the documentary record as climatologically and archivally confirmed drought markers (Elleder et al. 2016; 2020). An Elbe River stone in the Czech city of Děčín reads "*Wenn du mich siehst, dann weine*" or, "if you see me, then weep" (Figure 1). A similar stone in Bleckede, Germany reads "*Geht dieser Stein unter, wird das Leben wieder bunter*" or, "when this stone goes under, life will become more colorful again." Hunger stones are known in Europe's Danube, Rhine, Elbe, Weser, and Oder Rivers. Though many hunger stones are anachronistic to the 10th–16th centuries, several coincide with local MFEH records and ichthyological patterns identified in prior published works.

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Figure 1: "*Wenn du mich siehst, dann weine"* (From: Brázdil et al. 2013:1988)

Hunger stones serve as “harbingers of famine and hardship” (Odbratt 2023:13) when exposed by dwindling waters. Their messages humanize the climatological record, persist in the collective memory (Odbratt 2023) as enduring warnings, and contextualize the social duress that inspired their carving into the earth itself. Treating the identified hunger stones as physical and cultural bearings (Figure 2) isolates the Danube, Rhine, Oder, and Elbe River basins (Figures 3–6) as definite drought-impacted areas of interest. These areas include the modern states of Germany, the Czech Republic, Poland, Austria, Hungary, Switzerland, Slovenia, Liechtenstein, Luxembourg, Lithuania, Latvia, Belarus, Belgium, Serbia, Croatia, Estonia, Romania, Bulgaria, and the Netherlands. For research purposes, the aforementioned states are to be broadly understood as Central Europe, but collectively represented a spectrum of medieval cultural, linguistic, and political identities. Notably, Slovenia and Belarus– medieval Czech and Lithuanian territories, respectively– only recently gained independence in AD 1991, and the identified basins also encompass smaller contributing rivers.

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Figure 2: Hunger stones and other low-water level indicators on map (From Elleder et al. 2020:1832). Note: An additional hunger stone is recorded in Budapest, Hungary in Odbratt (2023)

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Figure 3: The Danube River basin (From: Schlattmann et al. 2021:332)

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Figure 4: The Rhine River basin (From: Wantzen et al. 2022:334)

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Figure 5: The Oder River basin (From: UN Environment Programme GRID)

Figure 6: The Elbe River basin (From: UN Environment Programme GRID)

Hunger stones also represent an area of medieval Christianization with religiously linked settlements that fasted and increasingly demanded fish. More practically, the hunger stones geographically encompass the focus areas of all prior MFEH studies, providing a springboard for drought research. Furthermore, Europeans only carved hunger stones during the most extreme drought-induced social, ecological, agricultural, and economic emergencies (Glaser and Kahle 2020), which suggests particular duress in the region.

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Figure 7: A Weser River hunger stone (Photo by Axel Hindemith, 2018)

The 10th–16th century scope of prior MFEH studies– necessary comparisons for subsequent research– encapsulates two modernly defined climate epochs: the AD 950–1250 Medieval Climate Anomaly (MCA) (also known as the Medieval Climate Optimum or Medieval Warm Period) (Lamb 1965; Hoffmann 2004; Barrett et al. 2011; Primeau et al. 2019; ScienceDaily 2021; Tserendorj et al. 2021), and the AD 1300–1850 Little Ice Age (LIA) (Appleby 1980; Grove 2001; Proctor et al. 2002; Hoffmann 2004; Helama et al. 2009; Büntgen et al. 2011; Dobrovolný et al. 2015; Camenisch and Rohr 2018; Primeau et al. 2019; ScienceDaily 2021; Zhang et al. 2021; Hoffmann 2023). The MCA saw, as a year-to-year average, temperate, warm, and relatively crop-friendly conditions. The LIA brought generally colder and wetter weather. However, volatile MCA and LIA deviations brought "epic droughts" (Jones et al. 1999:137) that, as confirmed by soil, dendrological, and archival studies (Cook et al. 2015), occurred more frequently and for longer durations than in recent centuries. The MCA-LIA transition (AD 1250–1300)– a period of intense southward glacial movement (Grove 2001)– also brought pan-European "precipitation seesaws" (Bauch et al. 2020), which preceded excessive AD 1315–1321 rains, flooding, and freezing, appropriately named the Dantean Anomaly after *Inferno's* 9th circle of Hell (Bauch et al. 2020). Studying these climate epochs– and how specific events deviated from defined average conditions– contextualizes MFEH events and potentially informs ecological motivations for the marine turn. These defined climate epochs, along with archival material and the scope of published literature, identify AD 900–1540 for inquiry– beginning with the 10th century and ending with the well-documented AD 1540 pan-European megadrought (Cook et al. 2015).

1.2 *Research Questions, Aims, and Thesis*

AD 900–1540 Central Europe– as defined by hunger stones– frequently suffered drought, saw spreading Christian influence, and coincides with archaeologically recorded MFEH patterns. These factors define the region as appropriate for study. To begin addressing the ecological gap purported in *Cod and Herring* (2016), this research examines Central Europe, considering the following questions: In what ways did frequent AD 900–1540 Central European droughts impact freshwater fish and the humans who consumed them? What evidence can suggest that drought potentially inspired food substitution, especially Christian substitution for fish? How can drought events be cross-examined with the existing body of MFEH work; related medieval archaeology; and contemporary cultural, economic, and technological developments to assess its effects and suggest human responses to them?

Answering these questions requires a multipartite research approach. Human-environment interactions are intricate, and foodways are both bio-ecologically and culturally driven. Drought– a widespread and interconnected multi-level, multi-sector disaster (Wilhite 2000)– wholly permeates the human experience. Therefore, research must build a dynamic body of scientific and humanistic evidence to reflect these intricacies and accurately consider historic conditions and potential human motivations. After reviewing prior published MFEH theories, this research cites climatological reconstructions and archival accounts; ecological hydrodynamics; archaeological, ichthyological, osteological, and economic analyses; and contemporary documents and development histories to:

1) Understand pathways of drought harm in a medieval Central European context and chronicle drought effects
2) Assess drought's relationship to anthropogenic hardships detailed in prior-published studies using archival and reconstructive hydrodynamic evidence
3) Assess drought's impacts on public health, freshwater fish, agriculture, livestock, and industry, retrodicting drought effects using archival, agricultural, zoological, and reconstructive hydrodynamic evidence
4) Weigh the effects of potential drought-induced losses by consulting medieval dietary reconstructions to support the MFEH as food substitution

5) Compile archivally recorded and reconstructed droughts in the study area– using hydrodynamic, agricultural, and zoological studies to retrodict the effects of unrecorded droughts– and chronicle any foodway disruptions they caused
6) Compare these droughts and disruptions to osteological evidence to assess population-level stress during drought-impacted times
7) Compare droughts and foodway disruptions to ichthyological evidence and *Terminus Post Quem* (*TPQ*) dates of marine fishing and inland aquaculture developments to prove that droughts impacted periods of marine influx
8) Compare local droughts and foodway disruptions to the dates when cities joined the Hanseatic League to benefit from supply-and-protect pacts and marine fish monopolies
9) Compare droughts and foodway disruptions to Hanseatic Cog shipwreck data and development, which evidences increased marine industry and more extensive seafaring

Combining this evidence supports this thesis' argument that: drought impacts on freshwater fish, terrestrial agriculture, livestock, riverine industry, the medieval economy, and public health potentially inspired the MFEH as hardship-accommodating food substitution. Continual droughts exacerbated existing ecological hardships and acted as independent socio-ecological stressors, therefore proliferating MFEH developments and Hanseatic affiliation that subsequently economically advantageous. Secondarily, this thesis examines aquaculture as accommodation and exposes the pitfalls of epoch-length climate and cultural generalization, chronicling deviations from MCA and LIA norms and emphasizing the need for site and time-specific analysis of multidisciplinary material in human-environment analyses.

Critically evaluating the MFEH as a multi-causal product of many non-isolable cultural, temporal, and geographic conditions expounds its lasting impact on gastronomic, economic, and seafaring cultures. Drought also inevitably recurs in all climate regions, and many climatologists consider it the most complex and statistically harmful climate hazard (Wilhite 2000). Droughts– modified by temperature, length, severity, and humidity– comprehensively permeate the lived human, plant, and animal experience. As droughts progress through meteorological, hydrological, agricultural, and socio-economic phases (Pfister et al. 2006;

Bauch et al. 2020; Schreiner-McGraw and Ajami 2021), their effects mount and leave ecologies increasingly vulnerable. Studying historic droughts and human accommodation is critical as we enter an era of “global boiling” (UN News 2023:1). Summer 2023 brought “remarkable,” “unprecedented,” and “record-shattering” global heat spells, exacerbated by volatile precipitation patterns (UN News 2023:1). Though over 1,000 years have passed since the MFEH began, we remain susceptible to ecological variability. While approximately half of the fish consumed today are farmed (World Economic Forum 2023) and therefore relatively protected against drought and natural volatility, drought still interferes with most social, habitual, and economic sectors. As the world’s rivers and lakes more frequently drop to historic lows, we must question the future of aquatic industry. Studying human responses to historic drought ecologies implores us to understand historic afflictions in a modern, industrial context.

1.3 *Geographic and Temporal Scope Limitations*

Fundamentally, the MFEH represents an overarching pattern of change across Europe. This paper is data-driven and uses Barrett et al’s (2004) work as a heuristic to cross-examine drought with the archaeological and historical patterns defined as the MFEH. However, understanding the MFEH as a single “event” is difficult, given its geographic and temporal span. Individuals living in what this paper defines as Central Europe were not homogeneous, and their identities shifted between AD 900–1540– especially as trade, political relations, crusades, and expansion increased interaction. Marine fishing timelines varied across the region, and, though national identities were emerging, most modern state delineations had not been made. Much of the study area is united by archaeological patterns, trade, and Christianity, but recognizing disparate political, technological, linguistic, and cultural identities contextualizes individual MFEH and human-environment interaction timelines. The subsequent analysis mitigates these issues by recognizing individual MFEH, expansion, and industrial developments, relating development to droughts and events that impacted them at specific times.

10th–16th century Central Europe consisted mainly of sovereign and semi-sovereign principalities united under dynastic monarchies and their appointed vassals. To the North, gradually unifying Germanic Vikings ruled Sweden, Norway, and Denmark independently until the AD 1397 Kalmar Union (Jóhannesson 2013), which united Scandinavia. The Christian Holy Roman Empire (AD 800–1806) accounted for the largest Central European land mass and represented the most studied areas (modern Germany, Austria, Belgium, Luxembourg, the Netherlands, Czech Republic, Switzerland, Liechtenstein, Italy, and parts of France, Denmark, and Poland). The early Holy Roman Empire consisted of five post-Carolingian duchies (Saxony, Bavaria, Franconia, Swabia, and Lotharingia), but gained territory from the neighboring sovereign Polish, French, Burgundian, Bohemian, and Hungarian Kingdoms over time and through religious crusades to spread Catholicism. Czech Bohemia– Moravia's successor after Magyar occupation– joined the Holy Roman Empire as a sovereign vassal in AD 1002, as did Burgundy in AD 1033, Austria in AD 1156, Silesia in AD 1335, Luxembourg in AD 1443, and the Baltic coastal kingdoms of Westphalia and Pomerania in the early 12th century. The first Crusade took place in AD 1095 (Andrea 2003), 12th–13th century crusades enforced Christianity in already Christian-Pagan Scandinavia and Livonia (modern Estonia and Latvia), the Teutonic Order achieved political and militaristic power, and dynastic rulers spread their political influence across multiple states. The Polish, French, Prussian, and Lithuanian Kingdoms remained sovereign, Poland and Lithuania repelled 13th century Mongol invasions and became the joint Polish-Lithuanian Union in AD 1385, and Flanders became a prominent French territory. Hungary, the Slavic states, Serbian Zeta, and Bulgaria changed hands between sovereign and Byzantine rule, and Bulgaria and Hungary fell to the Ottomans in the 15th century. All the while, populations grew, despite sustaining mass 14th century plague casualties, suffering famine, and inter-duchy warfare.

As territories clashed, languages, religion, commerce, and technology evolved. People in the region increasingly practiced sedentary agriculture and plowing as they settled more cities, and saw an influx of Silk Road commodities in the 13th century. Feudalism structured social classes, and Latin– also a commercial and political lingua franca– reached the masses through sermons. Circulating writings increased literacy rates, especially when printing press technology diffused in the 15th century. While many elites spoke Latin, individuals in the AD 900–1540 study area also spoke Germanic, Franco-Germanic, French, Norse, and Old Slavic, Romanian and Bulgarian emerged in the 9th century, and Polish, Danish, and Bohemian Czech evolved between the 10th–12th centuries. The fully Christianized state is ideological but practically impossible (Petts 2011), and medieval Jews, present since the 5th century, persisted in the Holy Roman Empire, Lithuania, Livonia, and medieval Ukraine, significantly contributing to medicine, astrology, mathematics, and the arts (Roth 2003). Jews suffered pogroms and crusades (Walsham 2014), but often earned protection for maintaining important societal roles. Middle Eastern crusades introduced Islam and Arab culture to the region through enslavement and trade.

While the scope of this thesis is to compare drought and climatological factors with published MFEH ichthyological patterns, trade development, and osteological data, and to extend analysis to shipwrecks, future work should more closely examine the MFEH in relation to political, military, and human diaspora events.

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2 Methods

Open-source and institutionally accessible journals and archives provided the cited research material. Research included dendrological and paleosol climate reconstructions offering Self-calibrating Palmer Drought Severity (scPDSI) and Standard Precipitation (SPI) indices Lamb 1965; Helama et al. 2009, Büntgen et al. 2011; Glaser and Kahle 2020). The greatest contribution to this study came from the Old World Drought Atlas (OWDA) (Cook et al. 2015), a collection of scPDSI-coded maps from the Summer months of AD 0–2012, compiled from samples across Europe. These maps evidence droughts unrecorded in archives. Archival materials– many of which came from the Tambora.org historic climate database– and hunger stones integrated to identify, corroborate, and qualify historic drought and social change, filling gaps left by reconstructive modeling alone (Pribyl 2020). Reconstructed and archived medieval droughts are compiled in Appendix A, and hydrological, zoological, and agricultural data informed retrodictions of drought harm. Archivally supported foodway disruptions are recorded and aligned with droughts to demonstrate significant biological stress in Appendix B. Known dates of Hanseatic affiliation are similarly compiled in Appendix C. Open-source and institutionally provided dietary constructions that employed δ13C and δ15N isotope, osteological bone collagen, parasitic fecal matter, archaeobotanical, zooarchaeological and archival analyses are compiled in Appendix D. Dietary reconstructions inform harm retrodictions of drought crop and livestock losses. Osteological studies aligned with medieval drought and foodway disruption to evidence biological stress– compiled in Appendix E– also came from open-access and institutionally provided literature, as did the ichthyological evidence and development patterns compared with drought and foodway disruption in Appendices F, G, and H, and the cog shipwreck analyses and Hanseatic chronologies compiled and compared in Appendix I.

2.1 *Environmental Determinism and Religious and Cultural Motives*

It is important to acknowledge the potential influence of environmental determinism in human-environment interaction studies. Environmental determinism (Ratzel 1896), a concept coined in an era of rigidly structural and deterministic anthropology, is a pseudo-biologistic oversimplification of complex human behavior. Though first proposed in a laudable, albeit idealistic, effort to unite anthropology and geography (Peet 1985; Alexander 1999), environmental determinism reductively purports that human development, culture, activity, and even temperament (Semple 1911:620), is directly controlled by geographic location, climate, and the environment (Lewthwaite 1966).

While the environment impacts and “sets the frame or thresholds within which human groups exist” (Arponen et al. 2019:4), human adaptation is not steadfastly confinable by simple cause and effect. Cultural complexities make distinguishing extrinsic and intrinsic motivations for behavior nearly impossible (Coombes and Barber 2005). Ecological factors do not delineate specific cultural behaviors, and humans should be understood as agentive co-constituents in human-climate relations. At best, even the most responsible causal determinism selectively and incompletely explains reality, and is therefore not deterministic enough, or, incompletely deterministic (Stanton 2004; Arponen et al. 2019).

Religious doctrine alone confounds purely biologistic and causal MFEH explanations– only culture, not scientific law, explains Christian fasting regulations. For these reasons, analysis should suggest that people in the study area “adjusted” behaviors (Hoffmann 1996) within the parameters of their worldviews, subtly eliminating notions of cause and effect. Offering drought as a limiter of established freshwater fishing, agriculture, livestock, and industry that created enough biological and economic stress to feasibly *inspire* human change, rather than a determinant variable that *forced* adaptation, maintains human agency and eliminates incomplete analysis.

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3 Fish Event Theories and Drought

The following section recounts the prior published explanations for the MFEH: cropland clearing, industrialization, damming and fish trapping, and urbanization. Section 3 also adds polder construction to harm narratives, chronicles the MFEH, assesses pathways of drought harm on fish, people, industry, and agriculture, and assesses how drought exacerbated existing pressures.

The Human Products of Expansion and Cropland Clearing

To produce grain and wine cropland on watershed soils, settlers cleared and flattened natural terrain. Clearing land, however, destroys advanced root systems that trap moisture and anchor soil, and increases erosive and runoff potential (Barrett 2016; Hoffmann 1995; 1996; 2023a; 2023c; Zhang et al. 2021). Runoff from Central Europe's cleared lands over-introduced sediment and silt into waterways, smothering aquatic organisms and their eggs, increasing turbidity, and reducing the light penetration required by oxygenating photosynthesizing aquatic vegetation (Hoffmann 1995; 2004). Increased runoff also promotes inland and water source flooding, which similarly destroys crops, fish, and fish eggs. Central European land clearing peaked in the 12th century and, for example, the Rhine, Elbe, and Weser Rivers supported scattered settlements in AD 1000, but humans heavily populated and cleared both of each river's banks by AD 1300 (Zhang et al. 2021).

Furthermore, encroaching humans polluted waterways with excrement and urine, and inland pollutants washed into water with increased runoff. Settlers also left slaughtered animal waste, blood, and carcasses to dissolve in lifegiving waterways. Cesspit-like freshwater sources teemed with bacteria and dense algal growth and incubated waterborne illnesses (Hoffmann 1996). Algal growth inundated aquatic fish and plant environments, limited sunlight penetration, and made water deadly to humans and their livestock.

Industrial Milling and Artisanal Production

To process more raw agricultural, construction, and commodity materials, Central Europeans supplemented wind, human, and animal-powered milling with constantly turning water mills and ship mills (boat mills, floating mills). Water mills– Greco-Roman and Byzantine diffusions– peaked between AD 1150–1250 with population increase (Nützmann et al. 2011), and crushed, ground, spun, pulped, sawed, or hammered a wide variety of materials (Table 1). Water mills served Berlin and Brandenburg by AD 988 and appeared on nearly every tributary of Germany's Spree River by AD 1275 (Lucas 2005; 2006; Nützmann et al. 2011), successfully diffused throughout all of Central Europe in the 13th–14th century, and "By the close of the Middle Ages watermills were in use on streams of every type" (Reynolds 1983:69). Ship mills (Figure 8, 9), which rose and fell with rivers in high velocity flow stretches to increase production and save valuable bank space, expanded to Switzerland and France throughout the 6th century and populated the Rhine and Main Rivers during the early 9th century (de Decker 2011). By the end of the middle ages, the Rhine housed over 500 boat mills, Vienna and Budapest housed 62 and 88 respectively, the Mur housed over 90, and boat milling emerged in the Czech Lands, Croatia, Serbia, Bulgaria, and Romania (de Decker 2011).

Table 1 (From Lucas 2006: Appendix A)

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While hydraulic milling directly contributed to Europe's industrial revolution (Lucas 2005), water and boat mills impeded river traffic, disrupted fish migrations and spawning site access, polluted waterways, and altered hydrodynamics. Detritus from processing grains, coal, pigment, heavy metals (iron, lead), and even opium polluted waterways, inspired smothering eutrophication, altered homeostatic pH levels, and circulated toxins (Hoffmann 2004; 2023a; de Decker 2010; Lenders et al. 2016; Camenisch and Rohr 2018). Furthermore, mill backups diverted waterways into new, shallow streams and lakes (Reynolds 1983), reduced hydraulic flow speeds, and created more relatively still water. Slowed water drops floating solids, allowing gravel, silt, and alluvium to accumulate on river and stream beds, smothering eggs and inhibiting passage (Hoffmann 1996). Stagnant water absorbs more solar energy, which increases water temperatures, improves conditions for eutrophication, and overheats temperature-sensitive fish (Barrett 1996; Hoffmann 1996). Warm water, especially when already contaminated, is also a ready petri dish for Plague, Dysentery, Polio, Cholera, and Typhoid, and houses transmissive insect larvae. Ship mills, occasionally "carried away– sometimes with the people still inside– and smashed into boats, docks, bridges or other ship mills" (de Decker 2010), decomposed rapidly, and spread milling detritus over larger areas. Rotting mill wood and materials inspired quickly spreading algal and bacterial growth and larval infestations.

Figure removed due to copyright restriction

Figure 8: An AD 1531 depiction of Cologne's conjoined ship mills by German Painter Anton Woensam (From: de Decker 2011)

Lead, smelted for medieval jewelry, weaponry, utensils, roofing, gutters, pottery glaze, paint, and even food and medicine, released plumes of neurotoxic particles into the atmosphere, sediments, and waterways. Raw coal, coal dust and ash, and charcoal altered waterway pH, posed carcinogenic risks, introduced harmful trace heavy metals, and turned water into toxic sludge. Contemporaries across the Low Countries and Central Europe blamed fish deaths and pollution on ore and coal processing effluents (Hoffmann 2004), and harmful concentrations of toxic heavy metal can still be detected across Europe (Hoffmann 2004) and in the sediments of the Belgian and Dutch Meuse River watershed (Rang and Shouten 1989). Ice core samples dating from AD 1170–1220 from the Swiss-Italian Alps also evidence extensive atmospheric lead, isotopically linked to Central Europe (Loveluck et al. 2020). Medieval heavy metals in the Belgian and Dutch Scheldt River basin are still detectable in today's Scheldt eels (Van Neer et al. 2009).

Wet-decomposing or retting flax and hemp for textile production similarly inundated waterways by releasing quickly molding fibers and bacteria, and is recorded as a significant historic stressor (Lenders et al. 2016). Dyeing fabric required adding mordant aluminum sulfate to pigment baths to prevent colors from running, and discarded mixtures polluted waterways, altered pH balance, and poisoned fish, animals, and humans (Ardila-Leal et al. 2021).

To make leather, tanners trimmed hides of excess fat and sinew, discarded detritus into water sources, and soaked hides in caustic lime baths to remove hair and flesh. Tanning produced noxious ammonia gas, which settles in water to produce caustic ammonium hydroxide, and tanners routinely dumped bath solutions into waterways (van Neer et al. 2009). Tawing solutions– mixtures of flour, salt, aluminum sulfate, egg yolk, and human urine– catalyzed chemical reactions and often ended up similarly discarded (Hoffmann 2023a). Contemporary Europeans blamed tanning, tawing, and industrial pollution for massive fish die offs. Colcestrian brewers, fishermen, and general consumers remarked in AD 1425 that leather tanning and tawing caused "impayring and corrupcion" of the River Colne, and brought "destruction of the ffysche therynne" (Hoffmann 2023a:191). Similar reports exist throughout Belgium, Germany, and Poland (Van Neer et al. 2009, 2016; Andreska and Hanel 2015; Barrett 2016; Häberle et al. 2016; Lenders et al. 2016; Van Neer and Ervynck 2016; Lenders 2017; Wouters et al. 2021; De Cupere et al. 2021; Hoffmann 2023a).

Figure 9: Medieval Rhenish ship mills and fishermen; a detail from the AD 1411 painting (artist unknown) Martyrdom of St. Ursula before the City of Cologne, currently housed at the Wallraf–Richartz Museum, Cologne, Germany

Dams

Dams regulated water levels and limited physically denser and impotable seawater intrusion at estuaries during low pluvials, and conveniently enclosed densely packed resource pools of fish. European brook and headwater damming is first evidenced in 8th century records, and the oldest dams that served Berlin and Brandenburg, Germany date to AD 1000-1100 (Nützmann et al. 2011). Dams impeded river passage, inhibited spawning ground access, and, like mills, created more stagnant water and waterway backups. A Rhineland abbot, for example, stated in AD 1470 that a new dam on a Rhine tributary made so "neither salmon nor [other] fish [could] go up" (Hoffmann 1996:642).

Weirs and Fish Traps

Fish traps, gates, weirs, and sluice boxes became ubiquitous throughout medieval Europe by the 11th–12th centuries when Christian and growing population demand for fish exceeded what small-scale rod and net operations could provide (Lampen 1996; Hoffmann 2004; Nützmann et al. 2011). Weirs primarily served medieval monastic communities (Lampen 1996; Andreska and Hanel 2015) that sold their surplus at market. Additional gear, like the Czech *slup* sluice trap, first reported to have been built in AD 1043 in Cosmas' 12th century Chronica Boemorum, directly trapped fish in boxes for easy harvesting (Andreska and Hanel 2015). Fish weirs appear explicitly in the German written record in AD 1187 and, along the lower Havel River through the Holy Roman Empire, "there must have been an incredible number of fish weirs in the Middle Ages, totaling about 200–400 at the end of the 14th century" (Nützmann et al. 2011:46). Weir fishermen overfished waterways and, like mills and dams, weirs diverted rivers and blocked fish passage to spawning grounds to prevent recovery.

Polders

First constructed by 10th century Frisian settlers in what is now the Netherlands, polders (Figure 10)– reclaimed plots of submerged land– supplemented quickly diminishing land acreage (Koohafkan; 2010; Lenders 2017; Zhang et al. 2021). To construct a polder, skilled workers built dikes around a desired area and pumped the water within further out to sea, into nearby rivers or streams, or into navigable channels between polder plots (Terra Scientifica Explained 2023).

Figure removed due to copyright restriction

Figure 10: Dutch Polders (Photo by Frans Lemmens 2022)

Once drained and desalinated (Goeldner-Gianella 2007; Terra Scientifica Explained 2023), polder land became arable field space for cropping, livestock storage, or city expansion. Dutch poldering increased in the 11th century, and today the Netherlands is 60% polder land. 12th century Germans called on Dutch and Flemish dike builders to help polderize the North Sea coast and Oder and Elbe wetlands (Zhang et al. 2021), and polderization spread throughout northern Europe, Germany, Slovenia, Poland, and Lithuania in the 13th–14th century.

Poldering, however, pumped inundating sediments, other nutrients, and frequently salinated water into freshwater sources, once again smothering fish and chemically altering aquatic ecologies. Inland lake and river poldering also diverted waterways and created more stagnant, slow-flowing water, and polder use introduced natural and livestock waste. Polderization has been widely confirmed to greatly reduce local fish stocks (Goeldner-Gianella 2007).

Collectively, human industry and encroachment directly blocked fish passage and made navigable waters uninhabitable with excess sediment, pollution, and eutrophication. Even after returning to sea, anadromous and amphidromous salmon and sturgeon likely suffered, since spawn environments determine their long-term viability (Hoffmann 1996). With additional overfishing, fish stocks declined. Medieval eutrophication is evidenced by archaeobotanical analysis from Konstanz, Germany, where period samples revealed a disappearance of clean water plants and showed almost exclusively filamentous algae remains (Hoffmann 1996). Records report poor fish quality and yields in AD 1210 southern Central Europe and Germany's Dhünn River in AD 1470 (Hoffmann 2004). Scheldt River catfish became extinct in the early 14th century and in the Meuse River in the 15th century (van Neer et al. 2009; Häberle et al. 2016), and Central European salmon and sturgeon declined to near extinction from the 10th–14th centuries (van Neer et al. 2009). The Dutch noted polderization's negative impacts on fish as early as AD 1000 (Lenders 2017).

Fish prices rose as stocks declined (Hoffmann 1996; 2023b), and common Christians struggled to meet their dietary requirements. MFEH theories propose that Europeans in need of steady fish turned to the sea. Europeans also sought to mitigate anthropogenic harm by imposing riparian laws, privatizing waterways, setting fish size and yield limits, defining fishing seasons, removing weirs, and fitting dams with openings to allow access to spawning grounds (Hoffman 1996; 2023b). Instruments like the Austrian *Prittlmas* (Figure 11), which measured the gauges of seasonally controlled and size-confined nets (Dowling and Keyser 2020), became tools of the trade, and widely circulated posters and documents displaying catch size regulations became unambiguous law (Figure 12, 13). Appointed governing bodies (sometimes led by officials like the Austrian *Vischmeister*, or "Fish Master") policed public adherence to regulations, and slow stock recovery followed. Even still, the Elbe River's salmon, the majority of which perished in the 14th century, did not show signs of population recovery for nearly 200 years (Andreska and Hanel 2015).

Figure 11: The Austrian *Prittlmas* (Photo by R. Hoffmann with permission from the Mondsee Museum, Mondsee, Austria, From: Dowling and Keyser 2020:137)

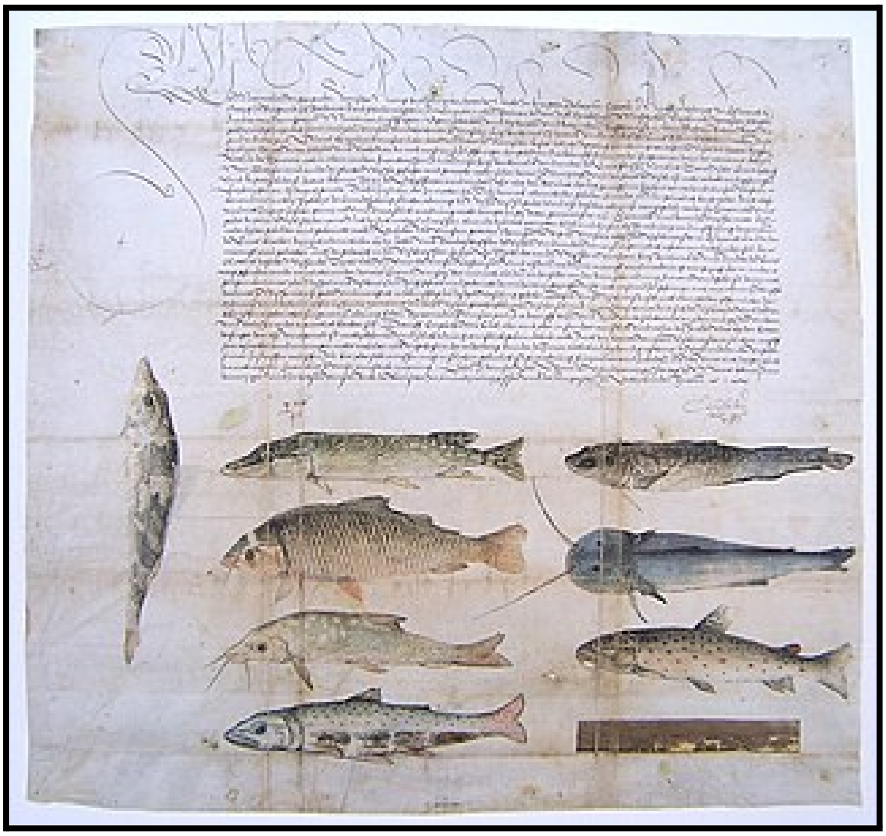
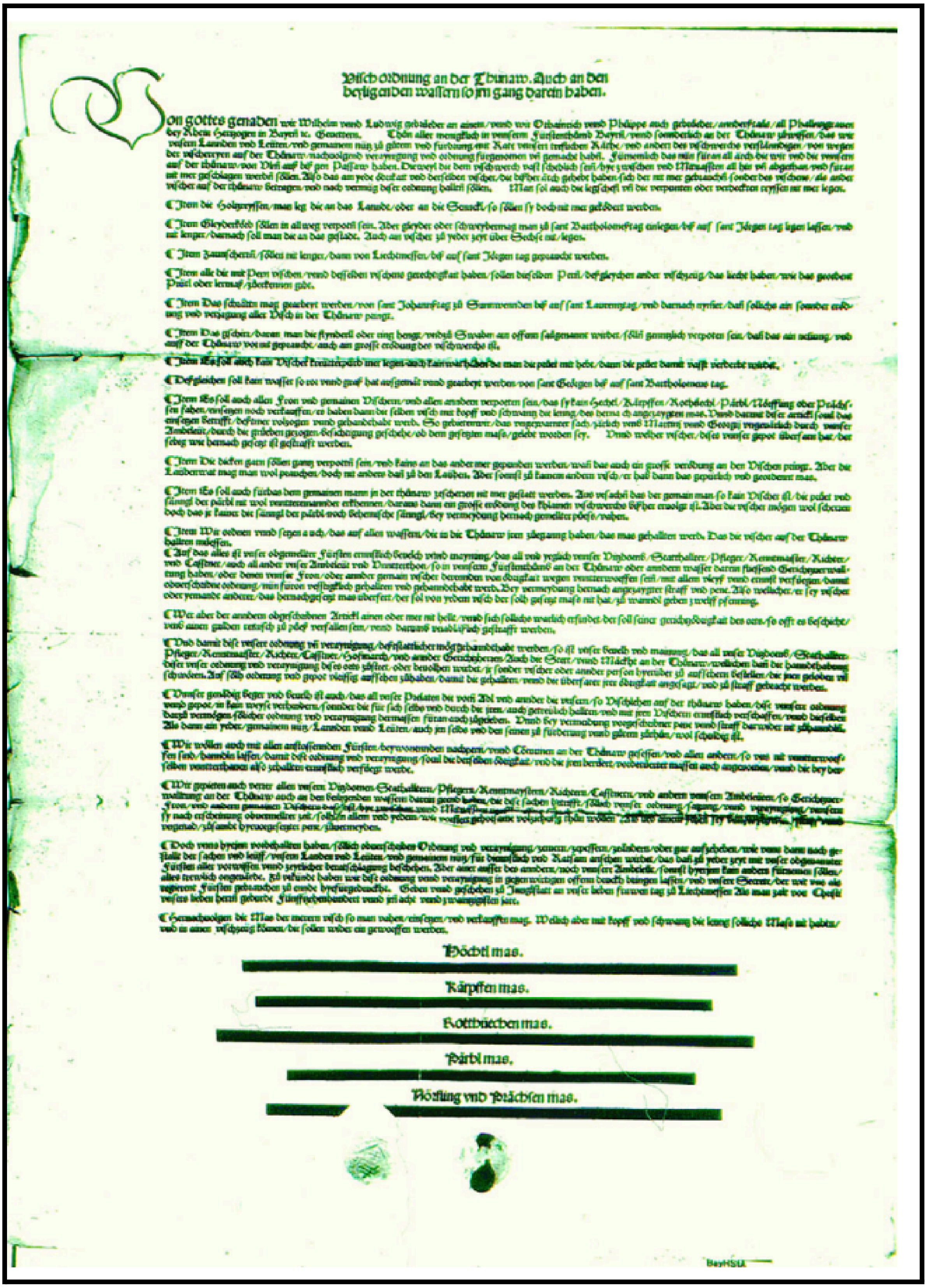


Figure 12: Emperor Maximilian's Patent (1506) regulating pike, carp, barbel, huchen, burbot, catfish, trout, and Zingel, size requirements, and a *Prittlmas* in the bottom right corner (From Hoffmann 2023b:257)


Vischordnung an der Thunaw. Auch an den beyligenden wassern so jm gang darein haben.

Höchtl mas.

Kärpffen mas.

Rottbüechen mas.

Pärbl mas.

Nösling vnd Prächsen mas.

Figure 13: A large-format fisheries ordinance for Bavarian waters (AD 1528). The black bars at the bottom of the page display fish length requirements (From Hoffmann 2023b:258)

3.1 Marine Fish Turns, Hanseatic Trade, and Aquaculture

To combat anthropogenic freshwater fish declines and increasing demand, some 10th–12th century Central Europeans traded trout, bullhead, pike, roach, bream, rudd, and eel between inland areas. Swiss, Serbian, Polish, and Czech merchants (Makowiecki 2001; Häberle and Hüster Plogmann 2019; Živaljević, et al. 2019; Kyselý et al. 2022) dealt fish from isolated and unpolluted waterways to areas with suffering stocks, allowing waterway and population recovery and diversifying markets and gastronomic preferences. Merchants used mobile water tanks to transport live fish, and traded lightly preserved fish up to 250 km away (Kyselý et al. 2022). Swedes and Hungarians also commenced an interior dried pike *strekfuss* trade (Hoffmann 2001; Barrett 2016). Simultaneously, coastal Baltic and North Sea subsistence fisheries active since the Mesolithic (Orton et al. 2011; Barrett 2016; Hufthammer 2016) began trading their fresh and processed surplus inland, bringing marine fish to mainlanders for the first time (Hoffmann 2004). With the exception of advanced 8th–9th century processed cod and herring trade from offshore to inland Viking territories in Poland, Norway, and Germany (Enghoff 1996; Makowiecki 2001; Halffman and Velemínský 2015; Barrett 2016; Makowiecki et al. 2016; Star et al. 2017; Atmore et al. 2022; Kyselý et al. 2022), Central Europe's MFEH began with small-scale, local trade (Barrett et al. 2011). Baltic fisheries targeted bountiful herring, and northern localities tapped cod stocks to process and transport locally over land or by river to markets. Consequently, Polish, Livonian, Flemish, German, Danish, Austrian, Swiss, and Czech diets included herring from nearby shores by AD 1000 (Hoffmann 2001; Lõugas 2001; 2016; Häberle and Hüster Plogmann 2019; Wouters et al. 2021).

Documents first confirm Czech-Polish herring trade in AD 1119–1125 via existing Oder River routes (Kaupová Drtikolová et al. 2019; Kyselý et al. 2022), and Austrians sailed the Danube for Baltic fish (Galick et al. 2015). Archaeologists recovered traded 11th century herring at the Swiss Altenburg Castle (Häberle and Hüster Plogmann 2019), traded and local herring at the Danish island of Bornholm (Lõugas 2001; Holm 2016) and Iru Hillfort, Viljandi, Vaabina, Viltina, Poïde, and Tartu in Livonia, (Lõugas 2001), and Flemish traders declared herring "necessity for a person to live on" (Tambora) by AD 1200. Polish herring trade intensified in the 13th century (Makowiecki et al 2016), and excavations at Piast Dynasty Grzybowo, Wolin, Wrocław, Santok, Ujście, Poznań, Kruszwica, Kołobrzeg-Budzistowo, Szczecin, Dziekanowice, and Kałdus recovered 9th–12th century herring that represented ~90% of all samples (Hoffmann 2001; Makowiecki 2001). In the AD 1159 *Life of Otto* written about a Pomeranian missionary, Gallus Anonymous recorded that Duke Bolesław Krzywousty sieged Kołobrzeg to acquire fresh fish, not “salted and stinking” fish that sufficed for their forebearers (Sparrow-Simpson and Lowther Clark 1920: Maioweicki et al. 2016). Anonymous’ account intimates interior herring trade to Lesser Poland and French trade relations. Kołobrzeg grew to supply herring to feudal Poland, the Holy Roman Empire, Russia, the Czech Lands, and Ukraine (Makowiecki 2001). 12th century Austrian and Silesian traders also sourced fish from Pomerania via the Oder River (Hoffmann 2001). Baltic Herring traded from Kraków reached Hungary, Lithuania (Piličiauskienė and Blaževičius 2019), and Serbian Zeta in the AD 1300s (Galik et al. 2015; Živaljević et al. 2019). European herring trade grew exponentially throughout the middle ages, surpassed only by grain and textile markets (Holm 2016).

Fueled by continual demand and anthropo-ecological pressure (Lotze 2007), and perhaps inspired by Vikings and those who benefitted from contact with them, industry expanded throughout Europe’s northern waters. In the 12th–13th centuries, prolific fisheries (Figure 16) emerged in modern Germany at Lübeck (Danish from AD 1201–1226 but an Imperial Holy Roman Empire State as of AD 1226) and the Baltic Island of Rügen (Dutch from AD 1168–1325 and Pomeranian from AD 1325–1648); in Norway at Bergen, Finnmark, Troms, Nordland, Bohuslän, and Vágar (or Lofoten) in the Faroe Islands; at Skanör-Falsterbo in Scanian Denmark; at Visby on the Swedish Øresund Strait Island of Gotland); and throughout most of Iceland (Gardiner and Mehler 2007). Northern fisheries targeted cod and other *Gadidae*, and resource pools expanded as European traders partnered with Scandinavian markets by about AD 1100 when local trade reached a surplus (Hufthammer 2016). Fishermen yielded more fish, which they traded in processed (smoked, dried, pickled, cured, salted) form to the interior via existing and developing trade routes. Dried stockfish cod (Figure 14), decapitated in processing, became a prolific international export. Therefore, in addition to isotopic provenancing to non-local areas, a paucity of cranial bones in assemblages also suggests that fish arrived as traded stockfish (Barrett et al. 2011). Traders, however, pickled and prepared herring whole, or only removed gills, innards, cleithra, and gullets (Hoffmann 2004; Barrett 2016; Holm 2016).

Figure 14: Stockfish (From: https://dryfish.no/products/stockfish-of-cod-in-50-kg-bales)

Norway consolidated cod at Bergen and Trondheim transhipment ports to trade to Holy Roman Empire, Westphalian, and Flemish merchants via the Baltic Coast and Rhine by AD 1100 (Nedkvitne 2016). An AD 1103–1107 royal tax to Vágar is the first record of its market (Nielssen 2016), and by AD 1300 stockfish constituted approximately 80% of Norwegian commerce (Hufthammer 2016). Once unified, Iceland provided an additional 750,000–1,200,000 stockfish yearly (Küchelmann 2019). Saxo Grammaticus wrote in AD 1200 that herring density in the Scanian sound made it difficult to row a boat (Holm 2016), and Scanian cod and herring reached German and Danish shores by the 12th century (Barrett 2016).

As northern European fisheries developed throughout the 12th–13th centuries, independent trade guilds, or *Hansa*, formed throughout the western Baltic. *Hansa* secured trade privileges throughout the region and abroad, establishing *kontor* camps as far as the Novgorod Republic of northern Russia. In AD 1241, salt-rich Hamburg and the Herring-rich port city of Lübeck formed an alliance along the "salt road," which provided materials for herring processing and facilitated salt distribution to northern fisheries. Their alliance formed the budding Hanseatic League (Sahrhage, D. and J. Lundbeck 1992; Van de Noort 2011), which came to include between 70–200 new and pre-existing cities across seven northern European countries at any given time (Sarnowsky 2015) (Figure 17, 18). Each city provided a specialty good (beeswax, furs, timber, resin, tar, cloth, flax, honey, wheat, rye, metals, salt, beer, cattle, and sulfur), and committed to protecting mutual trade interests.

Hanseatic traders increasingly targeted cod after earning rights to productive northern fishing grounds (Figure 16)– Lübeck's traders first sourced Norwegian waters in AD 1278, and

Hanseatic fish trade peaked in the 14th century after absorbing the Scanian and Øresund Strait fisheries and earning exclusive rights in Norway and Iceland in AD 1343 and 1361, respectively (Figure 15) (Gardiner and Nehler 2007). Fisheries thrived in the Hanseatic system, generated unprecedented financial and resource wealth, and created a European processed fish trade monopoly until the Dutch overtook the Hansa in the 16th century. While herring industries boomed, northern cod entered Hanseatic cities– and others affiliated with them– *en masse* for the first time. More formalized laws, companies, and relations promoted better record keeping, which today supplements the zooarchaeological and artifact record. Marine fish trade and consumption increased even during periods of mass Plague death and amid rumors that "bad air" from fish caused disease (Holm 2016, Wickler 2016), and dates of Hanseatic affiliation provide sure *Terminus Ante Quem* (*TAQ*) for marine fish entry into Central European countries when not otherwise documented.

Germans of the Holy Roman Empire first saw Hanseatic cod in AD 1250 (Barrett 2016), and Icelandic stocks reached Germany by AD 1310 (Hoffmann 2001). Bohemian Hanseatic cod import is first evidenced by an AD 1325 customs tariff from Pirna to Magdeburg and Děčín, and in Kolín by an AD 1371 record, and followed pre-existing routes through the Holy Roman Empire (Kyselý et al. 2022). Archaeological excavations recovered cod in Hungary dating to ~ AD 1400 (Galik et al. 2015). Cod arrived in Poland with Hanseatic affiliation, and only n = 4 cod appeared in 9th–12th century Polish excavations, but are represented in all excavated 13th–16th century sites (Orton et al. 2011). Excavations in Austria on the Hungarian border also produced 14th century Cod (Kyselý et al. 2022), and mid-14th century Austrian cookbooks and tax ledgers mention cod (Hoffmann 2001; Galik et al. 2015). Swiss records confirm cod trade by at least AD 1435 (Häberle and Plogmann 2019), excavations revealed 14th century Cod in Livonian Riga (Yeh et al. 2014; Brown et al. 2017), and Dutch traders sourced Bergen's cod in the late 14th–15th century (Barrett 2016). Very few Lithuanian cod remains have been found, but their presence on elite tables is archivally documented (Piličiauskienė and Blaževičius 2019).

Fish trade and Hanseatic affiliation offered an "economic parachute" in times of frequent instability (Barrett 2016:262; Küchelmann 2019), and granted Christians an alternative fish solution. By the late 14th century, Hanseatic fisheries produced over 300,000 herring barrels for trade (Holm 2016), over 17,000 Hansa men worked the Scanian seas by AD 1400, and the German fishing fleet burgeoned from only 40 vessels in the 12th century to over 2,400 on the

Island of Heligoland alone in AD 1520 (Lotze 2007). The promise of sure economic and commodity access during hardship may have inspired Hanseatic affiliation, and even non-Hansa traders interacted with Hanseatic merchants to spread marine fish throughout the remainder of the continent.

Figure removed due to copyright restriction

Figure 15: A 16th century illustration of stockfish piles, tents, and factories on the Icelandic coast by Swedish writer and Cartographer Olaus Magnus (From Gardiner and Nehler 2007:404)

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Figure 16: Medieval fisheries by taxonomic access and target species (From Hoffmann 2001:146)

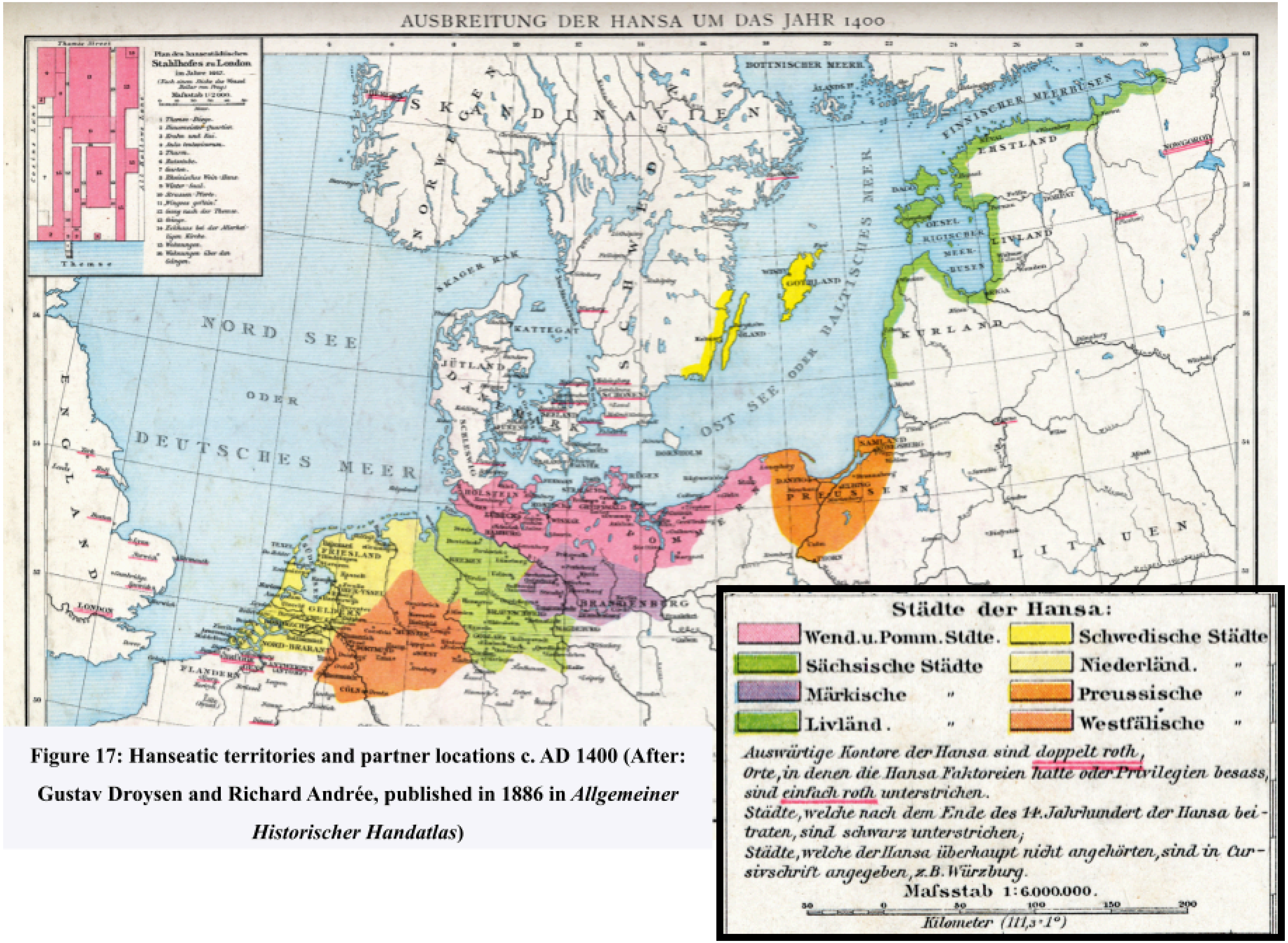

Figure 17: Hanseatic territories and partner locations c. AD 1400 (After: Gustav Droysen and Richard Andrée, published in 1886 in *Allgemeiner Historischer Handatlas*)

Figure 17 Cont.: Translation of map key (translated by the author from the original German), and highlighted territories

Wend.u.Pomme.Stadte = Pomeranian cities	Schwedische Städte = Swedish States
Sächsische Städte = Saxon Cities	Niederländ = The Netherlands
Märkische = District in eastern Brandenburg, Germany	Preussische = Prussia
Livländ = Livonia	Westfälische = Westphalia

Key Caption

Foreign offices of the Hansa are underlined in double red, places in which the Hansa had factories or had privileges are underlined in single red. Cities that joined the Hansa after the end of the 14th century are underlined in black; Cities that did not belong to the Hansa at all are indicated in cursive script, e.g. Würzburg

Single red underlined cities/regions (Hanseatic factories present or distinct privileges)

Stockholm, Warberg, Pskow, Kowno, Helsingborg, Helsingord, Kopenhagen, Schonen, Roskilde, Skanör (Scania), Malmö, Falsterbo, Svendborg, Flensborg, Ardenburg, Antwerpen, Gent, Damme, Ypern, Dinant, Ipswitch, Norwich, Yarmouth, Lynn, Boston, Hull, York

Double red underlined cities (Foreign Hanseatic offices)

Bergen, Novgorod, Brügge (Brussels), London

Black underlined cities (Joined Hanseatic League after the 14th century)

Breslau, Guben, Frankfurt, Krakow

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To supplement marine fish and to control waterway disruption, Central Europeans in Germany, the Czech Lands, Austria, Flanders, Lithuania, Hungary, Serbia, and Poland proliferated inland aquaculture (Hoffmann 2023c). Beginning in the 11th century and peaking in the 12th–14th centuries, those with the necessary means– often monastic populations– diverted waterways up to 35 km (Hoffmann 2001) into natural topographic depressions and intermittent wetlands to create fish storage and breeding ditches and ponds. Combating waterway privatization, aquaculturists stocked ponds with roach, pike, bream, bass, trench, eel, and non-indigenous carp. Fish ponds manipulated biological cycles (Hoffmann 2001) to make fish available on a human schedule (Hoffmann 2023c), and provided subsistence yields and surplus for local and distant market trade. Aquaculturists flooded hundreds of hectares, and, by the early AD 1370s, citizens in southern Bohemia described much of their land as "drowned by the pond" (Hoffmann 2023c:301). One Czech man stated in AD 1508 that "what was left after wars, fires, and plague is now mostly inundated by ponds" (Hoffmann 2023c:302). While rising freshwater fish prices– foiled by an influx of cheap marine fish– impacted the common man, wealthy and clerical fish farmers maintained a preference for fresh, locally sourced freshwater fish. Aquaculturists produced carp en masse by AD 1300 (Hoffmann 2004), and today's "'wild'" Central European carp are "feral descendants of domesticates" (Hoffmann 2023c:310).

Ponds at the German-Czech Holy Roman Empire frontier appeared in AD 1220, but may have existed earlier (Hoffmann 1995), and Czech Lords commissioned 87 new ponds between AD 1347–1418 (Hoffmann 1995; Drtikolová Kaupová et al. 2019; Piličiauskienė and Blaževičius 2019; Bartosiewicz 2021). Hungarians constructed between 3,000–4,000 fish ponds between the 11th–13th centuries, alone (Galik et al. 2015), Austrian nobles constructed ponds in AD 1227 (Federal Ministry of the Republic of Austria: Agriculture, Forestry, Regions and Water Management (n.d.)), Poles constructed ponds by AD 1300 (Hoffmann 1995), and Flemish aquaculturists constructed ponds by AD 1350 (Wouters et al. 2021). Serbian monks in Zeta and Estonians and Latvians in Livonia constructed ponds by the 13th century (Živaljević et al. 2019), and Lithuanians constructed monastic and city ponds in the 14th and 15th centuries (Hoffmann 1995; 2023c; Bonow et al. 2016). Collectively, the aquaculturists built 25,000 ponds in Bohemia, 22,000 in upper Franconia, and 25,000 hectares of man made ponds in upper Silesia between the 13th–15th centuries (Hoffmann 2023c).

Ponds, however could not house anadromous and amphidromous fish, and diverting water from natural freshwater and spawn-migrating fish habitats proved harmful. Diversions– for ponds and other aquatic infrastructure like moats (Hoffmann 1995)– disrupted natural fish pathways and spawning areas, and diminished natural water sources. Decreasing water levels thereby increased present pollutant concentrations, left waterways more susceptible to drying in heat or drought events, and created more easily contaminated still water. Some advanced ponds could also be drained back into their sources for easy fish harvesting or to accommodate livestock (Hoffmann 2023c), and draining carried oppressive rocks, silt, and dirt with it. Aquaculture aided a small subset of medieval individuals and greatly harmed natural fish ecologies, exacerbating the problem it attempted to solve.

The above outlined conditions– anthropogenic and industrial pollution from urban expansion, increased runoff from land clearing, polderization, the adverse effects of aquaculture, and growing demand from hungry, expanding, and Christianizing populations– are proven stressors to medieval fish and human populations. These sociocultural factors are accepted as inspiration for the European MFEH and inland aquaculture. However, scholars appreciate that hardship accommodation is frequently multi-causal. While previous work has examined the MFEH through a sociocultural lens, environmental variables doubtlessly impacted human and animal ecologies. The following sections explain drought's immediate and proximal harm to freshwater fish, crops, livestock, and human populations and foodways, and outline the likelihood that drought exacerbated already declining anthropogenically tainted ecologies and inspired the MFEH as foodway substitution.

3.2 Social, Biological, and Climatic Drought Effects

The following subsection places scientific and historical drought literature in a medieval Central European context. Drought's far-reaching effects, which create and are augmented by coterminous social conditions, immediately and proximally antagonize freshwater fish and humans. Highlighting drought dynamics theoretically supports drought as an exacerbating and catalytic factor in already declining medieval ecologies, and further reveals its role as an MFEH-inspiring stressor.

Drought, “a negative deviation of water balance from the climatological normal over a given area” (Brádzil et al. 2013:1985), progresses through meteorological, hydrological, agricultural, and socio-economic distinctions. Meteorological drought– a “lack of precipitation,” including snow, “over a large area and for an extensive period of time” (Pfister et al. 2006:967)– may immediately impact water source levels but, when combined with increased heat, evaporation, solar phenomena, wind, or low humidity, depletes groundwater sources (Kiss 2020). Groundwater deficiencies may deplete wells or aquifers, streams, rivers, lakes, and reservoirs, and characterize hydrological drought (Pfister et al. 2006; Bauch et al. 2020; Schreiner-McGraw and Ajami 2021). Both meteorological and hydrological drought impact crop yields and vegetation (Glaser and Kahle 2000), but agricultural drought begins when soil moisture is insufficient to support any crop growth (Pfister et al. 2006; Kiss 2020), leaving landscapes susceptible to increased erosion, landslides, and quickly spreading fires (Wetter et al. 2014; Labbé 2018; Camenish et al. 2020; Bauch et al. 2020; Pribyl 2020). Not all crops react equally to dry or wet conditions, but long term hydrological drought and extremely dry groundwater conditions are detrimental to European subsistence flora (Bauch et al. 2020; Tserendorj et al. 2021). Low water levels and crop failures impact livestock and animal husbandry success, decrease or contaminate drinking water, create stagnant water, and heighten concentrations of waste and pollutants, among other factors (Bauch et al. 2020; Pribyl 2020). Dramatic turns in food and water availability, public health, and ecological stress, made worse by lowered water levels that potentially cut off trade and travel or halt aquatic industrial procedures, create a heightened demand for vital sustenance and commercial goods. Finally, when the demand for crops or other goods exceeds available supply, drought escalates to the socio-economic level (Wetter et al. 2014; Kiss 2020).

Medieval Central European records recount water shortages, diminished large rivers, fish deaths, algal blooms, larva and insect infestations, forest fires, visible heat stress on vegetation, crop failure, soil cracking and dryness, dust, landslides, and heightened wind erosion (Hoffmann 1996; Glaser and Kahle 2020). Low water levels halted water mills, terminated shipping, trade, and riverine passage, and subsequently limited supplies during periods of increasing demand. In turn, drought inspired early or mass livestock slaughter to satisfy an unattainable nutritional need, or because dry conditions failed to sustain livestock farming and husbandry. Drought is directly linked to famine, heat deaths, mortality, and epidemics borne from stagnant water like Cholera, Dysentery, Typhoid, and Polio, all of which are exacerbated by contributing ecological and social variables (Pfister et al. 2006;

Glaser and Kahle 2020). Documents report economic inflation and social unrest following agricultural disasters (Glaser and Kahle 2020), supplications, processions, protests, pilgrimages, religious pleas (Kyselý et al. 2022), begging, migration, looting, robbery, murder, coping, speculation, rallied resilience, and social excess (Glaser and Kahle 2020). Timestamped records of social unrest allow historians to reconstruct drought severity as a proxy to social sentiments. These same social and ecological conditions are also understood as inspiration for hunger stone carving in commemoration of hardship and to cope. Together, drought's non-isolable, mounting, and uniquely pervasive effects can be taken as inspiration for food substitution, and aligning drought events with ichthyological, osteological, and documentary MFEH evidence illuminates their role in the marine turn. Specific reconstructions of drought harm pathways better illuminate potential stress conditions.

Drought and Waterway Dynamics

Prolonged drought has an immediate effect on both still and moving waterway bathymetry, total volume, and flow rate, and river, stream, and lake volume can drop in as little as a few weeks of precipitation deficit (U.S. Geological Survey (n.d.)). Heat enhances evaporation, and still water more readily absorbs heat than dynamic, running water (Center for Climate and Energy Solutions). Therefore, still water levels diminish more quickly than those of rivers. Given this, artificial fish ponds, despite being highly controlled, remained particularly susceptible to drought, especially when source waters dropped. Reconstructing drought harm to still ponds refutes claims that, in some areas with prolific supplemental aquaculture, limited inland fish availability proved negligible (Dyer 1988; Van Neer et al. 2009; Van Neer and Ervynck 2016).

In hydrological drought, decreasing ground, aquifer, and surface waters inherently impact drinking water access. Though full hydrological drought occurs after approximately two years of precipitation deficit, and the largest aquifers may remain viable for up to 15 years (Schreiner-McGraw and Ajami 2021), the average aquifer's level diminishes in as little as two weeks, and wells tapping water tables dry even more quickly. Full or multi-season drought certainly brought these consequences. Digging more or deepening extant wells, laying pipes for water transport, or digging river conduits further lowers source levels and speeds their drying in drought and heat events.

Additionally, estuaries are uniquely susceptible to oceanic saltwater intrusion as freshwater evaporates or fails to replenish with precipitation. Saltwater intrusion occurs when physically denser saltwater overwhelms diminishing freshwater levels, pushing the saltwater-freshwater interface inland (U.S. Department of Agriculture; Li et al. 2024). High saline levels may kill salt-sensitive freshwater plants *en mass*– thereby decreasing waterway oxygenation– and fundamentally alter water conditions for floral and faunal ecosystems many kilometers beyond the point of entry. Intruding saltwater may also diffuse into groundwater stocks (Li et al. 2024). Disrupted fresh water access likely distressed public health, cropping, and livestock, and antagonized economic activity– after saltwater intrusion in the Thames in AD 1326, London's Brewers "needed to content themselves with salty ale" (Pribyl 2020:1036). Multifaceted stress, especially in Central Europe's many estuarine cities and towns, may have inspired new subsistence and aid pathways as accommodation.

Drought in Relation to Anthropogenic Waterway Pollutants and Disease

By decreasing net water volume and flow rate, drought exacerbates present anthropogenic and natural (Center for Disease Control 2022) waterway contamination. Diminished water doubtlessly increased the concentrations of pollutive byproducts from urban expansion, milling, industry, and animal slaughter, and made any remaining water toxic, uninhabitable, and impotable (Center for Climate and Energy Solutions; Center for Disease Control). Diminished running water may also become stagnant (Center for Disease Control; Bauch et al. 2020; Pribyl 2020), which facilitates bacterial, mold, and algal eutrophication. Warm, marshy water also invites egg-laying mosquitoes and flies. In England (Pribyl 2020), where conditions paralleled Central Europe, malaria, digestive diseases, polio, plague, cholera, dysentery, and typhoid became endemic during droughts, and dysentery-laden wells ran red with "blood–" likely red algae (Pribyl 2020). For every 1° C MCA increase, droughts occurred more frequently and English and Central European death rates increased by approximately 4% (Pribyl 2020). Further, wildfire smoke caused respiratory distress– potentially fatal for already weakened populations (Center for Climate and Energy Solutions).

Drought as a Biological Stressor for Freshwater Fish

The mounting impacts of lowered water levels, increased water temperature, pollutant concentration increase, and saline intrusion can decimate freshwater fish populations in both the short and long-term (Wilhite 2000; Andreska and Hanel 2015), and drought's lasting effects can inhibit successful population recoveries. Both pulse disturbances– relatively acute or discrete events– and press disturbances– continual or long-term pressures– instigate partial or mass extinction events called fish kills (Figure 19) while decreasing vitality in surviving fish (Schnaser and Mundal 2022). Depending on severity, length, and pre-event conditions, droughts can be both pulse and press stressors.

When water levels drop or run dry, fish overheat, dry, or suffocate for lack of natural and plant-released oxygen in the water. Warmth speeds fish metabolism and respiration, thereby requiring more oxygen, but excessive heat diminishes water oxygenation, and shallow water more readily absorbs heat (Center for Disease Control). Warm water also facilitates algal blooms and eutrophication, which can smother fish, source oxygen at levels detrimental to fish, and increase water turbidity. As low water levels reduce flow volume and speed, phytoplankton thrive in heating, stagnant rivers, streams, and lakes, and total dissolved solids can more than double even in short droughts (Mosley 2015; Li et al. 2017; Yan et al. 2023). Turbid water clogs fish gills, and inhibits vision, hunting, and egg security. Pollutive agents and surface runoff also increase turbidity, smothering and poisoning fish. Toxic effects mount when concentrated in shallow water.

Furthermore, saline intrusion can impact both exclusively freshwater and migratory fish populations. Even non-estuarine bodies may become salinated by dissolving solids, which also increase water acidity (Mosley 2015; Li et al. 2017; Yan et al. 2023). In hypertonic conditions, freshwater fish and eggs cannot achieve cellular homeostasis and die in hours or days (Attrill and Power 2000; Alam et al. 2017; Yan et al. 2023). Combined waterway stressors amplify each others' effects (Matthews and Marsh-Matthews 2003). Explicit documentation of mass fish beaching and drying comes from throughout the study area in the Czech Lands, Silesia, Germany, Poland, Austria, and the Netherlands (Brázdil et al. 2019; Tambora). Furthermore, shallow habitats created by drought concentrate fish into topographically deep areas until "it literally looks like fish in a barrel" (J. Kappelmann in Zimmer 2024). Concentrated populations make easy work for natural predators and humans, and pathogens spread more easily among confined fish.

Fish kills, depending upon their cause, vary in magnitude. Partial kills may go unnoticed, while the largest kills yield virtual local extinctions (Schnaser and Mundal 2022). Population rebound "may take weeks, months, years, or even decades" (Schnaser and Mundal 2022:1180), but fish populations tend to recover and successfully spawn relatively quickly in advantageous natural conditions and without human pressures (Brander 2010; Schnaser and Mundal 2022; Hoffmann 2023d). Modern U.S. and European averages suggest that stocks recover from pulse disturbances in as little as one month, but press disturbances drastically alter environments and delay recovery for 5–52 years (Schnaser and Mundal 2022). These averages, however, reflect modern conditions and understandings of sustainable ecology, pollution, and fisheries management. Today, fish kills are mitigated by artificial fish stocking, but stocking natural rivers and streams likely did not occur in Europe until the 17th century (Conniff 2017). Therefore, natural recovery likely took considerably longer, especially with recurrent droughts, floods and other weather episodes, and pollution or blockage.

Additionally, saline intrusion during freshwater lowstands likely inhibited migratory fish from traveling inland to spawn in freshwater. Chemically altered water may have killed eggs, and diminished waterways may have simply been too low to access, especially if eutrophied and polluted. Central European migratory and freshwater fish also tend to prefer colder waters, and aquatic warming likely presented acute stress to unborn eggs during incubation. Further, dams, mills, and weirs, though regulated at times, blocked many Central European waterways. Recovery success and speed, as well as fish kill likelihood, also rely on general population health, but already challenged fish populations are more vulnerable when water composition changes (Rohr et al. 2021:9).

Fish stress and population decrease is evidenced by consistently smaller bones in assemblages from drought affected years– which may indicate that not all fish grew to maturity or that humans harvested them before maturity–or the decline or absence of fish in assemblages, entirely. Medieval fish kills are noted in the Elbe– one of the most densely populated rivers in Europe (Möller 1989)– and recurring drought pressures combined with consistent natural and anthropogenic pollution, waterway blockage, and demand-induced overfishing, may have been responsible for the river's near salmon extinction in the 14th century. By the time Elbe salmon stocks showed signs of recovery almost 200 years later, artificial river stocking had begun. Documentary evidence of fish kills (recorded in section 4) tends to be proximal, referencing requisite kill conditions rather than explicit events, but some records do mention fish drying. Further documentary and archival research into fish kills presents an avenue for future work. Ichthyological evidence for fish kills is also proximal, and fish that died in rivers without human contact are unlikely to appear in the archaeological record.

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Figure 19: A 2022 Fish kill on the Oder River (Photo by Annegret Hilse/Reuters; from: https://www.pbs.org/newshour/world/amid-severe-drought-in-europe-wildfires-spread-and-fish-die-off)

Drought Impacts on Agriculture, Industry, and Livestock

Fish, while increasingly important to Christianizing European populations, did not constitute the entirety of the diet, nor were they the most important component of it. Discussing drought impacts on other human and animal foodways can reconstruct the food insecurity and hardship that may have inspired MFEH developments and food substitution.

Low pluvials, groundwater and atmospheric humidity depletion, soil and water salination or pollution, and quickly spreading ground fires compromise fruit, nuts, tubers, and leafy greens during and after germination, causing death or low, undesirable yield. Other long-root medieval staples like carrots, walnuts, chestnuts, pistachios, parsnips, beets, radishes, and eggplant (aubergine) have longer root systems that are comparatively more resilient to drought (Gervais et al. 2021), but no European crop thrives in total hydrological drought. Grapes, legumes, millet, and cereal grains– medieval economic and dietary staples are relatively drought resistant, and some modern reconstructions (Bauch et al. 2020) suggest that droughts aided medieval European wine and grain production. However, pulse disturbances still diminish grain and grape yields if crops sprout (Li et al. 2020; Pribyl 2020), and hydrological drought precludes growth and reproduction (Collet and Krämer 2017; Bauch et al. 2020; Li et al. 2020; Pribyl 2020; Wan et al. 2022). Diminished grape yields decimated wine economies, and wine could not be produced without clean water. Wine, consumed by all Europeans regardless of age, often presented a safe alternative to contaminated water, and therefore losses also strained public health. Depleted groundwater–particularly on reclaimed polder land– also allows soils to salinate, becoming a hypertonic mixture unable to sustain most plant life (Shrivastava and Kumar 2015; Alam et al. 2017). High soil salinity decreases crop yields, culls forests, promotes salt-tolerant invasive species growth and eutrophication, and leaves vegetation susceptible to drying (U.S. Department of Agriculture). Scorched earth also welcomed forest fires (Büntgen et al. 2011; Wetter et al. 2014; Labbé 2018; Bauch et al. 2020; Camenisch et al. 2020; Tambora), which destroyed settlements and could easily cross diminished bodies of water or even entire rivers (Bauch et al. 2020). If farmers diverted waterways to bring fresh water, any water available during a drought had the distinct possibility of being polluted, or salinated if in a coastal or estuarine location (Renes et al. 2020). Diversions also further diminished natural waterways, concentrating any pollution.

Furthermore, livestock kept for food, dairy, eggs, and animal power also potentially suffered a lack of water or access to only contaminated water, a lack of grain and grass for feed, and other proximal stressors like heat or fire. Where possible in Central Europe, farmers satiated herds with food substitutes like seaweed (Buckley et al. 2023), however many slaughtered their herds early when they could not be sustained (Jilkova et al. 2019). Corrupted herd health also disrupts dairy production and husbandry, and medieval accounts confirm production hardship. Given that meat and animal products were “never absent from medieval European diets” (Hoffmann 2001:137)– except for during Christian fasts– losing vital animal resources along with agricultural yield suggests a devastating fallout.

Famine conditions almost invariably occurred throughout medieval Europe during consecutive harvest failures or long-term press perturbations like muti-season drought or flooding (Collet and Krämer 2017; Labbé 2018; Bauch et al. 2020), and economic, political, or military factors often exacerbate droughts (Collet and Krämer 2017). Therefore, documented famines and foodway disruptions during the MFEH that align with known and reconstructed droughts bolster evidence for the MFEH as a response to drought-induced food insecurity and distress.

Furthermore, droughts frequently halted or stunted yields from the river and ship mills upon which medieval Central Europeans relied (Tambora). The inability to produce flour presented tremendous biological and economic stress, and mills also contributed other social and economic staples. Mill failures caused commodity inflation (Pfister et al. 2006), which occasionally instigated socioeconomic drought (Rieman et al. 2014). Low rivers also froze more quickly or became impassable by ships (Kiss 2020), thereby cutting off trade routes and aid for struggling principalities (Hoffmann 2001; Bauch et al. 2020). Rhenish documents recount that traders had to off-load the majority of their goods to avoid wrecking on typically submerged rocks (Pfister et al. 2006). The hunger stones and archival accounts of fully dried rivers, arrested milling, and rivers passable by foot or horseback constitute a record of ship and trade inaccessibility and adverse fish ecologies. Droughts presented medieval Central Europeans with a catch-22 where grapes, barley, rye, millet, livestock, and alcohol– often the safest beverage– could not be produced, nor could they be imported. Areas close enough to engage in overland trade likely also suffered the same large-scale droughts, and any traded livestock could not thrive on arrival to a drought-impacted area. Production and trade difficulties may be taken as inspiration for food substitution by way of the MFEH, and potentially for Hanseatic affiliation.

Overall, reconstructing the pathways of ecological, foodway, and economic drought harm in a medieval Central European context illuminates the potential conditions during droughts not recorded or memorialized on hunger stones. Recounting these pathways of harm allows for more complete reconstruction of drought ecologies and lived human experiences in long, short, and multi-season events, which may inform accommodative motivations.

Assessing Drought Impacts on Foodways Through Medieval Dietary Reconstructions

Site-specific archival, zooarchaeological, chemical, parasitological, archaeobotanical, and osteological studies representing multiple population conditions and classes reveal an average pre- and early-MFEH medieval Central European diet reliant upon staple crop and animal components that suffer greatly in droughts and rely heavily on milling. Osteology bolsters the written record, which typically "under-represents daily lives of individuals outside elite classes" (Reitsema et al. 2010:1413). Understanding the whole diet and the relative caloric contributions of its components illuminates the potential and archivally recorded fallout of their loss, and informs accommodative actions and more broadly contextualizes the MFEH.

Generally, medieval Europeans consumed most of their calories from cereal grains– primarily millet– in porridges, beer, and bread, and the average 10th–16th century per capita grain consumption exceeded 300 liters per year (Hoffmann 2001; 2004; Nedkvitne 2016). Medieval Europeans routinely ate cheese, eggs, milk, legumes, berries, apples, pears, figs, and quinces, C_3 and C_4 vegetables like potatoes, cauliflower, cabbage, lettuce, brussels sprouts, eggplants (aubergines), carrots, and other tubers (Hoffmann 2001; 2004). Though grain and grapes are semi-drought resilient, yields suffer in any drought and crops fail in press-disturbance hydrological drought. Central Europeans invariably consumed most of their protein from meat, and urbanites ate primarily domestic pigs and cattle (Jilková et al. 2019). Those in the hinterlands continued subsistence hunting, and meat consumption varied highly across gender and economic status. Meat outweighed freshwater fish in reconstructions, and freshwater fish contributions varied across the region, but most Central Europeans supplemented protein intake with locally sourced river, stream, and lake fish before the MFEH. Fish, however, gained importance when St. Benedict's Rule forbade quadruped (and, in some interpretations, poultry) consumption for ~150–182 fast days per year (Hoffmann 2004), rendering them one of few permitted protein sources. Even when St. Benedict's Rule excepted the "weak and sick" (1931)– probably including those suffering from dietary, plague, or waterborne illnesses– from fasting, drought still contraindicated livestock keeping even in the unlikely event that devout, albeit suffering, Europeans desired to break fasts. Freshwater fish accounted for 1–2% of calories consumed at most studied sites, but Christian doctrine amplified their losses for much of the year. After the MFEH, fish grew to supply, on average, 3–5% of calories consumed in Europe (Hoffmann 2004), which exceeds contributions in some caloric breakdowns today.

Appendix D compiles dietary reconstructions of individuals from Czech (Halffman and Velemínský 2015; Kaupová Drtiklová et al. 2018; Jílková et al. 2019; Kaupová Drtiklová et al. 2019), Polish (Reitsema et al. 2010; 2017; Błaszczyk et al. 2021; Brown 2022), German (Hakenbeck et al. 2010; Halfmann and Velemínský 2015; Knipper et al. 2015; Olsen et al. 2016; Küchelmann 2019; Tserendorj et al. 2021), Dutch (McManus et al. 2013; Schats et al. 2022), Hungarian (Gugora et al. 2021; Faragó et al. 2022), Austrian (Herold 2008), Serbian (Borojević 2005; Smuk and Sad 2021), Belgian (Spros et al. 2022), Latvian (Yeh et al. 2014;

Brown et al. 2017; Pētersone-Gordina et al. 2022; 2023), and Croatian sites. Individuals sourced the same resources, but meat consumption and grain preference socially and economically varied. While no dietary reconstructions are published on medieval Slovenia, Switzerland, Romania, Liechtenstein, Luxembourg, Lithuania, Bulgaria, Belarus, or Estonia, climates there supported many of the same resources.

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4 Identified Drought Events

As a comprehensive ecological, human, fish, and foodway stressor, drought must be considered as an inspiration for the MFEH resource revolution. Establishing the mounting and interconnected pathways of drought harm informs condition retrodictions when not explicitly stated in documentary sources. Compiling drought occurrences places drought in conversation with MFEH events and other supporting evidence.

The 10th–16th centuries in Central Europe, which include the MCA (AD 950–1250) and LIA (AD 1300–1850) climate epochs, brought “Epic droughts” (Jones et al. 1999)– confirmed by soil, dendrological, and archival studies (Cook et al. 2015)– that occurred more frequently and for longer durations than in recent centuries. AD 1100–1250 solar maxima (Helama et al. 2009) enhanced frequent Spring and Summer MCA droughts that deviated from the “optimal” reconstructed norm (Proctor et al. 2002; Pfister 2006). As a composite, MCA Central Europe endured a severe precipitation deficit frequently yielding fewer than 60 mm of precipitation per year (Figure 20). Consistently negative scPDSI value reconstructions (Table 2) evidence century-long megadroughts that impacted the majority of the continent. Between AD 1000–1200, North-Central Europe experienced a reconstructed scPDSI mean of -0.72 ± 0.10 (Cook et al. 2015), with many years demonstrating moderate to extreme dryness. Additional recurrent drought occurred between the hotter MCA and colder, wetter LIA during the early AD 1300s, including the “once-in-a-century” AD 1302–1307 drought (ScienceDaily), actually proven longer by scPDSI reconstructions (Helama et al. 2009; Hoffmann 2023d).

Frequent LIA heat and dry spells (Dobrovolny et al. 2015; Camenisch and Rohr 2018) also deviated from epoch averages (Grove 2001). Combined with droughts, these conditions brought a 400-year agricultural regression and frequent public health challenges (Pfister 2006; Pfister et al. 2006; Wetter et al. 2015; Zhang et al. 2021). scPDSI reconstructions reveal multi-year LIA droughts like the stretch between AD 1360–1362 (ScienceDaily), and a 15th century megadrought lasting for thirty-seven years from AD 1437–1473 with an average scPDSI of -1.84 ± 0.20 and only two isolated years of positive wetness (Cook et al. 2015).

Table 2: scPDSI Value Key (After: Palmer 1965; van der Schrier et al. 2013)

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scPDSI (and map color code progression)	Event Class
≥ 4.0	Extremely Wet
3.0 – 4.0	Severely Wet
2.0 –3.0	Moderately Wet
1.0 – 2.0	Slightly Wet
0.5 – 1.0	Incipient Wet Spell
-0.5 – 0.5	Near Normal
-0.5 – -1.0	Incipient Dry Spell
-1.0 – -2.0	Slightly Dry
-2.0 – -3.0	Moderately Dry
-3.0 – -4.0	Severely Dry
≤ -4.0	Extremely Dry

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Figure 20: AD 1000–12000 scPDSI map, with much of Europe reading below -4.0 (From Cook et al. 2015:4)

Though extreme MCA and LIA variance is apparent and published, wet and dry extremes offset as antipodes (Figure 21) to yield a relatively medial average. Averages define a general climate event and highlight the limiting potential of epoch-long studies without event-specific analyses. Accepting epoch averages potentially kept drought from prior analyses, as did the rhetorical implications of cold and optimality associated with the LIA and MCA. Drought's mounting and "creeping" (Böhret 1990) nature may have also prevented contemporaries from detecting it until damage caught the eye, thus making event terminals hard to decipher or record (Wilhite 2000), and contemporaries may have actually welcomed droughts after semi-frequent floods (Tannehill 1947). Further, today drought is a statistically exceptional event (Benestad 2003), but medieval conditions varied. Shedding modern worldviews to embrace a multipartite methodology of scientific, archaeological, and archival analysis accounts for gaps in inherently imperfect reconstructions. Reconstructive confirmation decreases exponentially in pre-documentation events, however, per Figure 20, Central European droughts project to have been more severe than in England where researchers first identified MFEH patterns.

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Figure 21: MCA and LIA scPDSI values showing a red line of best fit revealing recurrent 10th–16th century Central European droughts. Reconstructive offset extremes are indicated in blue (After: Cook et al. 2015:4)

Archivally documented, hunger stone evidenced, and reconstructed multi-area and country-wide Central European drought events between AD 900–1540 are listed in Appendix A**.** Summers with mean scPDSI values of -2.0 and below potentially brought all outlined ecological, agricultural, and public health pathways of drought harm, including the drying of rivers and increase of riverine pollutants (Cook et al. 2015). Spring-Summer droughts also coincide with fish spawning season, significantly impacting populations.

Appendix A lists 541 years (≥ 84.5% of the studied time period) between AD 900–1540 during which at least one studied area in Central Europe experienced sustained drought conditions. The earliest droughts are taken as initial MFEH inspiration since, by the time marine fisheries expanded significantly, ocean fishing and trade became profitable even in times of plenty. Subsequent droughts, however, likely inspired continual fishing and industry development. 68 Central European Summer droughts are recorded in the 10th century, 85 are recorded in the 11th, 87 are recorded in the 12th, 85 are recorded in the 13th, 85 are recorded in the 14th, 95 are recorded in the 15th, and 36 are recorded between AD 1500–1540.

Dried inland water, wells, and aquifers; river boat impassibility or enabled foot traffic; mill stoppages; or the full-thickness freezing of diminished rivers are explicitly mentioned in: AD 1000, 1022, 1032, 1073, 1087, 1088 1135, 1153, 1170, 1171, 1172, 1177, 1178, 1194, 1198, 1234, 1302, 1303, 1304, 1305, 1306, 1312, 1332, 1337, 1407, 1413, 1442, 1446, 1448, 1472, 1474, 1479, and 1534 in Germany; AD 1073 in Switzerland; AD 1137 in Belgium; AD 1393 in Prague; for all major rivers in AD 1076–1077 and 1540; AD 1455 for the Oder River; AD 1458 in Latvia; AD 1460 in Estonia; and in AD 1473 in Hungary (Tambora). Hunger stones can be found in the Elbe River in Pirna (AD 1155) and Děčín (AD 1417, 1473), and two more hunger stones dating to AD 1461 and the mid-15th century have been lost to the elements (Odbratt 2023). Hunger stones mark instances of drought severe enough to have altered natural water volumes, and scPDSI values lower than those corresponding with hunger stones likely represent similar conditions. A drought-induced fish kill is recorded in Ottobeuren in AD 1083, others are recorded in AD 1442–1443 Dortmund, AD 1473 Göttingen, and in AD 1516–1518 and 1540 throughout Europe (Tambora). More fish kills likely occurred when water levels dropped and pollutant concentrations increased in extremely low scPDSI reconstructed droughts. In AD 1442 Dortmund, when the Ruhr, Hesse, Ems, and Else ran dry, locals reported fish as "*venk*," which loosely translates to "kaput" (Tambora). The River Vltava in the Czech Lands ran "green as grass" and "stinking" in AD 1393 and 1482, and likely failed to support fish life and spawning (Brádzil et al. 2013). Diminished Autumn, Spring, and Summer River Tisza sturgeon yields are explicitly recorded in the Eger diocese in AD 1506–1507, and have been linked to pervasive drought in Hungary, Romania, Serbia, and the Czech Lands (Kiss 2020). AD 1506 also inspired Emperor Maximilian's Patent for better *Vischmeister* regulation of the Danube and mandatory *Prittlmas* usage (Figure 10). The great Hungarian droughts of AD 1362, 1474, 1479, 1494 and 1507 are even stated to have weakened the country's military defense, further demonstrating drought's manifold impacts (Kiss and Nikolić 2015).

Cold and wetness during the Dantean Anomaly (AD 1315–1321) also induced famine over Northwestern Europe (Bauch et al. 2020; ScienceDaily), but the OWDA (Cook et al. 2015) reconstructs regional Summer dryness in AD 1318, 1319, and 1320. Detrimental Summer droughts followed harsh Autumn and Winter rains (Figure 22). Since the Dantean Anomaly intersperses frequent drought, it is noted as a potential source of hardship in subsequent ichthyological, osteological, and documentary analyses. Further research should more closely examine floods and wet events.

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Figure 22: A late 14th century illumination from *Divina Commedia, Inferno*, Canto VI: The Gluttons (Oxford, Bodleian Library, MS. Holkham misc. 48 9r; from: https://www.historicalclimatology.com/projects/-the-dantean-anomaly-project-tracking-rapid-climate-change-in-late-medieval-europe)

4.1 Osteological and Documentary Markers of Biological Drought Stress

Most medieval Central Europeans experienced at least one drought in their lifetimes. Drought hardships are potentially visible as skeletal pathologies in the burials of those impacted by them. As indicators of biological stress, pathologies may proximally evidence motives for foodway substitution. While skeletal pathologies are often multi-etiological (Appleby 1980; Rivera and Mirazón Lahr 2017; Yaussy and DeWitte 2018; Drtikolová Kaupová et al. 2020;

Simpson 2020), remains geo-temporally aligned with drought events, especially those archivally associated with food insecurity, may evidence drought-induced pressures. Environmental, biological, and socio-economic variables present a matrix of potential skeletal stressors acting simultaneously to preclude one-factor explanations. However, drought connects otherwise indistinguishable morbidities. Buttressing interpretations with documentary contributions also thwarts pure confirmation bias (Simpson 2020).

Further, a single drought year may diminish yields, but does not necessarily constitute a famine (Engler 2012), and skeletal remains alone cannot definitively identify famine or population-level starvation (Simpson 2020). However, all multi-month food shortages cause detectable skeletal osteopathies and nutrient deficiencies on the population level (Marklein et al. 2016; Brzobohatá et al. 2019), and even a single low-yield year can inspire human environmental adaptation, given the Osteological Paradox of mounting pressure and predisposition (Obertová and Thurzo 2008; Curtis et al. 2017; Krenz-Niedbała 2017; Brzobohatá et al. 2019; Jilková et al. 2019). Urban life also tended to have significant negative health impacts (Betsinger and Dewitte 2017; Jilková et al. 2019; Pribyl 2020), further ambiguating interpretations. Floods and excessive pluvials are also recorded as medieval foodway stressors and, since wet hardships cannot be distinguished from droughts in skeletal material, must also be considered. Wet events therefore present an avenue for future work.

Documentation of medieval public health crises during droughts comes mostly from England, but scPDSI reconstructed conditions throughout the study area corroborate or surpass most mentioned English droughts (Cook et al. 2015). In general, periods of drought align with steeped mortality rates, famine, malaria, water-borne gastrointestinal disease, and plague. The English experienced, on average, 10 years of ecologically induced famine per century (Yaussy and DeWitte 2018), which yielded mortality peaks in AD 1236, 1288, 1300, and 1328, caused “fever” or “ague” outbreaks in AD 1222, 1242, 1252, 1285, 1305, 1464, 1473, and 1540, and malaria and gastrointestinal disease outbreaks in AD 1252 and 1446 (Pribyl 2020). English famines and mass burials are recorded in AD 1155–1165, 1235–1255, 1401, 1416, 1434, 1439, 1440, 1486, 1491, 1497, and 1521 (Yaussy and DeWitte 2018). Similarly, analyses from Bernau, Germany demonstrate severely increased mortality from the beginning of the 13th century to the turn of the 16th (Faber et al. 2003), and Czech mass graves are recorded in AD 1282 and 1318 (Brzobohatá et al. 2019; Ljunqvist et al. 2024; Tambora).

Drought also frequently occurred during the Black Death years beginning in AD 1346, especially in Northern Europe.

Appendix B compiles archivally recorded famines and foodway disruptions in medieval Central Europe, which are compared with osteological material and expound MFEH-era food insecurity. Cross-referencing Appendix B with twelve osteological studies spanning the MCA, LIA, and Dantean Anomaly reveals steeped pathological frequencies of linear enamel hypoplasia (LEH), Harris lines, cribra orbitalia, cribra femoris, cribra humerus, osteoarthritis, rickets, hyperostosis, extra bone growth, maxillary sinusitis, scurvy, compensatory muscle attachments, carious lesions, and aberrant δ15N and δ13C levels (Heaton et al. 1986; Horocholyn and Brickley 2017; Faragó et al. 2020; Walter 2020). Samples exclude clerical figures with different nutritional access and eating habits (Miszkiewicz et al. 2019), and represent commoners who purportedly observed Christian fasts and consumed the average diet. These human afflictions evidence the heightened biological stress that drought caused, and suggest the coterminous MFEH as an accommodative turn to the ocean.

For example, N = 117 individuals buried in 68 graves in the 12th–14th century Vinča-Belo Brdo cemetery on the right bank of the Serbian Danube potentially represent at least 163 Summer drought events. f = 79.5% of individuals displayed skeletal pathologies indicating nutritional deficit and anemic stress, including osteoarthritis, dental caries, cribra orbitalia, cribra femoris and humeral cribra, LEH, extra bone growth, and compensatory muscle attachment. LEH appeared in every (f = 100%) individual, cribra orbitalia appeared in 12 (f = 10.3%), and cribra femoris and humeral cribra appeared in N = 21 (f = 17.9%) and N = 2 (f = 1.7%) individuals, respectively (Nikolić et al. 2021). Another proximal 12th–14th century Serbian necropolis excavation (Marković and Jovanović 2019) sampled N = 50 skulls, f = 85% of which showed cribra orbitalia, and f = 75% of which displayed LEH. All frequencies sit above the regional average.

A Czech study (Obertová and Thurzo 2008) examined N = 451 8th–12th century individuals buried in Borovce, which represent known foodway disruptions in AD 1121, 1124, and 1176–1177, and likely earlier famine events between AD 900–1200, and 238 Summer drought events. More than 40% of the studied individuals died before the age of 20, and cribra orbitalia and dental lesions showed significant affinity to early mortality and low life expectancy. f = 48.8% of all individuals displayed cribra orbitalia, with the most affected age categories between 10–14 (f = 85.7%), 5–9 (f = 83.3%), and 0–4 year olds (f = 71.7%). LEH appeared in f = 27.2% of individuals, and 10–14 year olds once again displayed the most LEH (f = 44.4%) and lesions (f = 52.9%). f = 11.2% of all individuals with at least one intact orbit showed both cribra orbitalia and LEH or lesions, and f = 28.6% of 10–14 years olds displayed both anomalies.

Additional analyses of drought and hunger impacted Polish, Czech, and Danish burials are listed in Appendix E, and corroborate extensive population-level drought stress, interpreted as partial inspiration for the MFEH.

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5 Plenty of Fish in the Sea: Ichthyological Evidence and Drought

Comparing ichthyological patterns, archival accounts, the date ranges of archivally confirmed marine fish introductions, and specific ichthyological assemblages with drought and foodway disruption, proves that marine fish– the majority of which must have been traded– appeared in Central European diets during times of drought and associated hardship. Comparison also reveals that both drought and marine influxes align with freshwater fish population declines and size reduction– indicating stress and harvesting before maturity. While freshwater fish declined semi-asynchronously across the study area, both marine fish entry and freshwater fish declines invariably occurred in periods frequently impacted by drought. Less populated and rural regions apparently maintained freshwater stocks for longer periods of time, potentially given lower levels of pollution, lower populations, or less access to urban marine trade centers. However, fish remains in rural sites still demonstrate size reduction in drought-impacted assemblages, and droughts still affected cropping and other foodways.

The referenced ichthyological assemblages represent both population-level (i.e. streets, markets, community latrines) and individual samples (i.e. cesspits, houses), and include evidence from all social statuses. Diachronic single-location studies with strata dated to distinct time periods most apparently demonstrate change, however comparison of taxon concentrations between proximal sites can still be useful. The most dynamic data is published as quantified matrices, but some studies present only processed data in graph and chart form. Data published as absolute percentages is helpful to assess trends, but interpretations are limited without knowledge of the initial sample size. Interpretations are further limited since many studies do not analyze freshwater and marine fish in relation to each other, focusing rather on dietary reconstructions or the influx of marine samples, alone. Furthermore, Barrett (2016:250) notes that MFEH materials are “based on only a tiny and biased sample of what was initially consigned to the earth and that many aspects of fishing (including most activities conducted at sea) will not have entered the ground in the first place.” Only more recently has wet and dry sieving, as opposed to hand-collection, been implemented to recover more and smaller easily deteriorating fatty and cartilaginous bones. Researchers identified bones visually, genomically, or by stable isotope and trace element measurements, and dated bones contextually or by radio-carbon sampling. Marine origins are generally indicated by increased δ13C (+ ~8%) and δ15N levels relative to freshwater fish in bone collagen and tissue (Olsen

2023; Halffman and Velemínský 2015; Jilkováet al. 2019; Drtikolová Kaupová et al. 2019), and stable isotopes can provenance samples (Barrett et al. 2011).

General patterns from sources without quantified data matrices offer that cod consumption increased from minuscule to predominant in Sweden and Poland from the 9th–14th centuries (Orton et al. 2011). AD 900–1400 Poland saw at least 357 Summer droughts, and foodway disruptions in AD 1076–1077, 1262–1264, 1268, 1270–1271, 1281–1282, and 1315–1321. Sturgeon also declined dramatically in 10th–13th century Sweden and Poland, (Makowiecki 2001– Figure 58), over the MCA and LIA in Austria and Hungary (Galik et al. 2015), to near extinction in 11th–14th century Dutch records, and from f = 70% of consumed fish in the 7th–10th centuries to only f = 10% in the 11th–13th centuries at seventeen Baltic sites (Hoffmann 1995; 1996; 2004). At least 255 years of Summer drought occurred in the 11th–14th century Netherlands, and Dutch foodway disruptions are recorded in AD 1163, 1219–1222, 1245–1246, 1248–1249, 1257–1258, 1268, and 1272–1273. Figure 23 displays 10th–14th sturgeon declines in Gdańsk assemblages.

Furthermore, catfish became extinct in the Scheldt River basin in the early 14th century, and pressures eradicated catfish from the Belgian Meuse River in the 15th century (Hoffmann 1996). 13th century archaeological assemblages in Ghent, Belgium also show that less than 10% of recovered fish bones had freshwater origins, and salmon nearly became extinct between the 10th–14th centuries (Van Neer et al. 2009; Häberle et al. 2016). 10th century Belgium experienced 61 years of Summer drought, and 13th–15th century Belgium experienced at least 189 years of Summer drought and foodway disruptions in AD 1219–1222, 1257–1258, 1281–1282, 1315–1321, 1406, 1437–1438, 1440–1441, 1480, 1482, and 1491–1492. In Nürnberg, Germany, 11th century assemblages contained only freshwater taxa, but herring dominated 12th century assemblages (Hoffmann 2001). 166 Summer droughts occurred between the 11th–12th centuries in Germany, and foodway disruptions are recorded with regularity. Additionally, approximately 40% of 13th–14th century freshwater remains from Aalst, Belgium belonged to small fish < 10 cm in length, and the 13th–14th century Swiss record is dominated by an “outspoken preponderance” of minute fish (Wouters et al. 2021). Switzerland experienced 137 years of Summer drought in the 13th–14th centuries, and foodway disruptions are recorded in AD 1217–1218, 1225–1227, 1282, 1318, and 1363. Meanwhile, assemblages from AD 500–1500 represent both an increased quantity of total marine fish, and an increase in marine taxa represented in Denmark, Germany, and the Netherlands (Lotze 2007).

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Figure 23: Sturgeon in 10th–14th century Gdańsk ichthyological assemblages (From Makowiecki 2001:196)

Specific ichthyological assemblage data comes from The Portus of Ghent and Mechelen in Belgium, and Kołobrzeg-Budzistowo, Mala Nieszawka, Wolin-town, and Gdańsk in Poland, among other locations recorded in Appendix F. Appendix F presents the full suite of ichthyological support for this thesis' claims.

In Ghent, excavations at the 8th century Abbey of St. Bavo produced only freshwater fish, and the 9th–10th century Abbey of St. Peter revealed f = 92% freshwater fish, a single herring bone, and n = 13 marine flatfish in 208 samples (Van Neer and Ervynck 2016). While the Abbeys likely represent a monastic preference for local fish, they also establish an 8th–10th century baseline. Most Belgian sites show decreased freshwater and anadromous fish frequencies from the 10th century on, and later examples from Ghent and Mechelen display both freshwater fish decreases and marine fish increases.

The Portus of Ghent–the first urban area with formalized trade infrastructure– has cultural layers radiocarbon dated from the middle of the 10th century to the end of the 12th century. Summarized data reveals a marine fish frequency > 40% in the Portus' 10th century layers, while frequencies increase to > 70% by the 12th century (Figure 24). Herring and flatfish dominated the marine samples, while cod appeared in the youngest layers (Van Neer and Ervynck 2016). While herring data is not quantified in the study, Figure 25 illustrates that herring increased from f = ~30% in the mid-10th century, to approximately f = 80% in the site's 8th layer, and approximately f = 60% in the 12th century (Van Neer and Ervynck 2016). Belgium experienced at least 198 years of Summer drought between the 10th–12th centuries, and recorded foodway disruptions in AD 1005–1006, 1051, 1056, 1061, 1069–1070, 1090, 1095, 1106, 1113, 1125, 1144–1148, 1153–1155, 1166, 1191, and 1195–1198. An early 14th century assemblage at Mechelen showed approximately f = 50% *Clupeidae*, f = 12% *Gadids*, and a combined f = 14% smelt and flatfish, while earlier layers in the city revealed greater concentrations of freshwater fish paralleling those at the Abbeys of St. Bavo and St. Peter. Freshwater fish accounted for only f = 22% of remains at the early-14th century Mechelen site (Hoffmann 2023a). Belgium experienced at least 174 Summer droughts between the 12th–14th centuries that can be credited, at least in part, as inspiration for these changes.

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Figure 24: Marine, anadromous, and freshwater fish frequencies from the Portus of Ghent. Data spans from the middle of 10th century (Layer 11) to the end of the 12th century (Layer 1) (From Van Neer and Ervynck 2016:19)

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Figure 25: Marine fish frequencies (from sieved samples > 1 mm) from the Portus of Ghent. Data spans from the middle of 10th century (Layer 11) to the end of the 12th century (Layer 1) (From Van Neer and Ervynck:20)

Specific analysis of *Gadidae* (cod, haddock, whiting, pollock) from the Portus of Ghent and the heavily trafficked Belfortstraat St., as well as Mechelen's Lamot neighborhood and Het Steen medieval prison, also display diachronic change (Van Neer and Ervynck 2016). An early 10th–11th century layer at the Portus of Ghent produced NISP = 3 *Gadidae* (of N = 1,791; f = < 1%), but an 11th–12th century layer revealed increases in total fish to N = 3,191, the majority being herring and flatfish, and increases of *Gadidae* to f = 3.3% (NISP = 107). A 13th century layer from Belfortstraat St. revealed *Gadidae* increases to f = 17.7% (NISP = 39 of 220 total) and reflected the continued growth of the cod stockfish industry. Similarly, a 9th–12th century layer in Mechelen's Lamot neighborhood revealed NISP = 85 *Gadidae* (of N = 2,462 total; f = 3.4%), but a 13th–14th century layer at the Steen Hen prison revealed a significant increase in total marine fish, largely herring and flatfish, and an increase in *Gadid* frequency and number to f = 24% and NISP = 3,904 samples (of N = 16,265 total).

Polish evidence comes from the coastal Baltic cities of Kołobrzeg-Budzistowo and Gdańsk (Makowiecki 2001). As sturgeon populations declined across Poland– at estuarine and inland sites alike– marine fish entered the diet following MFEH patterns. Excavations produced NISP = 365 *Clupeidae* (herring, spratt) in a 9th–10th century layer at Kołobrzeg-Budzistowo, but this number increased to NISP = 2,743 in two layers spanning the 11th–12th centuries (Makowiecki 2001). Comparing diachronic data from another test unit in Kołobrzeg-Budzistowo, herring comprised NISP = 3,235 of 3,418 ichthyological samples (f = 94.6%) from 9th–13th century layers, while a layer spanning the second half of the 8th century to the first half of the 9th century produced only NISP = 4 total herring bones (Makowiecki et al. 2016). From the 10th–12th centuries in Kołobrzeg– which saw 213 Polish Summer droughts and recorded foodway disruptions in AD 1076–1077, 1113, and 1166– herring accounted for only f = 42% of samples (Hoffmann 2001), but frequent 13th century droughts inspired archivally supported mass herring trade.

In Gdańsk, diachronic analysis of a test pit on Olejarna St. evidenced steady cod introduction: an AD 1255–1295 layer produced NISP = 4 cod in a sample of 198 total remains (f = 2%), an AD 1295–1350 layer at the same site produced NISP = 16 cod in a sample of 350 total remains (f = 4.5%), and an AD 1350–1400 layer revealed NISP = 17 cod in 104 total remains (f = 16%) (Makowiecki et al. 2016). Across these same layers, freshwater fish steadily declined in number. Herring also reached upwards of 400 km inland by the 11th century, and excavations 160 km from the Baltic sea in 14th–15th century units in Mala Nieszawka produced at least 561 traded cod (Makowiecki et al. 2016).

Ichthyological data from site 1, pit 6 of an excavation in coastal Wolin-town, Poland (Chełkowski et al. 2001) spans the late 8th–13th centuries and displays diachronic change in species frequency and overall fish prevalence. Roach frequency and overall number declined from f = 8.4% (NISP = 39 of N = 463 total recovered remains) in an AD 965–966 layer to f = 1.4% (NISP = 1 of N = 69 total) in an 11th century layer. Roach and total fish remains also declined from f = 9% (NISP = 42 of N = 437 total) to f = 16% (NISP = 11 of N = 68 total) in two consecutive 12th century layers. Another 12th century layer produced f = 18.7% roach (NISP = 172 of 916 total), which decreased in absolute number to NISP = 7 (of N = 35; f = 20%) in a transitional layer between the 12th–13th centuries. The total fish declines displayed in these layers likely reflect both ecological and anthropogenic stressors on fish populations exacerbated by the 291 years of Summer drought in 10th–13th century Poland. Sturgeon frequency and total number in pit 6 declined from f = 3.7% (NISP = 9 of N = 241 total) in an early 10th century layer to f = 1.4% (NISP = 1 of N = 69 total) in a layer dating to the first half of the 11th century, and then again from f = 4.5% (NISP = 18 of N = 396 total) in a layer dating to the second half of the 11th century to only f = 1.2% (NISP = 4 of N = 337 total) in a

12th century layer. Eel frequency declined from f = 1.8% (NISP = 9 of N = 495 total) in the early 10th century to f = 1.1% (NISP = 5 of 463 total) in an AD 965–966 layer, further in number to NISP = 4 (of 241 total; f = 1.65%) in a later 10th century deposit, then to NISP = 1 (of N = 69 total; f = 1.4%) in layers spanning by the 11th century. Bream remains, though relatively consistent in frequency, also declined in absolute number from NISP = 105 (of N = 463 total; f = 22.7%) in AD 965–966 to NISP = 53 (of N = 241 total; f = 22%) later in the 10th century, then to NISP = 20 (of N = 69 total; f = 29%) in the first half of the 11th century. Both absolute bream numbers and frequencies declined again from NISP = 244 (of N = 916 total; f = 26.6%) to NISP = 9 (of N = 35 total for a frequency of 25.7%) between the 12th –13th centuries. Pike declined in absolute number from NISP = 11 in (of N = 463 total; f = 2.4%) in AD 965–966 to NISP = 6 (of N = 241 total; f = 2.5%) in a late 10th century layer, then to NISP = 4 (of N = 69 total; f = 5.8%) by the 11th century, and again in both relative frequency and absolute number from NISP = 10 (of N = 337 total; f = 3%) to NISP = 1 (of N = 68 total; f = 1.5%) in adjacent 12th century layers. Perch declined in relative frequency from f = 17.4% (NISP = 42 of N = 241 total) in an early 10th century layer to f = 2.8% (NISP = 13 of N = 463 total) in AD 965–966**,** from f = 23.3% (NISP = 92 of N = 396 total) in the first half of the 11th century to f = 17.8% (NISP = 60 of N = 337 total) and f = 17.6% (NISP = 12 of N = 68 total) in adjacent 12th century layers, and in both frequency and number from NISP = 175 (of N = 916; f = 19.1%) in the late 12th century to NISP = 4 (of N = 35 total; f = 11.4%) in the early 13th century. Herring entered the record appreciably in pit 6's 10th century layers, and nearby excavations recovered 9th–11th century woven herring nets and net needles (Chełkowski et al. 2001). A lack of salmonid remains at the site evidences the recorded rampant salmon declines.

To date, no comprehensive fish bone assemblage data is published on the Czech Lands, Slovenia, Liechtenstein, Luxembourg, Croatia, Latvia, Belarus, Romania, and Bulgaria. However, comparing archaeologically supported *terminus post quem* (*TPQ*) dates of marine fish trade to inland areas to reconstructed ecological data is valuable. Appendix G compares marine entry *TPQ*s with recent droughts and foodway disruptions recorded before (roughly within the prior 10 years) or concurrently to marine fish developments. All compiled, Germany experienced at least 153 drought events and 38 foodway disruptions while herring entered the market (AD 900–1100), and 134 drought events and 41 foodway disruptions during cod introductions (AD 1100–1250). German rivers reportedly ran dry or diminished in AD 1000, 1022, 1032, 1073, 1076, 1077, 1088, 1135, 1137, 1153, 1170–1172, 1194, and

1198, and mass fish kills are documented in AD 1083 (Tambora)–remarkable evidence supporting this thesis. The Czech Lands experienced 117 Summer droughts as herring trade began (AD 950–1100) and 6 drought years and 4 foodway disruptions surrounding the *TPQ* entry of cod into the record in AD 1371. Poland experienced 127 Summer droughts during herring introductions (AD 900–1100) and 121 Summer droughts and at least 8 documented food disruptions during cod introductions (AD 1150–1300). Austria experienced at least 144 Summer droughts and at least 9 foodway disruptions during transitional herring years (AD 900–1100), and 70 Summer droughts and at least 10 foodway disruptions during cod introductions (AD 1300–1380). Hungary experienced at least 69 Summer droughts during herring introductions (AD 1250–1350) and 83 Summer droughts during cod introductions (AD 1350–1450), and Switzerland experienced 69 Summer droughts during herring introductions (AD 950–1050) and 9 preceding the *TPQ* entry of cod in AD 1435. Lithuania experienced 38 Summer droughts as herring and cod were introduced (AD 1250–1300), Latvia experienced 62 in transitional herring years (AD 1180–1260) and 53 in transitional cod years (AD 1250–1350), and Estonia experienced 54 in transitional herring years (AD 950–1050) and 73 in transitional cod years (AD 1150–1250). Belgium experienced 65 Summer droughts during transitional herring years (AD 950–1050) and 36 during transitional cod years (AD 1050–1100), Serbia experienced 46 during transitional herring years (AD 1300–1400) and 61 during transitional herring years (AD 1350–1450), and the Netherlands experienced 37 during transitional herring years (AD 1050–1100) and 60 during transitional cod years (AD 1300–1400). Given that water levels can drop after a few dry weeks, as many as 14 and 21 consecutive drought Summers in Hungary, 9 in Switzerland, 17 in Latvia, 13 in Belgium, 16 in Serbia, 27 in Estonia, and 13 in the Netherlands likely decimated ecologies.

Drought and food hardships often preceded noteworthy economic transactions, infrastructural developments, and specific events. For example, relentless late-11th century Summer and Spring droughts, and droughts in all of the prior ten years, preceded the earliest mention of salted herring in Cosmas's AD 1119–1125 *Chronicle of the Czechs* (Kyselý et al. 2022). A hunger stone marked AD 1115 is recorded in the German town of Pirna, a mere 30 km from the Czech border. Pirna is only 40 km from Děčín, where other stones are recorded. Czech foodway disruptions–though more likely occurred in this span– are recorded in AD 1113, 1121, and 1124 (Tambora). The AD 1187 shipment of 150,000 herring to Flanders (Hoffmann 2001) followed consecutive Belgian Summer droughts from AD 1175–1185, and multi-season drought may be reflected in dendrological data from AD 1188 (Cook et al.

2015). An AD 1187 drought also brought grain pestilence in neighboring Austria (Tambora). The Piast Dynasty invasion of Kołobrzeg, recounted in Gallus Anonymous's Chronicle (AD 1112–1116) and inspired by a desire for fresh fish, also aligns with the end of consecutive summer and seasonal Polish droughts from AD 1058–1116. All of Central Europe suffered crop disruptions in AD 1113 (Tambora). Vágar's rise to international commerce by AD 1100 also aligns with many droughts that impacted much of Europe, and Vágar's royal tax of AD 1103–1107 may evidence the height of drought-riddled mainland Europe's demand. Summer droughts in AD 1103–1107 reconstruct as widespread and critical, with many scPDSI readings below -4.0 (Cook et al. 2015). Germany, Austria, Switzerland, and Belgium experienced documented food hardships in AD 1102 and 1106.. Even the first alliance of the budding Hanseatic League between Hamburg and Lübeck in AD 1241 reconstructs to be a critical drought year in Germany and Central Europe. Their partnership, which formalized the exchange of herring and salt to preserve fish, may have been in response to drought-induced losses and a need for fish during fasts.

The AD 1278 Hanseatic expansion into Norway also aligns with critical drought years in Germany, Denmark, Liechtenstein, Luxembourg, Switzerland, Austria, and northwest Poland. Foodway disruptions are recorded in Germany, the Netherlands, the Czech Lands, and Austria in AD 1270–1273 and 1275–1278 (Tambora). Increased rights to Norway in AD 1341 came after northern European droughts and German foodway disruptions in AD 1338–1339, and the AD 1361 Hanseatic expansion into Iceland came during severe pan-European drought. AD 1361 brought mass crop failure and low inland water levels, and foodway disruptions are recorded throughout Austria, Germany, the Czech Lands, and likely occurred in the rest of Europe. AD 1368, one of Bergen's most prolific herring export years, also aligns with critical pan-European drought and documented food hardship (Tambora) in the Czech Lands– one of the biggest marine markets. An AD 1371 record of significant herring shipments to Kolín also aligns with critical drought in the Czech Lands and a documented low crop yield (Tambora). Large customs tariffs from German herring shipments in AD 1325 and 1390 (Hoffmann 2004) align with critical droughts, and a herring tariff from AD 1501 aligns with moderate drought. These tariffs also mention riverine transport of goods into Děčín and deeper into Bohemia. AD 1390, in which the Czech cities of České Budějovice, Most, and Kolín, earned the right to operate warehouses where goods did not have to be centralized through Prague, also reconstructs as a critical pan-European drought Summer.

Secondarily, the genesis of inland freshwater aquaculture may also evidence natural fish stock declines and food replacement. Alignment with drought further reinforces claims that drought reduced natural resources and inspired food substitution. Remarkably, the AD 1465 “Fisch Preis Taxe in Eger,” a document from Eger, Hungary, recounts the import of cheap, salted marine fish to compensate for an under-supply of resources (Galik et al. 2015). Summer droughts are documented and reconstructed in AD 1465 Hungary and elsewhere, and 20 consecutive years of mounting Summer and seasonal drought pressures preceded AD 1465.

Artificial fish ponds still suffered in droughts, leaving marine substitution as a more reliable pathway. Aquaculture also likely advanced as a response to pollution, especially given elite desires for clean food. As with natural stocks, domestic taxa also display ichthyological declines in relative frequency over time. Appendix H presents the recorded dates of aquacultural developments, along with droughts and foodway disruptions occurring before or concurrently to aquaculture advancements. Roman *vivarium* fish ponds already existed in Romania and Bulgaria, but aquaculture expanded in the middle ages. All periods of development are interspersed with or preceded by drought and hunger events, and, in both Germany and the Czech Lands where aquaculture is definitively dated, the 10 years preceding development are punctuated by 10 consecutive Summer droughts and food insecurity. An AD 1220 pond in Waldsassen, Germany followed AD 1218–1219 drought, aquaculturists built the first Bohemian first fish pond during drought in AD 1263 (Bartosiewicz 2021), and the 87 ponds commissioned by Czech Lords between AD 1347–1418 may have been in response to the at least 54 reconstructed drought summers in that span (Hoffmann 1995; Drtikolová Kaupová et al. 2019; Piličiauskienė and Blaževičius 2019). AD 1280 ponds in Zwettl and Waldviertel, Austria, and earlier AD 1227 ponds also followed drought (Federal Ministry of the Republic of Austria (n.d.)). In AD 1393, during the development of Swiss aquaculture, Switzerland and Austria endured what was recorded to be the “greatest drought in memory” (Tambora). These hardships, and those undocumented and reconstructed, can be taken as inspiration for food substitution and attempts to control the environment, especially when mounting as press disturbances over stretches of consecutive years.

Overall, comprehensive comparison of ichthyological data to reconstructive and archival drought and famine data reveals that freshwater fish tended to decline in both absolute and relative number across the studied area, and in quality and size in assemblages during drought-riddled periods. Furthermore, droughts and foodway disruptions invariably preceded marine fish introductions across the studied area. Additionally, specific archival accounts of fish shipments, infrastructural trade and fishery developments– including the early pre-Hansa alliance between Lübeck and Hamburg– and patterns in artificial pond construction align with devastating droughts that doubtlessly harmed inland fish populations. Therefore, the argument that drought hardship inspired food substitution in the form of the MFEH, especially when taken with osteological evidence of the era, is well supported. Marine fishing emerged as a reliable alternative in the midst of pervasive and frequent environmental chaos and growing Christian demand in Central Europe.

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6 Marine Fish in Social, Technological, and Economic Contexts

The 10th–16th century Central European MFEH inevitably instigated periods of drastic gastronomic, maritime, and commercial cultural change. Cod and herring changed European foodways in perpetuity, and became the cheap and bountiful backbones of prolific commercial endeavors. Hungry Austrians sailed the Danube to reach the sea, Czech merchants collaborated with coastal Poles to source processed fish, and German, Danish, and Dutch seafarers first took advantage of Anglo-Saxon and Viking fisheries, then took to the fruitful oceans, themselves to replace lost inland stocks.

Offering much needed fish, especially during Christian fasts, the Hanseatic League enticed the continent, and acquired, built, or chartered over 140 partner cities and towns by AD 1400. The Hanseatic League grew to include approximately 200 member cities– each of which contributed a quota of workers, soldiers, and specialty goods other than fish– by the time it dissolved into the Dutch fisheries in the 15th–16th centuries. With fish as its specialty, the Hanseatic League blossomed into a prolific monopoly.

Comparing recorded and reconstructed droughts and foodway disruptions to the years that cities joined the Hanseatic League reveals that many Hanseatic partner cities first affiliated with the Hansa during, and perhaps in response to, drought-induced ecological hardship. The Hanseatic League's trade unions and mutual supply-and-protect pacts offered relief to struggling markets and promised consistent food and protection, especially as its monopoly became harder to compete with. Appendix C lists droughts and foodway disruptions that occurred within the prior 5 years of a city's Hanseatic affiliation, and reveals that many cities joined while, or shortly after, suffering periods of pervasive drought and hunger.

Lübeck began marine fishing in the 12th century. Between AD 1100–1237 (5 years prior to alliance with Hamburg in AD 1241), Germany experienced 125 drought events and a preponderance of foodway disruptions. In AD 1135, forest fires blazed and streams ran dry (Tambora), in AD 1171–1172 all water except the diminished Danube dried up (Tambora), in AD 1177–1178 everything south of the North Sea reportedly ran dry and crops failed, and in AD 1194, crops failed, prices soared, and all rivers became unnavigable (Tambora). Foodway disruptions are recorded in AD 1099–1102, 1113, 1115, 1124, 1128, 1135, 1137, 1144–1148, 1149–1150, 1150–1151, 1153–1155, 1166, 1173, 1175, 1176–1177, 1194, 1195–1198, 1204–1206, 1217–1218, 1223–1224, 1225–1227, and 1234 (Tambora). From AD 1234–1241, droughts occurred in AD 1238, 1240, and 1241. These events can be taken as inspiration for food substitution and the turn to the sea. Also during this time, Lübeck began sourcing fish at Visby and Türku, likely in response to increasing need. Additional evidence for the MFEH as a response to drought comes from Lübeck's rights to Skanör-Falsterbo, acquired in AD 1203 and 1225 (Barrett 2016). Droughts plagued Germany in AD 1197, 1199–1200, and 1202, and in AD 1220–1223, and 1225.

Examples of post-AD 1241 Hanseatic affiliation in response to drought-induced need are also readily apparent. Salzwedel, Germany, for example, joined the Hansa in AD 1263 after suffering droughts in AD 1259–1263 and foodway disruptions in AD 1257–1258 and 1262–1264. Toruń, Poland joined in AD 1280 after 5 consecutive drought Summers, and Stralsund and Paderborn, Germany, who joined in AD 1294 and 1294, respectively, affiliated in the midst of droughts in AD 1284–1289 and 1292–1294. Reportedly, German crops and cattle failed dramatically in AD 1294 (Tambora), thereby potentially inspiring replacement.

By the 15th century Hanseatic affiliation presented an economic opportunity appealing enough to inspire affiliation on its own. However drought-induced need continued. Duisburg and Emmerich am Rhein, Germany joined in AD 1407 as the Rhine reportedly ran dry (Tambora). Earlier, Zutphen and Maasbommel, Netherlands joined in AD 1312, another year where the Rhine and its tributaries dried (Tambora). Mühlhausen, Germany joined between AD 1428–1420, and Alfred and Ascherschleben, Germany joined in AD 1426 after consecutive droughts since AD 1414 and foodway disruptions in AD 1419, 1420, 1425 (Tambora). Kaunas, Lithuania became a *kontor* in AD 1441 after droughts in AD 1437–1439, and Bolsward and Arnhem, Netherlands joined in AD 1442 and 1443, respectively, after consistent drought and hunger since AD 1437. Doesburg and Soest, Germany joined in AD 1447 and 1449, respectively, after nearly 20 straight years of Summer drought, and hunger in AD 1442–1443 and 1446–1448 (Tambora). Schwerte, Germany joined in AD 1461 after drought caused forest fires that reportedly destroyed crops for "5,000 miles in length and breadth" (Tambora). Comprehensively, Hanseatic affiliation dates can prove that Central Europe sought marine fish as food replacement when suffering drought and hardships. Ecological and social disasters continued during the Hanseatic League's growth into a major world player. Drought and foodway disruption is noted in nearly all Hanseatic cities prior to their affiliation.

As the initial backbone of the growing Hanseatic League and eventually the Dutch fisheries, marine fish trade created a massive network of European exchange. Growing trade markets, inspired by need, facilitated the exchange of surplus wine, salt, wood, livestock, grain, wax, precious metals, textiles, and artisan materials, in addition to money, manpower, ideas, and Christianity. With this system, goods like grain or cattle– viable in some areas, but perhaps not in others– could be evenly spread throughout the Hansa's influence, offering struggling territories a metaphorical "economic parachute" (Barrett 2016:262). Given the extent of the Hansa's network, the majority of marine fish consumed in medieval Central Europe– even in areas unaffiliated with the Hansa (Czech Lands, Austria, Hungary, etc.)– likely came from Hansa boats. Hansa men funneled marine fish into major cities or distribution points where merchants–even those unaffiliated with the Hansa– purchased fish to distribute in their respective homes. These transactions helped the Hansa grow through diffusion as affiliation became necessary or fruitful, and profits and protections became enticing. Occasionally, the Hansa acquired new members by force. Furthermore, Europe's major players like the Saxon Order, the Teutonic Order, the Pomeranian House of Griffin, and the Bohemian Přemyslid Dynasty could have spread fish and goods throughout the entirety of their dominion if even one city connected or affiliated with the Hanseatic League. For example, the Přemyslid Dynasty, spanning Poland, Hungary, and Bohemia, likely used their Hanseatic influence in Toruń, Poland to bring preserved fish hundreds of kilometers south to Hungary in times of need. All told, the impacts of the cultural, physical, and economic exchange facilitated by the MFEH and its continual trade growth are countless.

Massive infrastructural networks necessarily supported international trade, which grew and adapted concurrently with the burgeoning Hansa. The Hansa operated offices and distribution centers abroad, achieved military status to protect its assets and privileges, and earned significant political influence. Physically, trade relied on manpower and transportation over both land and sea, and the trademark Hanseatic cog ship shouldered much of this responsibility. Though the term cog or *kogge* is recorded as early as the 9th–10th century (Van de Moortel 2011), cogs took form and came into frequent use in the 11th–12th centuries. Built in the edge-sealed, overlapped-timber, clinker style, cogs demonstrate variations of traditional Romano-Celtic shipwriting elements that help identify the first seafaring cog's probable origin to the Rhine, Meuse, and Scheldt River valleys of the Rhineland or the Frisian coast (Van de Noort 2011). However, taller, wider, more versatile, and more easily maneuverable than the Viking *knarr* or Romano-Celtic long ships of the era, rudder-steered and tall-masted cogs carried more men and cargo more quickly than any European ship before, and became Europe's dominant seafaring vessel by the mid-13th century (Van de Moortel 2011).

Embracing a shipbuilding application of the Functionalist Organismal Niche Construction Theory (ONCT) (Smith 2010), analysis of cog origins and technological development supports the MFEH as an initial and continued response to drought-hardships in several ways. Smith's (2010) application of the ONCT posits that shipbuilding technologies develop functionally, and adapt to fit ecological needs or constraints. Therefore, if the MFEH occurred in partial response to drought hardships and drought-exacerbated inland fish pressures, then cogs also developed from this need and accommodated drought conditions. Efficient, cargo-bearing cogs clearly developed to trade and source food at sea, and reflect drought-ecologies in their hull and resilient building style. Cogs featured gradually curving flat-bottom hulls with long, shallow-sitting keels (Figure 26; Figure 27)**,** and this form served several purposes**.** Cog crews utilized this design to offload cargo by sailing close to shore during high tide, then allowing the outgoing tide to beach them without damaging the vessel (Gardiner and Mehler 2007). Beaching the cog made unloading simple and superseded the need for harbors or docking, thereby making trade more accessible in even the remote settlements. However, cogs also transported goods inland over rivers. Flat bottoms permitted safe passage of shallow and rocky stretches that only became shallower in the frequent droughts of the era. Cogs had to pass shallow rivers, as droughts increased demand and in turn, economic opportunity. Furthermore, the cog's sturdy, overlapping oak, sealed, iron-braced, and nailed hull could withstand running aground in drought-diminishing rivers, inlets, and harbors while also protecting against the North Sea's rocky coasts (Tipping 1994). Simultaneously, curved hulls allowed cogs to gracefully cut through ocean chop, thereby making the vessel adaptable and allowing extensive seafaring that increased with demand and the rise of fisheries (Wickler 2016). Cogs holds also surpassed *knarr* and longboat cargo capacities, suiting the needs as the MFEH progressed in periods of continual ecological stress. Demand functionally required efficiency, and ambitious seafaring and inland shipping necessitated drought-resistant cog technology (Tipping 1994; Smith 2010; Wickler 2016).

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Figure 26: The hull cross section of a model cog at the National Maritime Museum, Gdańsk, Poland (From: https://en.wikipedia.org/wiki/Cog_(ship)#/media/File:CMM_-_Przekr%C3%B3j_poprzeczny_kogi_(cropped).JPG)

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Figure 27: A diagrammed hull cross section of the 15th century IJsselcog shipwreck, recovered near Kampen, Netherlands (From: Waldus et al. 2019:424)

As the MFEH escalated, cogs– the earliest of which held 20–80 tons of cargo– grew to accommodate larger loads and more workers. Later cogs prioritized midship hull height, which facilitated better cargo stacking and efficiency (Van de Moortel 2011) and accommodated loads routinely reaching 200 tons (Gardiner and Mehler 2007). For example, the wrecks of the the *Kollerup cog* (AD 1155), *Kolding cog* (AD 1188–1189), *Zuyderzee cog* (~ AD 1270–1300), and *Bremen Cog* (AD 1378) revealed hull height increases from 2 m, to 3 m, ~ 3.5 m, and 4.26 m, respectively (Van de Moortel 2011). Hull height increases invariably intersect with droughts in the region that catalyzed fish demand. If accepting increased demand's connection to ecological hardship and drought, cog development not only demonstrates the Hanseatic League's expansion and burgeoning economic footprint, but also reflects the continually increasing demand caused by drought and stress on inland fish– more demand required bigger ships to move more product. It is also compelling that cogs, fisheries, the Hanseatic League, and MFEH assemblages all continually developed through periods of devastating plague, including the outbreaks of the AD 1340s–1350s. Increased demand and development, even as plague left fewer mouths to feed– evidenced here by ship adaptations and Hasselt, Bergen, Göttingen, and Darłowo joining the Hansa during the Black Death– intimates that another, likely ecological event like drought partially inspired resource replacement and the MFEH.

Smith (2010) also posits that, when demand– now associated with drought– pushed fishermen further North and East, bigger cogs developed to make longer, more treacherous journeys through swell and ice. More robust cogs could reach the most lucrative Scandinavian fishing grounds– areas necessary to fish given demand– more safely and easily, and could bring back more cargo. Additional room in the hold also allowed for fish processing on board to expedite production (Hoffmann 2001). Smith (2010) supports this ecological niche theory with shipwreck evidence of consistently longer and taller vessels recovered in Scandinavian waters as opposed to those documented on the Baltic shores. Eventually, even larger *holk*, *kraweel*, carrack, and galleon ships developed from this need (Gardiner and Mehler 2007), and cogs also became specialized military vessels.

In accordance with Smith's (2010) ONCT adaptation, and given the drought-inspired origins of MFEH seafaring supported in this thesis, additional evidence for the MFEH as a response to drought comes from the dendrological provenances and construction dates of known cog wrecks. No original cogs remain intact today, so most known data comes from archival sources, art, shipwrecks, and their reconstructions. Cog wrecks are exceedingly rare, the Hansa typically scrapped vessels after 40 years, and the oldest known wrecks date to the 2nd half of the 12th century (Van de Moortel 2011). Cross-analyzing dates and provenances with historic and reconstructed droughts and foodway disruptions demonstrates that seafaring cog constructions frequently occurred during or shortly following droughts and their effects on fish and crops. Appendix I compiles cog wreck data with droughts and foodway disruptions in the 2 years prior to a wreck's dendrological date in the area of its origin. Though wreck dates are unknown, cogs may have wrecked while fishing, bringing fish to port, bringing fish to a ship's Hansa city of origin, or bringing fish to allied merchants in its wreck site. Future archival work or contextual archaeology may reveal wreck dates for recovered and unrecovered ships, which may align with drought or need in wreck areas and further substantiate this thesis. Two years represents enough time to have experienced a drought and built a ship, and partially accounts for dendrological error. At the height of Hanseatic shipbuilding and seafaring, even large cogs likely took less than a year to construct (Van de Moortel 2011). Given accepted error in dating, other proximal droughts may have also been inspirations.

At their earliest, cog origins in the Rhineland and Frisia prior to the 12th century are also compelling to analyze from a functional viewpoint. The development of seafaring technology in inland territories is a significant technological and cultural feat that potentially suggests an inland European need or desire to turn to the sea. At these early 10th–11th MFEH stages, environmental inspiration is well supported by the extent of reconstructed droughts, while economic inspiration likely represents a more feasible explanation in later periods of more connected and fruitful trade.

Several wrecks align with long stretches of dryness and archival hunger. The *Dyngö III* shipwreck, documented in Sweden and originating between AD 1233–1240 in Lower Saxony or Northwest Germany (von Arbin 2023), aligns with drought in Germany from AD 1231–1236, and reports of diminished rivers, plague, famine, and cannibalism in Germany, Latvia, and Estonia (Tambora). *Dyngö III* potentially represents a turn to sea as a response to need in all impacted areas. Shipwreck *A57 Rutten*, recovered in Zuyderzee, Netherlands and originating between AD 1265–1275 in Northeast Germany (van de Moortel 2011), aligns with at least 6 drought events in Germany, including several foodway disruptions and documented livestock culls and die-offs (Tambora). *Doel 1*, wrecked in the Belgian Scheldt

River and originating between AD 1325–1326 in Aller or Weser, Germany (van de Moortel 2011), aligns with drought from AD 1323–1326. The *Vejby Cog shipwreck*, recovered in Denmark and originating in AD 1372 from Baltic wood (van de Moortel 2011), aligns with drought in AD 1370–1372, and a German foodway disruption in AD 1370. The *Bremen Cog* shipwreck, originating in AD 1378 Weser (van de Moortel 2011) also aligns with drought in AD 1376–1377, and *NZ43 Spackenberg*, recovered in Zuyderzee, Netherlands and originating in AD 1404–1414 in the Netherlands or Westphalia (van de Moortel 2011) aligns with drought in AD 1405, 1407–1409, and 1411–1414. *IJsselcog* (Figure 28), recovered in Kampen, Netherlands, where it was produced between AD 1415–1420, also aligns with Summer droughts from AD 1413–1420. The *Wismar-Wendorf Cog* shipwreck, recovered in Wismar Harbor (Germany) and originating from German Baltic wood that dates to AD 1476 (Heinrich 2012), presents a final remarkable example of potentially need-based cog production, even after maritime trade became a massively lucrative venture. Drying springs and low water levels are recorded in AD 1473–1474 Passau, and drought is recorded to have reduced potable drinking water in AD 1476 Koblenz (Tambora). These unsuitable freshwater fish conditions offer potential inspiration for sea fishing, and an assemblage of large (> 100 cm) Atlantic cod and ling remains originating far from the Baltic, along with wooden skewers frequently used to dry stockfish recovered in the wreck support the notion that, in severe droughts and periods of hardship, ships sailed further north and east to access more and larger fish.

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Figure 28: *Ijsselcog* being recovered (top) and wet-preserved (bottom) (From: Waldus et al. 2019:467; https://www.medieval.eu/late-medieval-cog-from-kempen/)

Born from the MFEH, proliferated by the Hanseatic League, and adapted by necessity to bring a struggling Europe fish and other goods, cog ships became part of the European social, political, and economic identity. Cog fleets grew exponentially as the MFEH progressed, and medieval contemporaries iconographically immortalized cogs on city seals, coins, and flags (Figure 29). As providers of fish during fasts and occupying the social consciousness, cogs even permeated religion, and are depicted on two medieval altarpieces– the Master of St. Ursula's (painter) *St. Ursula Altarpiece*, painted in AD 1482 for a cathedral in Bruges, Belgium (Timmermann 2023; Figure 30), and Lübeck master Hermen Rode's AD 1478–1481 *Retable of the High Altar: Saints Nicholas and Victor Altarpiece*, commissioned by St. Nicholas' Church in Tallinn, Estonia (Eesti Kunstimuuseum; Figure 31). St. Ursula's Altarpiece, an *ex-voto* painting commemorating a miracle or divine intervention, includes a small detail of a cog on its right wing, likely commemorating a donation from thankful shipwreck survivors or victorious navy men (Timmermann 2023). On a panel of the half-open work, Rode's altarpiece depicts St. Nicholas– the patron saint of sailors and merchants– saving a cog crew in a storm. Trade and seafaring became significant enough to garner religious appeals for protection across Europe. Medieval cogs continue to occupy the contemporary memory, and the storied F.C. Hansa Rostock, for example, proudly features a medieval cog ship on their logo today (Figure 32).

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Figure 29: A) The Straalsund Seal (AD 1329) (A figure from Timmermann's (2023) presentation); B) a coin and seal insignia from AD 1299–1300 Gdańsk (From: https://www.hubert-herald.nl/Gdansk.htm); C) and the Lübeck AD 1223 seal (From Timmermann 2023)

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Figure 30: The Bruges Master of St. Ursula's *St. Ursula Altarpiece* (AD 1482) and its cog detail (From: Bruges, Groeningemuseum; annotations by the author)

Figure 31: Rode's depiction of a cog on *Retable of the High Altar: Saints Nicholas and Victor Altarpiece* (From: Tallinn, Eesti Kunstimuuseum)

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Figure 32: F.C. Hansa Rostock Logo (From: https://www.fc-hansa.de/)

All told, the MFEH's effects on technology and European maritime culture– and by extension the maritime cultures of the "New World" and Europe's colonial territories– are impossible to fully recount. Practically, the MFEH brought the building of great fleets, technologically advanced ships to explore and profit from the world's oceans, and extensive trade networks over which goods, money, people, and ideas passed. Marine fishing began as a response to frequent drought, among other factors, and this act of human resilience developed from necessity into a prolific, enduring, and intricately advanced powerhouse that not only spread vital food aid throughout Europe, but also commanded military and political roles across the continent. Drying, salting, smoking, and curing fish diffused to preserve and profit from surplus, and, noting inland stock destruction, Europeans learned to manage pollution and overfishing. The turn to marine fish failed to satisfy some elite groups, who responded by developing inland aquaculture, further demonstrating mastery over nature. Furthermore, providing fish for fasting Christians allowed Europeans to worship as desired.

Less tangible, though, is the fact that the MFEH made the ocean itself, in addition to its bounties and boundless opportunities, ideologically "real" to many Europeans for the first time. Hungarian peasants and Czech farmers who had never seen the ocean began to benefit from its spoils. Swiss traders bartered for fish with Hanseatic mariners who shared their seafaring tales. Austrians seized opportunities to work on ships off distant shores. Cogs carrying stockfish down inland rivers, or off-loading onto carts that dispersed goods inland, became iconic symbols of profit, salvation in times of need, technological advancement, and the oceanic frontier. The ocean captured the social collective, and became a staple of medieval European life even far from the coasts. The MFEH not only answered Europe's need for food substitution, but also facilitated the growth that provided the infrastructural and cultural foundations for decades of European seafaring and commerce to come.

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7 Conclusion

MFEH scholar James Barrett stated that identifying a single cause for the MFEH would be inappropriate (MercoPress 2009), explaining that cultural turns are dynamic and inspired by indefinite matrices of lived conditions and cultural particularities. Necessarily included in this matrix are environmental challenges, which uniquely and indiscriminately impact ecologies and the inhabitants therein. However, no MFEH studies to date have examined environmental factors in great detail. After thorough multidisciplinary analysis and comparison, this thesis proves that the widespread and recurrent droughts that plagued 10th–16th century Central Europe cannot be understated—and certainly not omitted— as a factor in the genesis and continued proliferation of Central Europe's medieval MFEH. Drought presented its own suite of pulse and durational press hardships that independently impacted inland fish and agriculture, but also exacerbated the coterminous challenges presented by pollution, urbanization, population growth, and Christian demand. Together, these challenges presented adequate enough stress to necessitate a turn to the sea.

Compiling documented and scPDSI reconstructed Central European Summer drought events during peak MFEH years (AD 900–1540) reveals the overwhelming extent and severity of drought during the turn. As compared to other epochs, both the MCA and LIA– and especially the transition between the two– display anomalously high drought frequencies. While significant, this information alone cannot substantiate claims for the MFEH as a human response to drought. Reconstructing and compiling the aquatic and terrestrial conditions these droughts created, and how droughts likely exacerbated extant issues in freshwater ecologies, however, is revelatory. In river and lake ecosystems already suffering from overfishing; milling and damming; pollution from encroaching settlements; and cropland runoff; lowered water levels concentrated pollutants; promoted inundating eutrophication and algal blooms; suffocated, overheated, beached, or baked fish populations; spread disease to fish and humans; and inhibited migration and spawning. Drought salinated estuaries, thereby decimating sensitive lifeforms within. Environmental stress culled fish, and potentially impacted recovery for years to follow. MFEH-era documents from throughout Central Europe corroborate these occurrences, and begin to substantiate the potential for the MFEH as food substitution, especially in times of mass Christian need.

On land, records provide explicit accounts of drought's impacts on cropping and livestock, and comparative ecological studies can be used to reconstruct the issues that Central Europe likely faced as drought progressed through meteorological, hydrological, agricultural, and socio-economic stages. Crops withered, dried, or burned in fires, animals starved, dehydrated, failed to reproduce, or went to slaughter early, and the mills that supported agricultural industry stopped turning during riverine lowstands. On reclaimed polder land and estuarine shores, soil likely salinated for lack of fresh precipitation, killing the crops planted therein. Drought's mounting and top-down effects impact all inextricably connected corners of ecology, and available records state that crops and crop industries, animals, and fish suffered to the extent of foodway disruption and famine. Dietary reconstructions evidence the particularly harmful impact of losses in these sectors. Comparable or even more negative scPDSI levels in years unrepresented by archival materials likely indicate similar conditions to those recorded in a preponderance of years between AD 900–1540. A compilation of recorded 10th–16th century Central European foodway disruptions and their coincidence with recorded and reconstructed droughts confirms the extent of drought hardships and further evidences the need for the MFEH as food substitution. Accepting these established ecological possibilities and recorded conditions as factors of drought allows for a more complete reconstruction of the Central European lived experience.

Hardship for humans– the active players in the MFEH– is potentially evidenced by the osteological record. 10th–16th century Central European human remains reveal distinctly high pathological frequencies indicating dietary deficiency and disease, a generally high rate of morbidity, and young life expectancies. The diets of the humans who experienced these frequent droughts suffered, and public health declined. With drought's effects in mind, recording the amount of droughts and foodway disruptions represented by human bone assemblages evidences the extent of human hardship during the MFEH, thereby suggesting the need for food substitution by proxy. Analyses suggests that humans and terrestrial resources suffered enough to inspire a turn to the sea, and its continued exploitation. Finally, accepting all of these drought conditions, cross-analyzing drought and foodway disruption data with marine fish bone assemblages confirms that Central Europeans experienced these hardships as their freshwater fish exploitation declined in number and quality, and their marine fish exploitation skyrocketed. Reconstructed and recorded drought experiences and ecologies evidence lived hardship, which partially inspired the marine turn as food substitution. Additionally, comparing when countries first sought marine fish with drought and foodway disruption data reveals that extensive drought hardship punctated each country's turn. As marine fishing continued and expanded, Central Europeans also experienced droughts and foodway disruptions shortly before and during the creation of the Hanseatic League, and drought hardships appear as possible inspiration for Hanseatic affiliation and seafaring ship building in many cities from AD 1241 onward. Given this, human responses to drought can be taken as catalysts for the creation of one of history's greatest trade empires, and the development of cogs, the most prolific medieval seafaring vessels. While profit and competition with monopolies also drove Europeans to the sea as fishing industries boomed, Central European droughts continually remained pervasive stressors that necessitated marine exploitation.

All told, the Central European rise of marine fishing and fish trade, and the decline of freshwater fish consumption, encompasses drastic developments in both inland and maritime culture. For many Europeans who had never seen it, the MFEH offered a first introduction to the sea and registered the ocean in the collective consciousness. The MFEH not only fed struggling Europeans during complex times of ecological unrest, but also facilitated the commercial union of foreign states and spearheaded centuries of maritime, gastronomic, and shipbuilding advancement. Understanding the complex lived conditions of this vital historical period allows us to better understand the turn to the sea and its inspiration. While drought's effects may seem obvious— fish cannot swim in dried river beds, and humans, animals, and plants need water to survive– the far-reaching extent of drought hardships, and the frequency and ferocity with which drought occurred in 10th–16th century Central Europe are profound. While fish were not the largest component of the diet, Christians required a food alternative that aligned with their religious beliefs. Drought both created and exacerbated fish and human survival challenges, which, combined with increasing Christian need, inspired Central Europe's turn to the sea– a turn that became, and continues to be, prolifically profitable. Complex products of human-environment interaction necessarily develop from the culturally impacted and lived human experience, and therefore Central Europe's pervasive, frequent, and devastating droughts must have combined with other social and ecological motives to inspire human action.

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Appendix A
Recorded and Likely Significant Reconstructed Central European Droughts (AD 900–1540)

Appendix A is available for download on the Flinders University thesis archive, and at the following link:
https://drive.google.com/uc?export=download&id=1njuv0oy1PJirmSIeTOeilXZFQyPQdclW

Appendix B
Documented Central European Famines and Major Foodway Disruptions (AD 850–1540)

Year	Recorded Location(s)	Notes	Source(s)	Weather Event
AD 850–851	Germany, Low Countries	Though anachronistic to the studied time period, individuals who survived may have witnessed the beginning of the MFEH. Documents report *twere zeit* ('hard times') in Frisia (Netherlands) as early as AD 851	Walford 1878; Cook et al. 2015; Curtis et al. 2017	Drought
AD 942	Germany	Excessive rain is reported to have brought mass crop and livestock deaths in the Thüringen region	Tambora	Wet
AD 1004	Germany	Written accounts of famine in Köln (Cologne)	Cook et al. 2015; Tambora	Wet
AD 1005–1006	Germany, Austria, Switzerland, Low Countries	One of multiple episodes of Teuerung (dearth) and Hungersnot (famine/ starvation) that came at regular intervals is recorded. Drought is recorded to have been moderate to severe	Cook et al. 2015; Collet and Krämer 2017; Curtis et al. 2017	Drought
AD 1012	Germany	Crop fields flooded in Central Germany	Tambora	Wet
AD 1013	Danube River	Flooding is recorded to have disrupted local cropping along the entire Danube	Tambora	Wet
AD 1016	Germany	Grain destruction and famine is recorded in Burburgenheim. Drought is recorded to have been severe	Cook et al. 2015; Tambora	Drought
AD 1019	Germany	Flooding from melted snow accumulation on excessively dry land caused by drought and cold caused a famine. Drought is reconstructed to have been severe	Tambora	Wet + Drought
AD 1022	Germany	Drought-induced crop shortage is recorded in Koblenz along with human and livestock deaths. Drought is reconstructed to have been moderate	Cook et al. 2015; Tambora	Drought
AD 1032	Germany	Drought brought "severe economic losses." Drought is reconstructed to have been severe	Tambora	Drought
AD 1035	Germany	A Tremendous mortality of animals and bees is recorded. Drought is reconstructed to have been moderate	Cook et al. 2015; Tambora	Drought
AD 1038	Germany	A great crop failure with many deaths is recorded. Drought is reconstructed to have been moderate to severe	Cook et al. 2015; Tambora	Drought
AD 1041	Danube Basin	Cropland flooding is recorded	Tambora	Wet

Year	Recorded Location(s)	Notes	Source(s)	Weather Event
AD 1043–1046	**Germany, Austria, Switzerland**	**One of multiple episodes of *Teuerung* (dearth) and *Hungersnot* (famine/ starvation) that came at regular intervals is recorded. AD 1043 appears to have been slightly wet, and Munich records great summer rains, and the following years appear excessively dry in reconstructions**	**Cook et al. 2015; Collet and Krämer 2017**	**Wet and Drought**
AD 1051	**Low Countries**	**An episode of *twere zeit* is recorded. Drought reconstructs to have been severe**	**Cook et al. 2015; Curtis et al. 2017**	**Drought**
AD 1052–1054	**Germany**	**A shortage of field crops is recorded in Konstanz, Cologne, and Hamburg. Droughts in AD 1053 and 1054 reconstruct to have been severe**	**Cook et al. 2015; Tambora**	**Drought**
AD 1056	**Germany, Belgium**	**Famine is documented in Wurzburg, Liège, Stade, Hildesheim, Windsheim**	**Cook et al. 2015; Tambora**	**Wet**
AD 1058	**Germany**	**Freezing temperatures and snow inhibit milling causing a shortage of bread, and damage tree fruits**	**Tambora**	**Cold + Wet**
AD 1061	**Low Countries**	**An episode of *twere zeit* is recorded. Drought reconstructs to have been moderate to severe**	**Cook et al. 2015; Curtis et al. 2017**	**Drought**
AD 1069–1070	**Low Countries, Germany**	**An episode of *twere zeit* is recorded. Drought in AD 1070 is reconstructed to have been severe, while AD 1069 appears to have been moderately dry. A shortage of wine so that "one could hardly count the priest's mass as legitimate" is recorded after cold and hail in AD 1070**	**Cook et al. 2015; Curtis et al. 2017; Tambora**	**Drought + cold**
AD 1073	**Germany, Switzerland**	**Winter dryness is recorded to have eliminated milling activity. Drought is reconstructed to have been severe**	**Tambora**	**Drought**
AD 1076–1077	**Germany, Poland, feasibly other river basin countries**	**The Danube and Rhine reportedly ran dry, cattle pastures became barren, and arable land and the plants upon it withered. Drought in AD 1076–1077 and the immediately precedent years reconstructs to have been severe**	**Cook et al. 2015; Tambora**	**Drought**
AD 1083	**Germany**	**Extreme heat and drought reportedly caused a fish kill in Ottobeuren. Drought reconstructs to have been severe in southern Germany**	**Tambora**	

Year	Recorded Location(s)	Notes	Source(s)	Weather Event
AD 1086	**Denmark**	**“In that year a dreadful famine began in Denmark and lasted for seven (according to others: nine) consecutive years. For during this whole period of spring and summer there was such a drought and heat that almost nothing sown in the high country germinated, and the little that still sprout withered in the course of the summer; but in the autumn it rained so profusely and persistently that little of what had grown in low-lying regions could be brought in dry; indeed, these regions were partly under water and resembled lakes on which barges were sailed in order to cut off the ears of corn protruding over the water. Much of what was harvested had to be dried in ovens, and was not at all suitable for baking bread” Drought reconstructs to have been moderate in Denmark**	**Cook et al. 2015; Tambora**	**Drought and Wet**
AD 1088	**Germany**	**Famine is documented in Schleswig. Drought reconstructs to have been moderate**	**Tambora**	**Drought**
AD 1090	**Germany, Belgium**	**A reported unsuccessful harvest that yielded famine is documented. Drought reconstructs to have been moderate**	**Cook et al. 2015; Tambora**	**Drought**
AD 1093–1094	**Germany**	**Documents from Augsburg and Ottobeuren report that excessive pluvials yielded poor grain harvest and many deaths. While northern Germany reconstructs to have been overall wet, southern Germany reconstructs to have been moderately dry**	**Tambora**	**Locally wet, regionally dry**
AD 1095	**Belgium**	**A great famine is recorded through the whole of Belgium**	**Cook et al. 2015; Tambora**	**Likely wet**
AD 1097–1098	**Germany**	**Documents report excessive flooding that inhibited cropping and raised grain and flour prices**	**Tambora**	**Wet**
AD 1099–1102	**Germany, Austria, Switzerland**	**Excessive drought appears to have set in by AD 1100, especially in 1101 and 1102. Drought reconstructs to have been moderate in AD 1099–1100, and extreme in AD 1101–1102**	**Cook et al. 2015; Collet and Krämer 2017**	**Drought**
AD 1106	**Belgium**	**Documents from Liège report poor cropping and social stratification. Drought reconstructs to have been severe**	**Cook et al. 2015; Tambora**	**Drought**

Year	Recorded Location(s)	Notes	Source(s)	Weather Event
AD 1113	**Central Europe**	**Hay, barley, and rye are documented to have dried throughout the region. Drought in the eastern and western regions of the study area reconstruct to have been severe**	**Tambora**	**Drought**
AD 1115	**Germany**	**Drought is evidenced by a Hunger Stone recorded to have existed in the Elbe in Pirna. Hunger stones are assumed to correlate with only the most socially extreme events. Drought reconstructs to have been severe**	**Cook et al. 2015; Odbratt 2023**	**Drought**
AD 1121	**Czech Land**	**Field and sown crops are recorded to have dried out. Drought in the region reconstructs to have been severe**	**Brádzil et al. 2013**	**Drought**
AD 1124	**Germany, Czech Lands**	**Extreme frosts and cold are reported to have frozen crops, vines, trees, fish. An excessive snowfall is recorded in Hanau and Nuremberg. In Prague: "a great pestilence of cattle, sheep, and their own; many bees perished, the dearth of honey was too great. The autumn crops were wanting at the same time as the spring crops, except only the millet and the pea." About ⅓ of people are recorded to have perished in Wurzburg.**	**Tambora**	**Wet + Cold**
AD 1125	**Belgium**	**A great barrenness is recorded in Flanders. Drought reconstructs to have been severe.**	**Cook et al. 2015; Tambora**	**Likely Drought**
AD 1128	**Germany**	**Snow and cold yielded famine and plague, however scPDSI reconstructions suggest moderate drought, as well**	**Cook et al. 2015; Tambora**	**Wet + Drought**
AD 1135	**Germany**	**A great dearth reportedly followed drought-induced fires in Burgbernheim, and the Danube and other rivers dried in Regensburg, Amberg, and Munich. Drought reconstructs to have been severe**	**Tambora**	**Drought**
AD 1137	**Germany**	**Economic losses from prolonged drought are recorded in Koblenz. Drought reconstructs to have been severe**	**Cook et al. 2015; Tambora**	**Drought**
AD 1143	**Belgium**	**Both rich and poor reportedly perished in a famine. scPDSI values reconstruct to have been moderate to neutral**	**Cook et al. 2015; Tambora**	**Locally wet, regionally dry**

Year	Recorded Location(s)	Notes	Source(s)	Weather Event
AD 1144–1148	Germany, Austria, Switzerland, Belgium, Low Countries	One of multiple episodes of Teuerung (dearth) and Hungersnot (famine/ starvation) that came at regular intervals is recorded. Chronicles from the Low Countries record dearth and the "darkening of skies" that brought the "sword of famine"	Cook et al. 2015; Collet and Krämer 2017; Curtis et al. 2017	Wet
AD 1149–1150	Germany	Flooded crop fields in Münster, Pegau, Magdeburg that caused famine and illness	Tambora	Wet
AD 1150–1151	Germany, Austria, Switzerland	One of multiple episodes of Teuerung (dearth) and Hungersnot (famine/ starvation) that came at regular intervals is recorded. scPDSI numbers do not appear extreme	Cook et al. 2015; Collet and Krämer 2017	?
AD 1153–1155	Germany, Belgium	Grain crops reportedly dried, and crop and animal die-offs are recorded in Ottobeuren along with fires. scPDSI values reconstruct to have been positive	Tambora	Locally wet, regionally dry
AD 1163	Netherlands	Grain wetness and molding is recorded in Heiloo, followed by Summer drought	Tambora	Wet then Drought
AD 1166	Austria, Germany, Northern Europe	Documents from Innviertel report famine across "all countries," and deaths are recorded in Erfurt and Magdeburg. Drought reconstructs to have been extreme	Cook et al. 2015; Tambora	Drought
AD 1173	Germany	Summer grass and crop failures are recorded in Pegau. Drought reconstructs to have been moderate	Tambora	Drought
AD 1175	Germany	Excessive rain in summer reported delayed Autumn crops requiring almsgiving	Tambora	Wet
AD 1176–1177	Czech Lands, Germany	"Even the green dried up" in the Czech Lands, and famine and plague are recorded in Strasbourg along with record Summer heat. Drought reconstructs to have been extreme	Brádzil et al. 2013; Tambora	Drought
AD 1178	Austria	Documents from Innviertel report mass famine caused by a lack of field crops. Drought reconstructs to have been extreme	Cook et al. 2015; Tambora	Drought
AD 1187	Austria	Great pestilence and scarcity are recorded	Cook et al. 2015; Tambora	Wet
AD 1191	Low Countries	Dearth noted by medieval chroniclers over a wide geographic area. scPDSI numbers do not appear extreme	Cook et al. 2015; Curtis et al. 2017	?

Year	Recorded Location(s)	Notes	Source(s)	Weather Event
AD 1194	Germany, Czech Lands	In Hanau and Regensburg, milling was not possible and floods followed drought. Poor cropping and high prices are noted in Prague and Bohemia. Drought reconstructs to have been neutral to moderate	Brádzil et al. 2013; Tambora	Drought + Wet
AD 1195–1198	Germany, Austria, Switzerland, Belgium	One of multiple episodes of Teuerung (dearth) and Hungersnot (famine/ starvation) that came at regular intervals is recorded	Cook et al. 2015; Collet and Krämer 2017	Likely Wet
AD 1204–1206	Belgium, Germany	Records report many human and animal deaths from hunger, no plowing fields, cold frosts and dryness that yielded high prices for seeds, wine, and herring (which an AD 1205 document listed as a "necessity for a person to live on"). Drought reconstructs to have been moderate to severe	Tambora	Cold + Drought
AD 1211	Belgium	Summer and Autumn droughts followed by early frosts inhibiting cropping and causing hunger are recorded in Liège. Drought reconstructs to have been moderate to severe	Tambora	Cold + Dry
AD 1217–1218	Germany, Austria, Switzerland	One of multiple episodes of Teuerung (dearth) and Hungersnot (famine/ starvation) that came at regular intervals is recoded. AD 1216–1217 appear excessively dry in scPDSI reconstructions	Cook et al. 2015; Collet and Krämer 2017	Drought
AD 1219–1222	Netherlands, Belgium	Documents report that drought made barley yields weak, brittle, and thin, and a famine ensued. Drought reconstructs to have been moderate in AD 1222	Tambora	Drought
AD 1223–1224	Germany	Winds and cold reportedly killed crops and spread pestilence. scPDSI numbers do not appear extremely wet or dry	Tambora	Wind
AD 1225–1227	Germany, Austria, Switzerland	One of multiple episodes of Teuerung (dearth) and Hungersnot (famine/ starvation) that came at regular intervals is recorded. scPDSI numbers do not appear extreme, however AD 1227 appears slightly dry	Cook et al. 2015; Collet and Krämer 2017	?
AD 1229	Germany	Harsh winter and pluvials reportedly caused famine and pestilence. While scPDSI values in Germany are not remarkable, values in the western study area suggest severe drought	Cook et al. 2015; Tambora	Locally wet

Year	Recorded Location(s)	Notes	Source(s)	Weather Event
AD 1233	**Germany, Lavia, Estonia**	**Records report famine that was so great that "Even thieves were torn down from the cross and devoured by the hungry–" and plague outbreaks occurred. Drought reconstructs to have been severe**	**Cook et al. 2015; Tambora**	**Drought**
AD 1234	**Germany**	**Rivers and mills froze, and wine froze in cellars in Hanover. Drought reconstructs to have been severe**	**Cook et al. 2015; Tambora**	**Drought + Cold**
AD 1245–1246	**Germany, Netherlands**	**Records report drought that inhibited plowing and milling followed by rain that flooded crop fields causing bread shortage. Drought reconstructs to have been severe in AD 1244, and moderate in southern Germany in AD 1245–1246**	**Tambora**	**Drought + Wet**
AD 1248–1249	**Netherlands**	**Documents report soil salinization in Stadskanaal that destroyed crops, root systems, and entire livestock stores. Many deaths occurred, and AD 1249 reconstructs to have brought above-average rains**	**Tambora**	**Drought + Wet**
AD 1251–1252	**Czech Lands**	**Provisions, wine, and tree fruits reportedly failed after an almost entirely dry spring ending with an excessive pluvial. Documents report Summer famine and a lack of animal fodder. Both years reconstruct to be excessively dry**	**Tambora**	**Drought + Wet**
AD 1253–1254	**Germany, Czech Lands**	**Failed harvests reportedly caused food shortages and increased food prices**	**Cook et al. 2015; Tambora**	**Wet**
AD 1255	**Germany, Austria**	**Documents state that "Neither the crops of the fields, nor the vines, nor the trees yielded fruit to their cultivators, so much so that the rich and the poor endured hunger and starvation." Drought reconstructs to have been. Southern Germany and Austria reconstruct to have been moderately dry**	**Kiss and Nikolić 2015; Ljunqvist et al. 2024; Tambora**	**Drought**
AD 1256	**Latvia**	**Hunger is recorded in Livland. Drought reconstructs to have been minimal to moderate**	**Tambora**	**Drought**
AD 1257–1258	**Germany, Austria, Belgium, Denmark, the Netherlands**	**A great drought and food shortage is recorded in Neresheim. scPDSI values do not corroborate Summer drought, and drought must have therefore been seasonal**	**Cook et al. 2015; Ljungqvist et al. 2024; Tambora**	**Wet**

Year	Recorded Location(s)	Notes	Source(s)	Weather Event
AD 1262–1264	**Germany, Czech Lands, Poland**	**Grain, hay, fruit and fodder shortages that killed many people and livestock are recorded. Drought reconstructs to have been moderate to severe**	**Brádzil et al. 2013; Cook et al. 2015; Tambora**	**Likely Drought + Cold**
AD 1266	**Czech Lands**	**A Summer drought caused poor cereal, fruit, and wine harvest. Drought reconstructs to have been minimal**	**Brádzil et al. 2013**	**Drought**
AD 1268	**Germany, Netherlands Poland**	**Four years of excessive rain are recorded to have diminished crop growth and stores and caused a great famine and livestock die-off**	**Tambora**	**Wet**
AD 1270–1271	**Germany, Poland**	**In Osterhofen, Munich, and Niederalteich: "In the same summer there was such a drought everywhere such that all the crops dried up; and because of this a very great famine ensued. Only the wine (grapes) has grown in abundance." Famine is also noted in Ellwangen and Neresheim in Germany, and raised prices are recorded throughout Swabia. Drought reconstructs to have been severe**	**Cook et al. 2015; Tambora**	**Drought**
AD 1272–1273	**Czech Lands, Netherlands, Germany**	**Animal husbandry and cropping are recorded to have been strained, and grain shortage is recorded in Lübeck. Drought reconstructs to have been minimal**	**Tambora**	**Drought**
AD 1275	**Germany**	**Crops fail in excessive pluvials and cold temperatures**	**Cook et al. 2015; Tambora**	**Wet + Cold**
AD 1276	**Germany**	**A great wind is recorded to have destroyed crops and cattle. Drought reconstructs to have been moderate to severe**	**Cook et al. 2015; Tambora**	**Drought + Wind**
AD 1277	**Austria**	**Drought is recorded to have caused mass loss of livestock. Drought reconstructs to have been minimal**	**Kiss and Nikolić 2015**	**Drought**
AD 1278	**Austria**	**Cold frosts and drought are recorded to have induced famine in the Carinthia region, and cases of cannibalism are recorded**	**Cook et al. 2015; Tambora**	**Drought + Cold**
AD 1281	**Czech Lands, Austria, Poland, Germany, Belgium, Denmark**	**Heavy snows are recorded to have destroyed crop fields and created famine that killed many in Bavaria, Carinthia, Moravia, and throughout Poland**	**Ljungqvist et al. 2024; Tambora**	**Locally wet, regionally dry**

Year	Recorded Location(s)	Notes	Source(s)	Weather Event
AD 1282	Czech Lands, Germany, Poland, Hungary, Austria, Switzerland, Croatia, Belgium, Denmark, Luxembourg, Liechtenstein	There are documented famine mass graves in Kutná Hora-Sedlec, and famine is recorded in writings	Brzobohatá et al. 2019; Ljunqvist et al. 2024; Tambora	Wet
AD 1294	Germany	Reportedly, a dry, hot summer left cattle unable to be fed and caused early slaughter. However wine and grain were sustainable Drought reconstructs to have been moderate	Cook et al. 2015; Tambora	Drought
AD 1301–1304	Germany	Records tell that drought caused mass crop withering, and a famine ensued throughout Germany. In Stuttgart, fruits failed and mills ceased to operate, however wine was successful. Grain was sourced from Sicily. Drought reconstructs to have been moderate to extreme, especially in AD 1304	Tambora	Drought
AD 1307	Czech Lands	Reportedly, a wet winter with heavy snow inhibited crops, and a dry Spring and Summer are reported to have caused a poor harvest and famine	Brádzil et al. 2013; Tambora	Wet + Drought
AD 1310	Germany	There is documentation of a cold and dry-induced famine that necessitated the mass burial of over 2,300 corpses in Bavaria. Drought reconstructs to have been moderate to severe	Tambora	Drought + Dold
AD 1312	Germany, Austria, Czech Lands	Crop fields are documented to have burned in Nuremberg during a prolonged drought and dry summer. Mills in the river Cremsa reportedly ceased operation due to diminished water levels, and adjacent streams ran dry. Famine is recorded in Austria. Poor harvests, famine, and high prices are recorded in Prague Drought reconstructs to have been moderate to severe	Cook et al. 2015; Kiss and Nikolić 2015 Tambora	Drought
AD 1313	Germany, Austria, Czech Lands	Hunger is recorded in Miltenburg. Periods of hunger are recorded in Bavaria, Austria, and the Czech Lands. Drought reconstructs to have been minimal	Cook et al. 2015; Kiss and Nikolić 2015; Tambora	Drought

Year	Recorded Location(s)	Notes	Source(s)	Weather Event
AD 1315–1321	**Pan-Europe**	**An excessive pluvial is reported to have begun in AD 1314 that caused a near-universal crop failure in the following year throughout all of Europe. Severe to extreme reconstructed droughts appear in AD 1318–1320**	**Engler 2012; Brádzil et al. 2013; Cook et al. 2015; Collet and Krämer 2017; Camenisch and Rohr 2018; Bauch et al. 2020; ScienceDaily 2021; Ljunqvist et al. 2024; Tambora**	**Drought + Wet (Seasonal)**
AD 1318	**Czech Lands, Austria, Hungary, Germany, Poland, Belgium, Switzerland, Luxembourg, Liechtenstein, Croatia**	**There are documented famine mass graves in Kutná Hora-Sedlec associated with a great period of hunger Drought reconstructs to have been severe to extreme**	**Brzobohatá et al. 2019; Ljunqvist et al. 2024; Tambora**	**Drought**
AD 1326	**Czech Lands**	**Summer drought is recorded throughout the Czech Lands along with poor harvests and a complete loss of Spring crops. Drought reconstructs to have been extreme**	**Brádzil et al. 2013**	**Drought**
AD 1333	**Czech Lands**	**Poor harvest of Summer cereals and a low wine yield are recorded in Zbraslav and Bohemia. Drought reconstructs to have been Extreme**	**Brádzil et al. 2013**	**Drought**
AD 1337	**Czech Lands**	**Poor cereal and wine harvests and raised food prices are recorded in Zbraslav and Bohemia, scPDSI values suggest neutrality to slight dryness**	**Brádzil et al. 2013**	**Drought**
AD 1338–1339	**Germany**	**Generational locust swarms are reported to have decimated crops**	**Tambora**	**N/A Locusts**
AD 1343	**Germany**	**Flooding of the Dreisam River reportedly destroyed field crops**	**Tambora**	**Wet**
AD 1348	**Czech Lands**	**Poor crop harvests and dry soils are recorded in Prague and Bohemia. Drought reconstructs to have been minimal**	**Brádzil et al. 2013**	**Drought**

Year	Recorded Location(s)	Notes	Source(s)	Weather Event
AD 1352	**Germany, Czech Lands**	**A cold winter reportedly froze livestock, crops, and people, scPDSI numbers also show substantial reconstructed drought. Summer drought and poor harvest are recorded in Prague and Bohemia**	**Brádzil et al. 2013; Cook et al. 2015; Tambora**	**Cold + Drought**
AD 1360	**Austria**	**Dry, cracked soil and crop failure is recorded in Zwettl, in addition to a loss of livestock. Drought reconstructs to have been extreme**	**Kiss and Nikolić 2015; Tambora**	**Drought**
AD 1361	**Czech Lands, Germany**	**Grain and corn failures are recorded in Pressburg and Meissen. Drought reconstructs to have been extreme**	**Tambora**	**Drought**
AD 1362	**Hungary, Croatia, Czech Lands**	**Crop failure and low river levels are recorded. Drought reconstructs to have been severe to extreme**	**Kiss and Nikolić 2015**	**Drought**
AD 1363	**Germany, Switzerland**	**Drought reportedly resulted in livestock deaths, grain and fodder shortages, and great hunger. Drought was reportedly followed by a devastating cold. scPDSI reconstructions do not appear to corroborate drought in Germany**	**Cook et al. 2015; Tambora**	**Drought**
AD 1368	**Czech Lands**	**Drought is reported to have yielded poor Spring and Summer harvests. Drought reconstructs to have been moderate to severe**	**Brádzil et al. 2013**	**Drought**
AD 1370	**Germany**	**Drought in AD 1370 reportedly caused a shortage of hay fodder and grain, but corn and wine were sustainable. Cold ensued, then Spring was temperate. Drought reconstructs to have been moderate to severe**	**Cook et al. 2015; Tambora**	**Drought**
AD 1371	**Czech Lands**	**Documented frequent Summer fires caused low crop yields. Drought reconstructs to have been moderate to severe, especially in the north of the study region**	**Brádzil et al. 2013**	**Drought**
AD 1386–1387	**Germany**	**Flooding in Breslau reportedly decimated crop fields, mills, and villages causing a shortage of bread. An unproductive summer is recorded in Wurzburg**	**Cook et al. 2015; Tambora**	**Wet**
AD 1389	**Germany**	**Wine, grain, and fruit harvests are recorded to have been minimal. Drought reconstructs to have been extreme**	**Tambora**	**Drought**

Year	Recorded Location(s)	Notes	Source(s)	Weather Event
AD 1394	**Austria**	**Drought reportedly brought the mass loss of livestock. Drought reconstructs to have been moderate, however drought in the north of the study region appears to have been severe to extreme**	**Kiss and Nikolić 2015**	**Drought**
AD 1397	**Germany**	**An early, diminished harvest is recorded. Drought reconstructs to have been extreme**	**Büntgen et al. 2011**	**Drought**
AD 1403–1405	**Austria**	**Excessive pluvials in AD 1404 reportedly caused molding of crops and fruits, and flooding of the Danube inundated fields with sand and silt. An AD 1405 famine reportedly followed, crop prices more than doubled, and many perished. scPDSI data does not corroborate pluvials and suggests moderate drought**	**Cook et al. 2015; Tambora**	**Wet**
AD 1406	**Germany, Belgium**	**Excessive pluvials and winds are reported to have destroyed crops, and lightning storms spread several fires**	**Cook et al. 2015; Tambora**	**Wet**
AD 1415	**Poland, Austria, Czech Lands**	**Poor harvests are recorded after excessively wet Springs and Summers**	**Büntgen et al. 2011**	**Wet**
AD 1417	**Czech Lands**	**A carving on Děčín Hunger Stone in the Elbe River indicates drought. Drought reconstructs to have been extreme**	**Odbratt 2023**	**Drought**
AD 1419	**Austria, Germany**	**Raised prices, heat, and death are recorded in Austria and Germany. Drought reconstructs to have been severe in the Summer months, and records report severe winter cold and flooding**	**Tambora**	**Drought + Wet**
AD 1420	**Germany**	**Heavy winter frosts reportedly yielded food shortages followed by early blooming. Drought reconstructs to have been severe**	**Büntgen et al. 2011; Cook et al. 2015; Tambora**	**Cold + Drought**
AD 1425	**Germany**	**Fruit and wine shortages reportedly yielded many deaths, along with plague outbreaks in Wurzburg and Hanau. Reconstructions suggest extreme drought**	**Cook et al. 2015; Tambora**	**Drought**
AD 1426	**Austria**	**Drought reportedly caused mass losses of livestock. Drought reconstructs to have been severe**	**Kiss and Nikolić 2015**	**Drought**

Year	Recorded Location(s)	Notes	Source(s)	Weather Event
AD 1427	**Poland, Austria**	**Flooding of the Vistula reportedly caused water silting and mill damage increasing grain prices. Livestock losses are recorded in Austria. Flooding must have been seasonal, as Summer reconstructions suggest moderate to severe drought**	**Kiss and Nikolić 2015; Tambora**	**Locally wet, regionally dry**
AD 1430	**Germany**	**Famine and raised grain and corn prices are recorded throughout northern Germany. Drought reconstructs to have been moderate**	**Cook et al. 2015; Tambora**	**Drought**
AD 1433	**Germany**	**Freezing and floods inhibited wine production in Stuttgart. scPDSI reconstructions suggest extreme Summer drought, therefore flooding must have been seasonal**	**Cook et al. 2015; Tambora**	**Wet**
AD 1437–1438	**Germany, Austria, Hungary, Poland, the Netherlands, Belgium, Croatia, Denmark, Switzerland, Luxembourg, Liechtenstein**	**Many deaths due to a lack of grain are reported in Augsburg. scPDSI reconstructions suggest moderate to severe drought**	**Cook et al. 2015; Ljunqvist et al. 2024; Tambora**	**Drought**
AD 1440–1441	**Germany, Austria, Hungary, Poland, the Netherlands, Belgium, Czech Lands, Croatia, Denmark, Switzerland, Luxembourg, Liechtenstein**	**Cold, snow, and summer drought are reported to have caused hunger and many deaths in Sponheim, Augsburg, and Hanover as mills and fields froze. Bad harvests of cereals, fruits, fodder, and peas are recorded in Karlštejn and Bohemia. Drought reconstructs to have been severe to extreme**	**Brádzil et al. 2013; Cook et al. 2015; Ljunqvist et al. 2024; Tambora**	**Drought + Wet + Cold**
AD 1442–1443	**Germany, Czech Lands**	**Wheat, rye, and fish are reported to have dried up around Dortmund, and poor cereal and fodder harvests and water shortages are recorded in Prague, Bohemia, and Hradec Králové. Drought reconstructs to have been extreme in both years**	**Brádzil et al. 2013; Tambora**	**Drought**

Year	Recorded Location(s)	Notes	Source(s)	Weather Event
AD 1443	**Czech Lands**	**Major rivers reportedly froze and inhibited milling. scPDSI reconstructions suggest severe drought**	**Cook et al. 2015; Tambora**	**Cold + Drought**
AD 1446–1448	**Germany**	**“Great need” was recorded in Burburgenheim when rivers dried, however wine was reportedly successful. Mills are recorded to have stopped, and there was a great shortage of bread in Miltenburg, Schweinfurt, Franken, and Wurzburg. Severe economic losses are recorded in Koblenz. Drought reconstructs to have been extreme in all three years**	**Tambora**	**Drought**
AD 1451–1452	**Germany. Austria, Danube**	**Records report that rivers froze in Augsburg and Lech, inhibiting milling and causing a shortage of bread and flour. A great hunger is noted in Lemwerder. scPDSI reconstructions suggest moderate drought in AD 1451 and severe drought in AD 1452**	**Cook et al. 2015; Tambora**	**Cold + Drought**
AD 1455	**Oder River Basin**	**Summer crops reportedly withered after no rain for 16 weeks. The Oder River reportedly ran dry. Drought reconstructs to have been moderate**	**Tambora**	**Drought**
AD 1456	**Austria, Germany**	**King Ladislaus is recorded to have given great alms to the public who suffered in a time of barrenness. scPDSI reconstructions suggest above-average Summer wetness. Flooding and wind is recorded to have drowned fields and villages in Ulm. Drought must have been seasonal**	**Cook et al. 2015; Tambora**	**Wet**
AD 1459–1461	**Austria, Germany**	**Crops reportedly died and disease spread in Vienna and Munich. Significant price increases are recorded in Landshut. In Munich: “there was an excessive drought, so that even the grass of the meadows did not abound, [...] because of the bad weather and the hail, the crops were destroyed there for five thousand miles in length and breadth.” Drought reconstructs to have been severe to extreme in all three years**	**Cook et al. 2015; Tambora**	**Drought**
AD 1461	**Czech Lands**	**A carving on a Děčín Hunger Stone in the Elbe River indicates drought. Drought reconstructs to have been extreme**	**Odbratt 2023**	**Drought**
AD 1465	**Hungary**	**The “Fisch Preis Taxe in Eger” suggests that Hungarians sought cheap, salted fish to compensate for an under-supply of resources. Drought reconstructs to have been moderate in Hungary, but extreme in the north of the study region**	**Galik et al. 2015**	**Drought**

Year	Recorded Location(s)	Notes	Source(s)	Weather Event
AD 1471	Germany	Severe drought is recorded in Achern which reportedly caused streams and lakes to run dry. scPDSI reconstructions suggest severe drought	Cook et al. 2015; Tambora	Drought
AD 1472	Germany	Summer drought is recorded after a temperate spring. Drought reportedly yielded fodder losses, however grain and wine were sustainable. scPDSI reconstructions suggest a temperate, seasonal Summer	Cook et al. 2015; Tambora	Non-extreme
AD 1473	Germany, Hungary, Lithuania, Poland, Czech Lands	Mill shortages, fish deaths, and crop failures are noted in Göttingen. Bohemian and German forests reportedly burned for 14 weeks, causing mass hunger and inhibiting production. scPDSI reconstructions corroborate extreme drought	Cook et al. 2015; Tambora	Drought
AD 1474	Germany, Hungary, Croatia, Czech Lands	Water shortages reportedly dried up springs for almost the entire year in Passau. Crop shortage and low rivers are recorded in Hungary, Croatia, and the Czech Lands. scPDSi reconstructions suggest moderate drought.	Cook et al. 2015; Kiss and Nikolić 2015; Tambora	Drought
AD 1479	Hungary, Croatia, Czech Lands	Crop shortages and low rivers are recorded in Hungary, Croatia and the Czech Lands. Drought reconstructs to have been severe	Kiss and Nikolić 2015	Drought
AD 1480	Germany, Austria, Hungary, Poland, the Netherlands, Belgium, Croatia, Denmark, Switzerland, Luxembourg, Liechtenstein	Flooding is recorded in Nuremberg and Basel	Cook et al. 2015; Ljunqvist et al. 2024; Tambora	Locally wet, regionally dry
AD 1482	Germany, Austria, Hungary, Poland, the Netherlands, Belgium, Croatia, Denmark, Switzerland, Luxembourg, Liechtenstein	A lack of grain is recorded in upper Swabia. scPSDI reconstructions suggest moderate drought	Cook et al. 2015; Ljunqvist et al. 2024; Tambora	Likely Drought

Year	Recorded Location(s)	Notes	Source(s)	Weather Event
AD 1485	**Germany**	**Grapes are reported to have failed in Sponheim. Reconstructed scPDSI numbers suggest wet conditions**	**Cook et al. 2015; Tambora**	**Likely Wet**
AD 1489	**Baltic Sea, Germany**	**A severe frost reportedly froze the Baltic shore, all wells, and smaller streams, thereby inhibiting milling and frosting grapes, grian, and fruit. scPDSI numbers suggest a relatively wet year**	**Cook et al. 2015; Tambora**	**Cold + Wet**
AD 1491–1492	**Germany, Netherlands, Belgium, Denmark**	**Fewer than 20 rain days were recorded in Germany, the Netherlands, Belgium, and Denmark, and dry and thin crops are recorded in Dortmund. scPDSI reconstructions suggest severe drought**	**Cook et al. 2015; Ljunqvist et al. 2024; Tambora**	**Drought**
AD 1494	**Hungary, Czech Lands**	**Crop shortages and low rivers are recorded in Hungary, Croatia and the Czech Lands. Drought reconstructs to have been moderate to severe**	**Kiss and Nikolić 2015**	**Drought**
AD 1495	**Baltic Maritime Countries**	**Immense flooding and the destruction of fields, buildings, and livestock is recorded in Poland, Germany, Latvia, and Lithuania.**	**Tambora**	**Wet**
AD 1501	**Germany, Switzerland**	**Hunger and lack of grain and bread is reported as a result of war. However, scPDSI reconstructions also suggest that AD 1500 was very dry while 1501 was temperate. Drought in AD 1500 may have impacted crops and supplies**	**Cook et al. 2015; Tambora**	**Drought + War**
AD 1503–1504	**Germany, Czech lands**	**Records from Bonn describe a cold winter followed by a hot and dry summer that dried up most all growth, especially wheat. Milling was halted and harvests were reported to be poor in Litoměřice. scPDSI reconstructions suggest severe drought in both years**	**Cook et al. 2015; Brádzil et al. 2019; Tambora**	**Drought**
AD 1506–1507	**Hungary, Romania, Serbia, Croatia and the Czech Lands**	**Diminished Autumn, Spring, and Summer River Tisza sturgeon yields are explicitly recorded in the Eger diocese in AD 1506–1507, and have been confidently linked with pervasive drought in Hungary, Romania, Serbia, and the Czech Lands. Drought reportedly brought mass crop failure and livestock die-offs. Crop shortage and low rivers are recorded in Hungary, Croatia and the Czech Lands. Drought reconstructs to have been severe**	**Kiss and Nikolić 2015; Kiss 2020**	**Drought**

Year	Recorded Location(s)	Notes	Source(s)	Weather Event
AD 1511	Germany, Rhine	Flooding of the Rhine reportedly caused a food shortage in many villages	Cook et al. 2015; Tambora	Wet
AD 1512–1514	Germany, Austria, Switzerland	Intense cold, river and ground freezing, and water shortage that arrested mills, livestock, wine making, and cropping are noted in Sulzbach and Amberg. Bread prices more than doubled, and it is said that people had to boil wheat to eat it. scPDSI reconstructions suggest moderate to severe drought in AD 1512, 1513, and 1514	Cook et al. 2015; Tambora	Drought
AD 1515	Germany	A dry summer that created food insecurity is noted in Burburgenheim and Stralsund. scPDSI numbers do not corroborate drought, and suggest a moderately wet Summer	Cook et al. 2015; Tambora	Drought
AD 1516–1518	Germany, Switzerland, Netherlands, Poland, Hungary, Austria, Czech Lands, Luxembourg, Liechtenstein	A lack of all fruits, grain and water shortages are recorded throughout central Europe. Fish and cattle are recorded to have perished en masse. scPDSI numbers corroborate extreme drought throughout the continent	Cook et al. 2015; Ljunqvist et al. 2024; Tambora	Drought
AD 1521–1523	Germany, Austria, Hungary, the Netherlands, Poland, Czech Lands, Croatia, Serbia, Switzerland, Belgium, Luxembourg, Liechtenstein	A series of 14 or more great rains reportedly caused floods and damage to mills and crop fields in Leipzig, Erfurt, and Neumark. scPDSI reconstructions suggest moderate Summer drought in the southern study area	Cook et al. 2015; Ljunqvist et al. 2024; Tambora	Wet
AD 1529–1531	Germany, Austria, Hungary, the Netherlands, Poland, Czech Lands, Croatia, Serbia, Switzerland, Belgium, Luxembourg, Liechtenstein	A great shortage of food is noted in Kassel, and famine is noted throughout Dietz and in Koblenz. scPDSI reconstructions suggest a very wet year in AD 1529, and accounts of flooding in Regensburg report damage to mills and increased bread prices. Europeans were reportedly covetous of surplus in AD 1530, prices remained high, and the poor suffered a great dearth	Cook et al. 2015; Ljunqvist et al. 2024; Tambora	Wet

Year	Recorded Location(s)	Notes	Source(s)	Weather Event
AD 1534	**Germany**	**A great drought reportedly diminished milling and caused all foliage to wither. Many livestock perished. scPDSI reconstructions corroborate severe drought**	**Cook et al. 2015; Tambora**	**Drought**
AD 1536	**Germany**	**A shortage of water for livestock was reported in Stuttgart and Windsheim, however wine was sustainable. scPDSI reconstructions corroborate severe drought**	**Cook et al. 2015; Tambora**	**Drought**
AD 1540	**Pan-Europe**	**Mills were recorded as being unable to run, despite grain and wine grapes being abundant, so food prices skyrocketed and there was a shortage of bread. Fish were recorded to have dried out in water sources, and plague outbreaks occurred. scPDSI reconstructions corroborate severe to extreme drought**	**Wetter et al. 2014; Dobrovolný et al. 2015; Camenisch and Rohr 2018**	**Drought**

Appendix C
Dates of Foreign Fishing and Hanseatic Affiliation in Central Europe and Beyond

Cross-examination of Hanseatic affiliation years with recent drought and foodway disruptions can evidence the potential need or desire to join the Hanseatic trade union monopoly to benefit from and mutual protect and supply pacts. These pacts would have ensured access to marine fish among other staple goods

City	Date of Hanseatic Affiliation or Foreign Fishing	Notes	Source	Recent Drought Years (~prior 5 years including streaks) or Droughts per Time Period (if indicated)	Recent Foodway Disruptions (~prior 5 years including streaks) or Disruptions per Time Period (if indicated)
			Pre-Hanse Lübeck Fishing Abroad		
Lübeck, Germany	**AD 1241**	Lübeck had active fishermen and merchants in the 12th century, but formalized early Hanse relations with Hamburg in AD 1241 *** **the AD 1173–1175 Köln-English alliance also fell in a stretch of drought and foodway disruption**	Die Hanse	**Droughts between AD 1100–1237 (When Lübeck began sourcing marine fish):** AD 1100–1121, 1123–1135, 1137–1139, 1142–1143, 1146–1147, 1150, 1152–1153, 1155–1156, 1159, 1161–1186, 1188–1189, 1191–1194, 1197, 1199–1200, 1202, 1204–1205, 1207–1209, 1211–1223, 1225–1237 (**125 total** between AD 1100–1237) --- **Droughts between AD 1238–1241 (Hamburg alliance):** AD 1238, 1240, 1241	**Recorded Disruptions between AD 1100–1237:** AD 1099–1102, 1113, 1115, 1124, 1128, 1135, 1137, 1144–1148, 1149–1150, 1150–1151, 1153–1155, 1166, 1173, 1175, 1176–1177, 1194, 1195–1198, 1204–1206, 1217–1218, 1223–1224, 1225–1227, 1234 --- **Recorded Disruptions between AD 1238–1241:** ?

Skanör-Falsterbo, Sweden	**AD 1241**	Pre-Hanse rights were extended to Lübeck traders in AD 1203 and 1225		**Since Sweden already exploited a preponderance of marine taxa, German droughts are more pertinent since Germans would have been seeking fish;** **German droughts ~ 5 years prior to AD 1203:** AD 1197, 1199–1200, 1202 **~ 5 years prior to AD 1225:** AD 1220–1223, 1225 **~ 5 years prior to AD 1241:** AD 1237–1238, 1240, 1241	**Since Sweden already exploited a preponderance of marine taxa, German disruptions are more pertinent since Germans would have been seeking fish;** **Recorded German disruptions ~ 5 years prior to AD 1203:** AD 1197–1198 **~ 5 years prior to AD 1225:** AD 1223–1225 **~ 5 years prior to AD 1241:** ?

Visby, Gotland, Sweden	**AD 1241**	Visby was occupied by Lübeck merchants in the 12th century, but goods began circulating more widely after the AD 1241 pact		**Since Sweden already exploited a preponderance of marine taxa, German droughts are more pertinent since Germans would have been seeking fish;** **German droughts between AD 1100–1237 (When Lübeck began sourcing marine fish):** AD 1100–1121, 1123–1135, 1137–1139, 1142–1143, 1146–1147, 1150, 1152–1153, 1155–1156, 1159, 1161–1186, 1188–1189, 1191–1194, 1197, 1199–1200, 1202, 1204–1205, 1207–1209, 1211–1223, 1225–1237 (**125 total** between AD 1100–1237) ——— **German droughts between AD 1238–1241 (Hamburg alliance):** AD 1238, 1240, 1241	**Since Sweden already exploited a preponderance of marine taxa, German disruptions are more pertinent since Germans would have been seeking fish:** **Recorded German disruptions between AD 1100–1237:** AD 1099–1102, 1113, 1115, 1124, 1128, 1135, 1137, 1144–1148, 1149–1150, 1150–1151, 1153–1155, 1166, 1173, 1175, 1176–1177, 1194, 1195–1198, 1204–1206, 1217–1218, 1223–1224, 1225–1227, 1234 ——— **Recorded German disruptions between AD 1238–1241:** ?

Turku, Finland	**AD 1241**	Trade with Lübeck was established in the AD 1170s	Die Hanse	**Since Finland already exploited a preponderance of marine taxa, German droughts are more pertinent since Germans would have been seeking fish;** **German droughts between AD 1170–1180 (When Lübeck began sourcing marine fish):** AD 1170–1180 **German Droughts between AD 1181–1237:** AD 1181–1186, 1188–1189, 1191–1194, 1197, 1199–1200, 1202, 1204–1205, 1207–1209, 1211–1223, 1225–1237 **German droughts between AD 1238–1241 (Hamburg alliance):** AD 1238, 1240, 1241	**Since Finland already exploited a preponderance of marine taxa, German disruptions are more pertinent since Germans would have been seeking fish;** **German disruptions between AD 1170–1180:** AD 1173, 1175, 1176–1177 **German disruptions between AD 1181–1241:** AD 1194, 1195–1198, 1204–1206, 1217–1218, 1223–1224, 1225–1227, 1229, 1233, 1234
			Early Hanseatic Affiliations	**(Local Droughts last ~5 years)**	**(Local Disruptions last ~5 years)**
Hamburg, Germany	**AD 1241**	Signed initial pact with Lübeck exchanging salt and herring	Die Hanse	AD 1239, 1240, 1241	?
Medebach, Germany	**AD 1241**	Trade extended in AD 1241 with Lübeck and Hamburg, but began in AD 1165 with the city charter	Die Hanse	AD 1239, 1240, 1241	**?**
Harderwijk, Netherlands	**AD 1252**		Die Hanse	AD 1251–1252	AD 1248–1259
Bruges, Belgium	**AD 1253**	Entered trade with Lúbeck and Hamburg. *Kontors* were established in AD 1280–1282	Die Hanse; Encyclopedia Britannica; Furthark	AD 1251–1252	?

Warendorf, Germany	**AD 1255**		Furthark	AD 1250–1252	AD 1253–1255
Wismar, Germany	**AD 1259**		Encyclopedia Britannica	AD 1259	AD 1255, 1257–1258
Braunschweig(Brunswick), Germany	**AD 1260**		Furthark	AD 1259–1260	AD 1257–1258
Salzwedel, Germany	**AD 1263**		Furthark	AD 1259–1263	AD 1257–1258, 1262–1264
Rostock, Germany	**AD 1264**	Mutual defense pact with Lübeck and Wismar chartered	Furthark	AD 1260–1263	AD 1262–1264
Pärnu, Estonia	**AD 1265**	Joined shortly after being granted city status	Die Hanse	AD 1260–1263	?
Stade, Germany	**AD 1267**		Die Hanse	AD 1263, 1265, 1267	AD 1262–1264
Goslar, Germany	**AD 1267**		Encyclopedia Britannica	AD 1263, 1265, 1267	AD 1262–1264
Magdeburg, Germany	**AD 1275**		Furthark	AD 1270, 1272, 1273	AD 1270–1271, 1272–1273, 1275
Greifswald, Germany	**AD 1278**		Encyclopedia Britannica	AD 1274, 1276, 1278	AD 1275–1276
Torún, Poland	**AD 1280**		Encyclopedia Britannica	AD 1276–1280	?
Riga, Latvia	**AD 1282**	First granted Lübeck traders a house in AD 1231 through Teutonic alliance	Encyclopedia Britannica; Furthark	AD 1276–1280	?

Köin (Cologne), Germany	**AD 1282**	Merged with Lübeck and Hamburg abroad in London	Encyclopedia Britannica; Furthark	AD 1278–1279	AD 1276, 1281, 1282
Groningen, Netherlands	**AD 1282**		Encyclopedia Britannica	AD 1276–1278	?
Anklam, Germany	**AD 1283**		Die Hanse	AD 1279	AD 1281, 1282
Demmin, Germany	**AD 1283**		Furthark	AD 1279	AD 1281, 1282
Kiel, Germany	**AD 1284**		Die Hanse	AD 1284	AD 1281, 1282
Tallinn (Reval), Estonia	**AD 1285**		Encyclopedia Britannica; Furthark	AD 1283–1285	?
Stavoren, Netherlands	**AD 1285**	Earlier trade is recorded, but affiliation formalized in AD 1285	Encyclopedia Britannica; Furthark	AD 1284–1285	**?**
Kalmar, Sweden	**AD 1285**	German Privileges were extended to Kalmar and Hanseatic partners in AD 1285, privileges were further granted in the Kalmar union of AD 1397	Furthark	**Since Sweden already exploited a preponderance of marine taxa, German droughts are more pertinent since Germans would have been seeking fish;** **German droughts ~ 5 years prior to AD 1285:** AD 1284–1285	**Since Sweden already exploited a preponderance of marine taxa, German disruptions are more pertinent since Germans would have been seeking fish;** **German disruptions ~ 5 years prior to AD 1285:** AD 1281, 1282
Stralsund, Germany	**AD 1293**		Encyclopedia Britannica	AD 1284–1289, 1292–1293	**?**
Zwolle, Netherlands	**AD 1294**		Encyclopedia Britannica	AD 1289, 1292–1293	?
Paderborn, Germany	**AD 1294**		Furthark	AD 1284–1289, 1292–1294	AD 1294
Minden, Germany	**AD 1295**		Furthark	AD 1292–1295	AD 1294
Lemgo, Germany	**AD 1295**		Die Hanse	AD 1292–1295	AD 1294

Hattem, Netherlands	**AD 1299**		Die Hanse	AD 1296–1299	?
Frombork, Poland	**AD 1310**	Allowed Lübeck traders rights	Encyclopedia Britannica	AD 1305–1310	?
Zutphen, Netherlands	**AD 1312**		Encyclopedia Britannica	AD 1308, 1310, 1311	?
Maasbommel, Netherlands	**AD 1312**		Die Hanse	AD 1308, 1310, 1311	?
Brandenburg, Germany	**AD 1314–1315**		Encyclopedia Britannica	AD 1310–1314	AD 1310, 1312, 1314
Antwerp, Belgium	**AD 1315**		Encyclopedia Britannica	AD 1310–1311	AD 1315
Recklinghausen, Germany	**AD 1316**		Furthark	AD 1310–1312, 1315–1316(?)	AD 1312–1313, 1315–1316
Königsberg, Prussia (now Kaliningrad, Russia)	**AD 1340**		Encyclopedia Britannica; Furthark	AD 1339	?
Narva, Estonia	**AD 1345**	Narva was chartered as a city under Lübeck law, and was a frequently visited port despite never formally joining the Hanse	Furthark, Encyclopedia Britannica	**-**	?
Hasselt, Netherlands	**AD 1350**	Prolific plague outbreak	Encyclopedia Britannica	AD 1346–1348	?
Bergen, Norway	**AD 1350**	The Hansa first established a Hanseatic office in Bergen, then gradually came to control the Stockfish trade with Bergen as its hub. Prolific plague outbreak.	Die Hanse; Encyclopedia Britannica	AD 1346–1349	?
Göttingen, Germany	**AD 1351**	Prolific plague outbreak	Die Hanse	AD 1246–1351	?

Darlowo, Poland	**AD 1352**	Prolific plague outbreak	Encyclopedia Britannica	AD 1348, 1351–1352	?
Bremen, Germany	**AD 1358**		Kovalchuk et al. 2024; Encyclopedia Britannica	AD 1346–1355, 1356–1357(?)	?
Werben, Germany	**AD 1358**	Withdrew in AD 1488	Die Hanse	AD 1346–1355, 1356–1357(?)	?
Gardelegen, Germany	**AD 1358**		Die Hanse; Furthark	AD 1346–1355, 1356–1357(?)	**?**
Osterburg, Germany	**AD 1359**		Encyclopedia Britannica	AD 1346–1355, 1356–1357(?)	?
Perleberg, Germany	**AD 1359**		Die Hanse	AD 1346–1355, 1356–1357(?)	?
Stendal, Germany	**AD 1358–1359**		Die Hanse, Furthark	AD 1346–1355, 1356–1357(?)	?
Kyritz, Germany	**AD 1359**		Encyclopedia Britannica	AD 1346–1355, 1356–1357(?)	?
Havelberg, Germany	**AD 1359**		Encyclopedia Britannica	AD 1346–1355, 1356–1357(?)	?
Pritzwalk, Germany	**AD 1359**		Die Hanse	AD 1346–1355, 1356–1357(?)	?
Seehausen, Germany	**AD 1359**		Die Hanse	AD 1346–1355, 1356–1357(?)	?
Szczecin, Poland	**AD 1360**		Encyclopedia Britannica; Furthark	AD 1357–1360	?
Gdańsk, Poland	**AD 1361**		Encyclopedia Britannica	AD 1357–1361	?
Stargard, Poland	**AD 1363**		Die Hanse	AD 1357–1361	?
Venlo, Netherlands	**AD 1364**		Encyclopedia Britannica	AD 1360–1361	?
Warburg, Germany	**AD 1364**		Die Hanse; Furthark	AD 1360–1361	AD 1361, 1363

Ulvila, Finland	**AD 1365**	Mecklenburg received trade rights	Die Hanse	**Since Finland already exploited a preponderance of marine taxa, German droughts are more pertinent since Germans would have been seeking fish:** **German droughts ~ 5 years prior to AD 1365:** AD 1360–1361 Other droughts are recorded elsewhere in Central Europe	**Since Finland already exploited a preponderance of marine taxa, German droughts are more pertinent since Germans would have been seeking fish:** **German disruptions ~ 5 years prior to AD 1365:** AD 1361, 1363 Other disruptions are recorded elsewhere in Central Europe
Hildesheim, Germany	**AD 1367**		Furthark	AD 1367	AD 1363
Elburg, Netherlands	**AD 1367**		Die Hanse	AD 1367	?
Einbeck, Germany	**AD 1368**		Die Hanse; Furthark	AD 1367–1368	AD 1363
Bialogard, Poland	**AD 1368**		Encyclopedia Britannica	AD 1365, 1367, 1368	?
Frankfurt, Germany	**AD 1368**		Encyclopedia Britannica; Furthark	AD 1367–1368	AD 1363
Kuldīga (Goldingen), Latvia	**AD 1368**	Strategic river port with Baltic outlet	JewishGen	AD 1367–1368	?
Hindeloopen, Netherlands	**AD 1368**		Die Hanse; Encyclopedia Britannica	AD 1367	?
Buxtehude, Germany	**AD 1369**		Furthark	AD 1367–1369	?
Uelzen, Germany	**AD 1374**		Furthark	AD 1369–1373	AD 1370 + ?
Hannover, Germany	**AD 1386**		Encyclopedia Britannica	AD 1381, 1384–1385	AD 1386
Koszalin, Poland	**AD 1386**		Encyclopedia Britannica	AD 1381, 1383–1386	**?**
Wrocław, Poland	**AD 1387**		Kovalchuk et al. 2024	AD 1383–1386	**?**

Halberstadt, Germany	**AD 1387**		Furthark	AD 1384–1385	AD 1386–1387
Tiel, Netherlands	**AD 1400**		Die Hanse	AD 1395–1397	?
Nijmegen, Netherlands	**AD 1402**		Die Hanse	AD 1391–1397	?
Duisburg, Germany	**AD 1407**		Furthark	AD 1403–1405, 1407	AD 1406 + ?
Emmerich am Rhein, Germany	**AD 1407**	Early trade happened in the late 14th century	Die Hanse	AD 1403–1405, 1407	?
Wesel, Germany	**AD 1407**		Furthark	AD 1403–1405, 1407	?
Osnabrück, Germany	**AD 1412**		Die Hanse	AD 1408–1409, 1411–1412	?
Mühlhausen, Germany	**AD 1418–1420**		Encyclopedia Britannica; Furthark	AD 1414–1420	AD 1419 + ?
Alfeld, Germany	**AD 1426**		Die Hanse	AD 1414–1426	AD 1419, 1420, 1425 Disruption is recorded in Austria in AD 1426
Aschersleben, Germany	**AD 1426**		Encyclopedia Britannica	AD 1414–1426	AD 1419, 1420, 1425 Disruption is recorded in Austria in AD 1426
Hameln, Germany	**AD 1426**		Furthark	AD 1414–1426	AD 1419, 1420, 1425 Disruption is recorded in Austria in AD 1426
Helmstedt, Germany	**AD 1426**		Encyclopedia Britannica; Furthark	AD 1414–1426	AD 1419, 1420, 1425 Disruption is recorded in Austria in AD 1426
Quedlinburg, Germany	**AD 1426**	Joined Saxon Alliance in AD 1384	Die Hanse	AD 1414–1426	AD 1419, 1420, 1425

Merseburg, Germany	**AD 1426**		Die Hanse	AD 1414–1426	AD 1419, 1420, 1425 Disruption is recorded in Austria in AD 1426
Gronau, Germany	**AD 1427**		Die Hanse	AD 1414–1427	AD 1419, 1420, 1425 Disruption is recorded in Austria in AD 1426 and 1427
Erfurt, Germany	**AD 1430**	Allied with Thuringian cities Mühlhausen and Nordhausen in AD 1306	Encyclopedia Britannica	AD 1426–1430	AD 1425, 1430 Disruption is recorded in Austria in AD 1426 and 1427
Nordhausen, Germany	**AD 1430**	Joined with Thuringian pact	Encyclopedia Britannica	AD 1426–1430	AD 1425, 1430 Disruption is recorded in Austria in AD 1426 and 1427
Naumburg (Saale), Germany	**AD 1432**	Records date to 18 May	Die Hanse, Furthark	AD 1430–1431	AD 1430
Roermond, Netherlands	**AD 1441**	Acquired right to mint coins in AD 1447	Furthark	AD 1437–1441	AD 1437–1441
Kampen, Netherlands	**AD 1441**		Die Hanse	AD 1437–1441	AD 1437–1441
Kaunas, Lithuania	**AD 1441**	Became a *Kontor*	Die Hanse	AD 1437–1439	?
Bolsward, Netherlands	**AD 1442**		Encyclopedia Britannica	AD 1437–1442	AD 1437–1441
Arnhem, Netherlands	**AD 1443**		Die Hanse	AD 1437–1443	AD 1437–1441
Doesburg, Germany	**AD 1447**		Encyclopedia Britannica	AD 1430–1447	AD 1442–1443, 1446–1447
Soest, Germany	**AD 1449**	Associated with Köln to join Hanse	Encyclopedia Britannica	AD 1430–1449	AD 1446–1448

Schwerte, Germany	**AD 1461**		Furthark	AD 1457–1461	AD 1455, 1547, 1459–1461
Telgte, Germany	**AD 1469**		Die Hanse	AD 1457–1469	?
Korbach, Germany	**AD 1469**		Die Hanse	AD 1457–1469	**?**
Hafnarfjörður, Iceland	**AD 1470**	Iceland granted privileges to German traders in AD 1470	Die Hansa	**Since Iceland already exploited a preponderance of marine taxa, German droughts are more pertinent:** **German droughts ~ 5 years prior to AD 1470:** AD 1457–1470 Much of Central Europe faced drought conditions	**Since Iceland already exploited a preponderance of marine taxa, German droughts are more pertinent:** **German disruptions ~ 5 years prior to AD 1470:** ?
Neuss, Germany	**AD 1475**		Die Hanse, Furthark	AD 1457–1474	AD 1471–1474
Lünen, Germany	**AD 1476**		Die Hanse	AD 1457–1474, 1476	AD 1471–1474
Neuenrade, Germany	**Before AD 1476**		Die Hanse	AD 1457–1474, 1476	AD 1471–1474
Kalkar and Grieth on the Rhine, Germany	**AD 1540**		Die Hanse	AD 1540, 1538, 1536	AD 1534, 1534, 1540
Haltern am See, Germany	**AD 1554**		Die Hanse	?	?
Hattingen, Germany	**AD 1554**		Die Hanse	?	?
Approximate Affiliation Time Periods					

Dortmund, Germany	**? 13th century**	Was the "chief city" of the Rhine, Westphalia, and Netherlandish spheres of Hanseatic trade in 13th-14th centuries	Die Hanse; Furthark	Must have affiliated after Hamburg in AD 1241, but before AD 1300 AD 1243–1244, 1247, 1250–1254, 1259–1263, 1265, 1267, 1270, 1272–1274, 1276, 1278–1279, 1284–1289, 1292–1294, 1296–1300 (**41 total** between AD 1241–1300)	**German disruptions Between AD 1241–1300:** AD 1245–1246, 1253–1254, 1255, 1257–1258, 1262–1264, 1268, 1270–1271, 1272–1273, 1275–1276, 1281–1282, 1294
Viljandi, Estonia	**? AD 1282–1300**	City founded in AD 1282–1283, joined Hanse in Late 13th century	Encyclopedia Britannica	AD 1283–1289, 1292–1294, 1296–1298 (**13 total** between AD 1282–1300)	**Estonian disruptions between AD 1282–1300:** ?
Słupsk, Poland	**? AD 1265–1300**	Słupsk was chartered in AD 1265 and joined the Hanse by the 14th century	Die Hanse	AD 1265, 1267, 1270, 1272, 1274, 1276, 1277–1281, 1283–1289, 1292–1294, 1296–1300 (**26 total** from AD 1265–1300)	**Polish disruptions between AD 1265–1300:** AD 1268, 1270–1271, 1281–1282
Dorpat (Tartu), Estonia	**? Late 13th century**	-	Encyclopedia Britannica, Die Hanse	AD 1250–1251, 1253, 1257, 1260, 1261, 1270, 1272–1273, 1276–1280, 1283–1289, 1292–1294, 1296–1298, 1300 (**28 total** between AD 1250–1300)	**Estonian disruptions between AD 1250–1300:** ?
Elbląg, Poland	**? Late 13th century**		Encyclopedia Britannica, Die Hanse	AD 1250–1253, 1255–1263, 1265, 1267, 1270, 1272, 1274, 1276, 1277–1281, 1283–1289, 1292–1294, 1296–1300 (**41 total** between AD 1250–1300)	**Polish disruptions between AD 1265–1300:** AD 1268, 1270–1271, 1281–1282
Koknese, Latvia	**? Between 1241–1400**	Founded in 1224 and flourished as a Hanse city during the 14th century. Certainly joined Hanse before AD 1400 but after AD 1241	Die Hanse	AD 1241, 1243–1245, 1247, 1250–1254, 1257–1263, 1267, 1272–1274, 1276–1280, 1283–1289, 1292–1294, 1296–1299, 1301, 1304–1311, 1314–1315, 1318–1320, 1322–1328, 1330–1333, 1337, 1339, 1346–1349, 1351–1353, 1356–1361, 1363–1364, 1367–1372, 1376, 1378–1379, 1388–1397, 1400 (**102 total** between AD 1241–1400)	**Latvian disruptions between AD 1224–1400:** AD 1256

Wenden (Cēsis), Latvia	**? 14th–15th century**		Die Hanse	1360, 1361, 1363–1364, 1367–1372, 1376, 1378–1379, 1388–1397, 1400 (**24 total** between AD 1360–1400)	**Latvian disruptions between AD 1360–1400:** ?
Valmiera (Wolmar), Latvia	**? During 14th century**	Was a Hanse member from 14th–16th century		AD 1301, 1304–1311, 1314–1315, 1318–1320, 1322–1328, 1330–1333, 1337, 1339, 1346–1349, 1351–1353, 1356–1361, 1363–1364, 1367–1372, 1376, 1378–1379, 1388–1397, 1400 (**62 total** between AD 1300–1400)	**Latvian disruptions between AD 1300–1400:** ?
Chelmno, Poland	**? 13th century**	Affiliated early with Lübeck traders	Die Hanse	AD 1202, 1204–1205, 1207–1209, 1211–1218, 1220–1236, 1238, 1240–1241, 1243–1245, 1247, 1250–1253, 1255–1263, 1265, 1267, 1270, 1272, 1274, 1276, 1277–1281, 1283–1289, 1292–1294, 1296–1300 (**77** total between AD 1200–1300)	**Polish disruptions between AD 1200–1300:** AD 1262–1264, 1268, 1270–1271, 1281, 1282, + ?
Bad Iburg, Germany	**? 13th century**	Affiliated early with Lübeck traders	Die Hanse	AD 1200, 1202, 1204–1205, 1207–1209, 1211–1223, 1225–1238, 1240–1241, 1243–1244, 1247, 1250–1254, 1259–1263, 1265, 1267, 1270, 1272–1274, 1276, 1278–1279, 1284–1289, 1292–1294, 1296–1300 (**72 total** between AD 1200–1300)	**German disruptions between AD 1200–1300:** AD 1204–1206, 1217–1218, 1223–1224, 1225–1227, 1229, 1233–1234, 1245–1246, 1253–1254, 1255, 1257–1258, 1262–1264, 1268, 1270–1271, 1272–1273, 1275–1276, 1281–1282, 1294

Brilon, Germany	**? 13th century**	Affiliated early with Lübeck traders	Die Hanse	AD 1200, 1202, 1204–1205, 1207–1209, 1211–1223, 1225–1238, 1240–1241, 1243–1244, 1247, 1250–1254, 1259–1263, 1265, 1267, 1270, 1272–1274, 1276, 1278–1279, 1284–1289, 1292–1294, 1296–1300 (**72 total** between AD 1200–1300)	**German disruptions between AD 1200–1300:** AD 1204–1206, 1217–1218, 1223–1224, 1225–1227, 1229, 1233–1234, 1245–1246, 1253–1254, 1255, 1257–1258, 1262–1264, 1268, 1270–1271, 1272–1273, 1275–1276, 1281–1282, 1294
Bielefeld, Germany	**? 14th century**		Die Hanse	AD 1300–1314, 1317–1320, 1322–1328, 1330–1337, 1339–1340, 1346–1349, 1351–1361, 1363, 1365, 1367–1373, 1375–1379, 1381, 1383–1385, 1389–1397, 1400 (**79 total** between AD 1300–1400)	**German disruptions between AD 1300–1400:** 1301–1304, 1310, 1312–1313, 1315–1321, 1338–1339, 1343, 1352, 1361, 1363, 1370, 1386–1387, 1389, 1397
Wippfürth, Germany	**? 14th century**	-	Die Hanse	AD 1300–1314, 1317–1320, 1322–1328, 1330–1337, 1339–1340, 1346–1349, 1351–1361, 1363, 1365, 1367–1373, 1375–1379, 1381, 1383–1385, 1389–1397, 1400 (**79 total** between AD 1300–1400)	**German disruptions between AD 1300–1400:** 1301–1304, 1310, 1312–1313, 1315–1321, 1338–1339, 1343, 1352, 1361, 1363, 1370, 1386–1387, 1389, 1397
Rijssen, Netherlands	**? 14th century**	-	Die Hanse	AD 1300–1308, 1310–1311, 1317–1320, 1322–1326, 1330–1337, 1339–1340, 1346–1348, 1351–1354, 1360–1361, 1367–1373, 1375–1377, 1381, 1384–1385, 1389–1397 (**74 total** between AD 1300–1400)	**Dutch Disruptions between AD 1300–1400:** ?

Meppen, Germany	**? 15th century**		Die Hanse	AD 1400, 1403–1405, 1407–1409, 1411–1427, 1429–1435, 1437–1444, 1446–1455, 1457–1474, 1476–1479, 1482–1486, 1491–1494, 1499–1500 (**92 total** between AD 1400–1500)	**German disruptions between AD 1400–1500:** AD 1406, 1419–1420, 1425, 1430, 1433, 1437–1438, 1440–1441, 1442–1443, 1446–1448, 1451–1452, 1455–1456, 1459–1461, 1471–1474, 1480, 1482, 1485, 1489, 1491–1492, 1495
Deventer, Netherlands	**?**	Played a crucial role in the cod stockfish monopoly. Deventer Was the parent city of Ommen, Enschede, Oldenzaal, Gramsbergen and Hasselt. Hasselt joined the Hansa in AD 1350, so it is likely that Deventer and the other subsidiary cities did, as well	Encyclopedia Britannica	**? (likely reference is Hasselt)**	**? (likely reference is Hasselt)**
Ommen, Netherlands	**?**	Likely joined AD 1350 given association with Hasselt	Encyclopedia Britannica	**? (likely reference is Hasselt)**	**? (likely reference is Hasselt)**
Enschede, Netherlands	**?**	Likely joined AD 1350 given association with Hasselt	Encyclopedia Britannica	**? (likely reference is Hasselt)**	**? (likely reference is Hasselt)**
Oldenzaal, Netherlands	**?**	Likely joined AD 1350 given association with Hasselt	Encyclopedia Britannica	**? (likely reference is Hasselt)**	**? (likely reference is Hasselt)**
Gramsbergen, Netherlands	**?**	Likely joined AD 1350 given association with Hasselt	Encyclopedia Britannica	**? (likely reference is Hasselt)**	**? (likely reference is Hasselt)**

Brielle, Netherlands	?	-	-	?	?
Dordrecht, Netherlands	?	-	-	?	?
Attendorn, Germany	?	-	-	?	?
Bockenem, Germany	?	-	-	?	?
Duderstadt, Germany	?	-	-	?	?
Quakenbrück, Germany	?	-	-	?	?
Dorsten, Germany	?	Chartered in AD 1251	Encyclopedia Britannica	?	?
Nieheim, Germany	?	-	-	?	?
Lüneberg, Germany	?	Municipal debt register chartered in AD 1290	Furthark		
Berlin, Germany	?	Withdrew in AD 1452 under Hohenzollern rule	-	?	?
Halle (Saale), Germany	?	Withdrew in AD 1479	-	?	?
Northeim, Germany	?	Withdrew in 1430 given pressures from Saxon lords	-	?	?
Hamm, Germany	?	-	-	?	?
Marienmünster, Germany	?	-	-	?	?
Rheda Wiedenbrück, Germany	?	-	-	?	?

Rüthen, Germany	?	-	-	?	?
Beckum, Germany	?	-	-	?	?
Marsberg, Germany	?	-	-	?	?
Dinslaken, Germany	?	-	-	?	?
Fürstenau, Germany	?	-	-	?	?
Höxter, Germany	?	-	-	?	?
Werne, Germany	?	-	-	?	?
Balve, Germany	?	-	-	?	?
Osterode Am Harz, Germany	?	-	-	?	?
Münster, Germany	?	Excluded in AD 1454	Furthark	?	?
Tangermünde, Germany	?	Received municipal charter in AD 1275	Furthark	?	?
Coesfeld, Germany	?	Likely late 13th century (?)	Die Hanse	?	?
Uslar, Germany	?	-	-	?	?
Unna, Germany	?	-	-	?	?
Werl, Germany	?	-	-	?	?
Herford, Germany	?	-	-	?	?
Kraków, Poland	?	-	-	?	?
Olsztyn, Poland	?	-	-	?	?
Słubice, Poland	?	-	-	?	?
Malbork, Poland	?	-	-	?	?
Lębork, Poland	?	-	-	?	?

Strzelce Opolskie, Poland	?	-	-	?	?
Sławno, Poland	?	-	-	?	?
Kwidzyn, Poland	?	-	-	?	?
Goleniów, Poland	?	Received town rights in AD 1268	Encyclopedia Britannica	?	?
Limbaži (Lemsal), Latvia	?	-	-	?	?
Bochum, Germany	?	-	-	?	?
Breckerfeld, Germany	?	Achieved town status in AD 1396	Die Hanse	?	?
Lippstadt, Germany	?	Town rights granted in AD 1185	Die Hanse	?	?
Roop (Straupe), Latvia	?	-	-	?	?
Windau (Ventspils), Latvia	?	-	-	?	?
Damme, Belgium	?	-	-	?	?
Stockholm, Sweden	-	Not a Hanse city, but was a major port of Hanseatic influence	-	?	?

Polotsk, Belarus	**?**	-	-	**?**	**?**
Nyköping, Sweden	**?**	The Hansetag was held in AD 1399 in Nyköping, so the city must have joined the Hanse earlier	Furthark	**?**	**?**
Zierikzee, Netherlands	**?**	Received city charter in AD 1248	Encyclopedia Britannica	**?**	**?**
Zaltbommel, Netherlands	**?**	-	-	**?**	**?**
Outside of Central Europe					
London, England	**AD 1282**	Merchants from Köln began trading in London as early as AD 1176, but the Hanseatic League codified in AD 1282	Die Hanse		
Novgorod, Russia	**-**	A *Kontor* established trade privileges to German merchants in AD 1189, and privileges were then extended in AD 1229		**~5 years prior to AD 1189:** **~ 5 years prior to AD 1229**	**~5 years prior to AD 1189:** **~ 5 years prior to AD 1229**
Smolensk, Russia	**-**	German merchants were granted privileges in AD 1229	Furthark	**~ 5 years prior to AD 1229 in Germany:**	**~ 5 years prior to AD 1229 Germany:**

Vyborg, Russia	**-**	-	-	**?**	**?**
Tver, Russia	**-**	-	-	**?**	**?**
Berwick upon Tweed, England	**?**	-	-	**?**	**?**
Boston, England	**? 13th century**	-	Encyclopedia Britannica	**?**	**?**
Edinburgh, Scotland	**?**	Minimal early relations with German traders, however never joined the Hanse	Encyclopedia Britannica	**?**	**?**
Aberdeen, Scotland	**?**	Minimal early relations with German traders, however never joined the Hanse	Encyclopedia Britannica	**?**	**?**
Scalloway, Scotland	**?**	Minimal early relations with German traders, however never joined the Hanse	Encyclopedia Britannica	**?**	**?**
Ipswitch, England	**13th century**	Ipswitch became *Kontor* in the 13th–15th centuries	Encyclopedia Britannica		
King's Lynn, England	**AD 1310**		Die Hanse	**?**	**?**
Pskov, Russia	**?**	-	-	**?**	**?**
Newcastle upon Tyne, England	**?**	-	-	**?**	**?**

Great Yarmouth, England	**After AD 1369**	Was one of the leading herring ports in the 12th–13th centuries	Die Hanse	**?**	**?**
York, England	**?**	-	-	**?**	**?**
Beverley, England	**-**	Trade relations are noted as far back as AD 1120, however Beverley never formally joined the Hanse	Die Hanse		
La Rochelle, France	**?**	**-**	**-**	**?**	**?**

Appendix D
Medieval Central European Dietary Reconstructions

Czech Lands

Kostelisko Cemetery, Mikulčice (9th–11th century)
Source: Halffman and Velemínský 2015

The Mikulčice burials represent a 2,000 person stronghold of the Christianizing Moravian proto-state (Halffman and Velemínský 2015). Archaeobotanical evidence and the remains of 33 humans and 18 animals at Kostelisko cemetery revealed frequent wheat, rye, millet, pea, lentil, broad bean, tree fruit, tuber, leafy vegetable, berry, pig, cow, and sheep consumption. δ13C and δ15N signatures from upper-class castle grave remains and common sub-castle grave remains demonstrated that over 33% of protein intake came from terrestrial animals, and that an additional 13–30% of protein came from millet and other cereal grains (Halffman and Velemínský 2015). Consistently high δ13C signatures in bone collagen suggest that high-calorie, low-protein cereal grains contributed far more calories and were more frequently consumed than low-calorie, high-protein meat. Freshwater fishing for Baltic Sturgeon occurred along the Morava River, but freshwater fish contributions grew significantly after inland aquaculture developments. Very few freshwater fish bones have been recovered at and around the site, which may be partially accounted for by human excavation techniques. The extent of Mikulčice's freshwater fishing is hard to decipher since Baltic sturgeon and other riverine fish display nearly identical isotopic values to the region's livestock and fauna, but Christian Czechs consumed fish during fasts, and fish contributed to protein intake throughout the year. Early still significant but relatively smaller marine contributions at the site illuminate the immense scale of the marine fish turn, which flooded the area with oceanic taxa by the 12th century.

Mikulčice, Pohansko, Josefov Burials I and II (Mutěnice), and Louky od Brtěclavksa Hillfort Burials
Source: Drtikolová Kaupová et al. 2018

Drtikolová Kaupová et al. (2018) examined 9th–11th Great Moravian burials in five locations. At Mikulčice, the team studied a subsample of 70 human burials and 38 animal bones, at Pohansko, the team examined 152 human burials, at the Josefov burial in Mutěnice, the team examined 32 confidently sexed human burials, at Josefov II, the team studied 21 adult burials, and at Louky od Brtěclavksa, the team studied 10 adult burials. High signatures of C_4 plant consumption, probably mostly millet, appear consistent across the sites and social statuses, as do indications of egg and poultry consumption (Drtikolová Kaupová et al. 2018). According to reconstructions, "millet was neither a staple in the diet of the poor, nor the favored dish of the rich…but was consumed across all socioeconomic groups and in both urban and rural contexts" (Drtikolová Kaupová et al. 2018:935). Isotopic bone signatures from the hinterlands suggest an overall lower consumption of animal protein when compared to urban inhabitants, and meat access appears to have been further stratified by social status. Elites generally consumed more pork and fowl from younger, more desirable, livestock (Drtikolová Kaupová et al. 2018). Females apparently consumed less meat, but more millet, than males. Hunted animals contributed a minor percentage of protein as compared to domesticates, but both urban and hinterland populations bolstered their diets with bear, beaver, elk, deer, and other game. Hunted animals made up > 33% of recovered material at the Kostice burial and in Pohansko (Drtikolová Kaupová et al. 2018). Fish– mostly carp, pike, catfish, eels, and feasibly sturgeon– contributed < 5% of the average caloric intake across all sites, until MFEH influxes (Drtikolová Kaupová et al. 2018). While few pre-MFEH fish bones are documented at the sites, freshwater fishing is known to have occurred when ecologically possible, and likely increased after the decree of St. Benedict's Rule.

Prague Castle interior, Střešovice–Triangl and Milady Horákové Street in its hinterlands, and Levý Hradec Castle
Source: Drtikolová Kaupová et al. 2019

In 2019, Dr. Sylva Drtikolová Kaupová and her teams examined n = 102 9th–11th century humans and 24 animals. Analysis suggested a reliance on wheat and rye for bread (Drtikolová Kaupová et al. 2019), and evidenced millet, legume, pea, and lentil importance across all social stratifications (Drtikolová Kaupová et al. 2019). Millet constituted a significantly larger percentage of the non-elite diet, while elite and clerical populations ate more domestic pigs and fowl. Zooarchaeological remains indicate that urbanites more frequently consumed pork and fowl while rural populations more frequently consumed cattle, sheep, and goats. Pigs and avian food could be easily kept even in dense urban centers. Cattle and sheep also provide animal power, milk, and wool, and therefore medieval humans consumed them relatively less frequently (Drtikolová Kaupová et al. 2019). Clerical populations more frequently consumed fish, though all of the sampled individuals likely consumed at least some locally sourced freshwater fish (Drtikolová Kaupová et al. 2019). Across all sites, C_3 plants accounted for 71–79% of calories, C_4 plants accounted for 11–16%, terrestrial animals accounted for 7–15%, and freshwater fish accounted for 1–2% (Drtikolová Kaupová et al. 2019). Despite only accounting for 1–2% of this subsample's lifetime diet (Drtikolová Kaupová et al. 2019), freshwater fish gained importance during fasts and to clerical communities.

Church VI Cemetery, Mikulčice
Source: Jílková et al. 2019

Evidence suggested a minimal lifetime calorie contribution from fish. Fish contribution may have been distinctly higher in clerical communities and during fasts, and low reconstructive levels may reflect ecological stress. The study revealed that children consumed more millet and less animal protein than adults, as isotopically and physically evidenced by consistent tooth wear from abrasives in grain. Greater meat access for elite individuals is evidenced by relatively higher δ15N levels in tooth dentin and bone collagen samples, and, though children consumed more millet than meat, elite children consumed more meat than non-elite children (Jílková et al. 2019).

Belarus and Lithuania
Sources: Brown 2004; Skipitytė et al. 2020; Haponava et al. 2022

Reconstructed diets parallel those of the Church VI Cemetery in Mikulčice, however some Belarussian territories display more reliance on freshwater and anadromous fish. Lithuanians also display varying reliance on fish, but meet the general terrestrial model of diet (Skipitytė et al. 2020). A reliance on millet is recorded in later medieval reconstructions for Belarus and Lithuania (Brown 2004; Skipitytė et al. 2020; Haponava et al. 2022).

Poland

Giecz Peasant Burial
Source: Reitsema et al. 2010

Reitsema et al. (2010) studied 24 confidently sexed 11th–12th century individuals from a peasant burial in Giecz. They reconstructed a mostly terrestrial, omnivorous diet similar to that of Czech contemporaries. Grains and C_3 vegetables like peas and cucumbers dominated the diet, however millet provided a large portion of the caloric intake as a cuisine staple. Meat appears to have been a staple in the male diet, while women consumed less meat overall. Disparate δ15 N indications evidence a similar divide for dairy consumption. Gender-based differences in meat consumption may be practically explained by consumption habits and the food served at taverns– popular male hang outs– and cultural beliefs that "heavy food" like meat was more "appropriate" for men and seen as an undesirable "aggravator of lust" (Reitsema et al. 2010:1420). In general, reconstructions from purchase records estimate that people consumed approximately half a pound of terrestrial meat daily (Reitsema et al. 2010). Cow and pig bones accounted for a combined 80% (~40% each) of all zooarchaeological material recovered at the site, while sheep accounted for ~15%, and fowl accounted for ~4%. Locally sourced wild deer and hare accounted for ~3% of consumed calories, and freshwater fish were sourced locally and contributed to the diet to varying extents. Fish may have been more expensive than meat and therefore only available to higher classes, or may have been reserved for religious communities. However, all of the sampled individuals are likely to have consumed fish to some degree, especially during fasts (Reitsema et al. 2010). Early indications of marine fish consumption are also present in the samples.

Kałdus and Gruczno Piast Cemeteries
Source: Reitsma et al. 2017

Remains from two AD 1000–1400 Piast cemeteries in Kałdus on the east bank of the Vistula River, and one cemetery across the river in Gruczno suggested that the medieval diet in North-Central Poland included a variety of "wild and domestic terrestrial animals (especially pigs, fowl, and cattle), freshwater and migratory fish, and…cereals, vegetables, and fruits, not to mention foods available through trade routes crisscrossing the state, such as marine fish" (Reitsema et al. 2017:41). The represented individuals consumed meat whenever religiously permitted and available, and zooarchaeological assemblages indicate that pork was the most common animal protein. Individuals also consumed beef, sheep and goat meat, and poultry, including organ meat, eggs, and dairy. Milk and cheese supplemented mostly domestic meat (Reitsma et al. 2017), and freshwater fish remains appear in significant numbers at the Kałdus site. At Kałdus, freshwater fish comprise 28.6% of present taxa, and carp account for 40% of this sample, alone (Reitsema et al. 2017). Milk and cheese supplemented mostly domestic meat (Reitsma et al. 2017), and freshwater fish remains appear in significant numbers at the Kałdus site. At Kałdus, freshwater fish comprise 28.6% of present taxa, and carp account for 40% of this sample, alone (Reitsema et al. 2017). It is known that Poles routinely sourced Pike, carp, salmon, sturgeon, eels, and catfish from the Vistula River and its associated lakes and tributaries, and early traded marine fish accounted for approximately 3% of the recorded fish bone assemblages (Reitsema et al. 2017). While freshwater fish trace signatures resemble those of terrestrial animals and plants and are therefore difficult to decipher, the many fishbones recovered at the site evidence their importance. It is postulated that non-farming populations more frequently consumed fish and the researchers also propose that Christian fasting regulations may have been literally lost in translation in rural areas where few people saw priests regularly and could not understand sermons delivered in Latin. Furthermore, fish purchased at market rather than caught naturally for subsistence exceeded other meats in cost, and therefore the researchers postulate that the average person conducted vegetarian fasts. As elsewhere, wheat, millet, and crabgrass, also known as “polish millet” or “sown manna” (Reitsema et al. 2017:41), contributed the bulk of caloric intake. However, sown manna may have been reserved for the elite, as suggested by its ethereal nickname.

Bodzia, Dziekanowice, Pień, and Sowink Elite Burials
Source: Błaszczyk et al. 2021

A 2021 study (Błaszczyk et al. 2021) examined the remains of 10th–11th century elites buried in chamber graves in the Polish towns of Bodzia, Dziekanowice, Pień, and Sowink. Research focused on the gender-based discrepancies in elite diets, and found that the male diet frequently sourced C_3 fruits and crops like peas, broad beans, lentils, carrots, beets, swedes, cucumbers, radishes, onions, cabbages, cherries, apples, plums, pears, and peaches, and C_4 millet. Males also consumed substantial animal protein, including a variety of freshwater fish. Meat likely contributed more calories than millet, which is unique for this location. δ13C and δ15N readings indicate that elite males consumed far more animal products than females and juveniles, whose diets more closely resembled commoners and relied on crops for the bulk of caloric intake. Domestic pigs, cattle, sheep, goats, chickens, and geese as well as their dairy and egg products, dominated animal proteins, however non-domestic remains of bear, elk, hare, aurochs, and deer appeared frequently as products of elite hunting trips (Błaszczyk et al. 2021). δ15N readings indicated a significant reliance on freshwater fish and an early influx of marine samples. Recovered fish bones include herring, cod, salmon, trout, sea trout, whitefish, perch, pike, catfish, carp, bream, roach, trench, eel, sturgeon and crayfish. Sturgeon may have been reserved for elites (Błaszczyk et al. 2021). In general, the Polish diet included relatively significant fish contributions across all social strata, as well as a reliance on staple crops that paralleled the majority of Europe.

Ostrów Lednicki, Giecz, Grzybowo, and Ostrów Tumski, Wielkopolska region
Source: Brown 2022

Brown (2021) analyzed 261 archaeologically recovered pot sherds for lipids and other biomarkers to substantiate both reconstructed and literary diet hypotheses. Results suggested reliance on ruminant, porcine, and poultry meat, and marine and freshwater fish (Brown 2022). Elites frequently drank milk, and all social classes consumed millet. Large ichthyological assemblages at Ostrów Lednicki included both marine and freshwater fish. Most bones recovered at the sites belonged to locally sourced freshwater taxa, showing that local fish were important components of the average diet.

<u>Latvia</u>

Riga
Sources: Yeh et al. 2014; Brown et al. 2017

Parasitological analyses of fecal matter in 14th century latrines in Riga (Yeh et al. 2014; Brown et al. 2017) recorded high frequencies of fish tapeworm (*Diphyllobothrium latum*), whipworm (*Trichuris trichiura*), and roundworm (*Ascaris lumbricoides*). These parasites are hosted in freshwater, marine, and anadromous fish, and do not pass to consumers once fish are cooked. The extent of parasitic evidence indicates that Riga’s population consumed plenty of uncooked freshwater and marine fish, perhaps in raw, pickled, or cured form (Yeh et al. 2014; Brown et al. 2017).

Lejasbitēni
Source: Pētersone-Gordina et al. 2022

Pētersone-Gordina et al. (2022) analyzed human remains from a 7th–10th century cemetery in Lejasbitēni. Zooarchaeological analysis revealed thirteen species of freshwater fish and molluscs, the consumption of which may explain consistently low δ13C at the population level. Remains suggest that men consumed more protein in Lejasbitēni, and remains of beaver, bear, cow, horse, chicken, and goose comprise both wild and domestic meat sources. Isotopic data suggests that the majority of the diet in Lejasbitēni came from domesticated animals and their products. While it is likely that both humans and animals consumed millet at the site, archaeobotanical analysis recovered no millet. Composite evidence suggests a subsistence style of living reliant on the full suite of edible crops in the area.

Čunkāni-Dreņģeri
Source: Pētersone-Gordina et al. 2023

Pētersone-Gordina et al. (2023) studied remains from the 7th–11th century population of Čunkāni-Dreņģeri. Analysis suggested homogeneous consumption practices across gender and social status. The diet in Čunkāni-Dreņģeri is known to have included both C_3 and C_4 plants, domestic livestock, and both freshwater and marine resources, however their relative contribution are currently unclear. Archaeobotanical evidence suggests that inhabitants grew barley, wheat, oats, rye, broad beans, peas, flax, millet, and turnips in fields, and a plethora of freshwater and migratory fish remains indicate reliance on the nearby Tērvete River for animal protein.

Germany

Early-Medieval Altenerding and Straubing-Bajuwarenstrasse Cemeteries
Source: Hakenbeck et al. 2010

Hakenbeck et al. (2020) focused on remains from the early Medieval cemeteries of Altenerding and Straubing-Bajuwarenstrasse. Analysis revealed signs of varied millet consumption, substantial amounts of animal protein consistent with the region, and semi-frequent consumption of freshwater fish sourced from the nearby Danube River.

Dalheim Parish Cemetery
Source: Olsen et al. 2016

Olsen et al. (2016) studied the 11th century Dalheim Parish Cemetery located in rural northwestern Germany. Analysis focused on 24 human burials and 17 faunal remains. Isotopic analyses suggest that, unlike elsewhere in Europe, the studied individuals did not rely heavily on C_4 resources like millet, and that the bulk of the diet could be accounted for by C_3 crops. While young children consumed mostly plant-based proteins and only later grew into eating animal products, perhaps in an effort to balance the theoretical bodily humors– blood, yellow bile, black bile, and phlegm– from a young age (Olsen et al. 2016), adults consumed a variety of animal products that provided the rest of the diet. Isotopic markers evidence the distinct potential for significant contribution from freshwater fish along with terrestrial mammals.

Additional German Reconstructive Evidence
Sources: Halfmann and Velemínsky 2015; Knipper et al. 2015; Küchelmann 2019; Tserendorj et al. 2021

In general, medieval Germans ate mostly crops (Tserendorj et al. 2021), but were less reliant on grains than the rest of central Europe (Küchelmann 2019). While some German regions consumed millet as porridge or beer, southern Germans consumed little to no millet (Knipper et al. 2015), but frequently fed it to livestock as fodder (Halfmann and Velemínský 2015). δ13C levels also suggest a substantial contribution from terrestrial C_3 plants in Southern German regions. Additional reconstructions (Knipper et al. 2015) reveal that 6th–10th century high-status individuals generally had elevated δ13C and δ15N levels matching the signatures of local freshwater fish, therefore potentially indicating their frequent consumption.

The Netherlands

Blokhuizen, Holland
Source: Schats et al. 2022
Schats et al. (2022) compared 8th–13th century and 15th–16th century burials from the rural village of Blokhuizen in Holland. Comparison evidenced an “increase in market dependence, availability of international trade products, and the growth of commercial fishing” (Schats et al. 2022:142). The rural peasant diet evidently included cereal grain staples, seasonal vegetables like cabbage, carrots, and legumes, fowl and their eggs, freshwater fish, and terrestrial meat. Dairy farmers also enjoyed butter, cheese, and milk, and isotopic signatures suggest a diet consisting of relatively equal parts beef, mutton, and pork (Schats et al. 2022). Frequent dental fissures suggest a reliance upon carbohydrates, and fish consumption is relatively certain given Blockhuizen’s proximity to abundant freshwater and marine fish stores and consistently high δ15N values in human bones.

Oosterbeintum, Frisia
Source: McManus et al. 2023

McManus et al. (2013) focused on 5th–8th century Oosterbeintum burials in Frisia. Frisia, a coastal region between mainland Europe and England, played a major role in the development of European and worldwide maritime trade. It is postulated that some of the sampled individuals may have actually lived outside of Frisia and migrated to work in trade industries. Oosterbeintum was a *terp* development built on a low-lying salt flat, and *terps* were frequently built around freshwater ponds that housed fish stores and provided drinking water (McManus et al. 2013). The studied individuals are, somewhat surprisingly, not expected to have relied on marine fish in any capacity, but consumed substantial amounts of freshwater fish, terrestrial animals, and cereals. A lack of marine fish in the diet juxtaposes with mass marine influxes that occurred only two centuries later.

Additional Dutch Reconstructive Evidence
Source: Błaszczyk et al. 2021

Millet seems mostly absent from the human diet in the Netherlands, along with much of Germany and Scandinavia.

Hungary

Keńezlo-Fazekaszug Cemetery, Carpathian Basin
Source: Gugora et al. 2021

Gugora et al. (2021) studied 24 child and adult humans from the 10th century Keńezlo-Fazekaszug cemetery, some of the first Hungarian settlers of the Carpathian Basin. The studied population not only reflects the pre-MFEH time period, but also demonstrates a shifting diet from semi-nomadism to sedentary agropastoralism. δ15N values demonstrate a moderate reliance on terrestrial animal protein, and that males had relatively better access to meat than females. Individuals of all social statuses consumed animal products like dairy, eggs, and meat, as well as bread and many C_3 plants. C_3 plants dominate dietary reconstructions, which may be explained by the steady development of Hungarian orchard and viticulture industries. All of the sampled individuals show that C_3 plants accounted for over 50% of the diet, with estimates exceeding 70% in some individuals, and that C_4 plants– probably millet– accounted for 7.1 ± 5.4% and 29.5 ± 10.6% of childhood and adulthood diets, respectively (Faragó et al. 2022). Though other locations display gender-based diet stratification from even young ages, female children at Keńezlo-Fazekaszug appear to have eaten just as much, if not more, meat than males. Additionally, though archaeologists recovered only few freshwater fish bones at the site, diminished δ13 signatures aligning with the isotopic values in local fish evidence a steady contribution from freshwater fish.

Tiszafüred and Hortobágy Cemeteries
Source: Faragó et al. 2022

Faragó et al. 2022 analyzed remains from 7th–9th century cemeteries in Tiszafüred and Hortobágy in what is now Hungary. The cemeteries sit on the east bank of the Tisza River, and belonged to semi-nomadic Avar groups who had conquered the Carpathian Basin and begun transitioning to a more sedentary lifestyle. Reconstructions show that Avar individuals consumed mostly cereals and millet, while animal proteins made up the bulk of the diet’s remainder. Between individuals at the two sites, millet made up 11.8–34.8% of caloric intake, and consistently high δ15N signatures indicate significant consumption of subsistence source freshwater fish.

Austria

Leobersdorf, Zwölfaxing, Wien-Csokorgasse, Pitten and Pottenbrunn Slav and Avar Cemeteries
Source: Herold 2008

To date, dietary reconstructions in Austria have been conducted only as part of a doctoral dissertation accepted by the University of Vienna (Herold 2008). Research focused on the 7th–9th century Slav and Avar cemeteries at Leobersdorf, Zwölfaxing, Wien-Csokorgasse, Pitten and Pottenbrunn in lower Austria. Still preliminary research revealed that, "although the spectrum of available foods is roughly known, the exact composition of the diet of the Avars and Slavs and the proportion of the components as meat, vegetables, legumes, fruits and cereals are yet unknown" (Herold 2008:88). The diet is assumed to be consistent with other terrestrial locations, including primarily C_3 plants, small amounts of millet, and meat from domestic cattle, horses, sheep, goats, pigs, chicken, and geese, and hunted deer. Females tended to have less access to meat than men, and it is assumed that the semi-nomadic people sourced freshwater fish given consistently high δ15N values in bone collagen.

Serbia

Braničevo
Source: Smuk and Sad 2021

While full human dietary reconstructions are scarce in Serbia, Smuk and Sad (2021) examined archaeobotanical evidence from 10th–13th century Braničevo. Legumes like broad beans and peas, as well as cherries and other fruits comprised the bulk of recordings, however cereals appear prominent. Protein intake likely came from hunted and domesticated meat and fish, but beans also supplied a substantial amount of protein (Smuk and Sad 2021).

Ras Fortress
Source: Borojević 2005

Borojević (2005) conducted archaeobotanical study at the medieval fortress of Ras, continually inhabited, exchanged, destroyed, and rebuilt from the 3rd–13th centuries. Excavations recovered carbonized remains of peach pit, corn cockle weed, cereals, and domesticated sheep, goat, cattle, and pigs– all resources that suffer in droughts.

Belgium

Koksijde
Source: Spros et al. 2022

Spros et al. (2022) analyzed a sample of 23 individuals from the 7th–8th century archaeological site of Koksijde, Belgium. Analysis revealed an expected, albeit early, partial reliance on marine resources, as well as sheep and other domesticated livestock. Where feasible, marine fishing always played some role even before the MFEH. The researchers postulate a reliance on C_3 and C_4 plants parallel to the majority of Europe.

Croatia

Dubravice, Strančе-Gorica, Konjsko polje-Livade, Omišalj-Mirine, and Vaćani-Laluše
Source: Novak et al. 2016

Novak et al. (2016) studied 30 early-medieval individuals from five coastal Adriatic sites. The isotopic makeups of the individuals examined in the 2016 study suggested a diet of mostly C_3 plants, varying amounts of millet, animal protein, and likely some amount of marine fish. The majority of the diet likely consisted of legumes, leafy vegetables, and small amounts of cereals. Two individuals, both male, display trace evidence of mass amounts of marine fish intake, and therefore, locally sourced marine fish can be established as a staple to some degree. Evidence also suggests local freshwater fish exploitation.

Nuštar
Source: Vidal-Ronchas et al. 2019

At an 8th–9th century cemetery in Nuštar, bone collagen and δ13C values indicate a balanced diet containing C_3 and C_4 plants, with enough millet consumption to appear meaningfully in isotopic analyses. Broomcorn millet emerged as the most frequently recovered cereal in Nuštar's archaeobotanical assemblages, and δ15N values suggest a mostly terrestrial diet without significant contribution from fish. Across Croatia, millet appears to have contributed significantly, and Nuštar's inhabitants likely consumed relatively congruent diets across social class and gender.

Additional Romanian Evidence
Sources: Bonsall et al. 2004

Millett emerged as a dietary staple (Bonsall et al. 2004).

Additional Estonian Evidence
Sources: Sillasoo et al. 2007

Medieval Estonians relied on rye and barley cropping (Sillasoo et al. 2007).

Appendix E
Additional Osteological Evidence

Denmark

Table E1: Danish Osteological Evidence

Site:	Source:	Represented Droughts N =	Represented Foodway Disruptions	Remains N =	Notes:
Randers and Tjærby Cemeteries (11th–16th c.)	Primeau et al. (2019)	326	AD 1086, 1257–1258, 1281–1282, 1437–1438, 1440–1441, 1480, 1482, 1491–1492, and 1540	241 adults	• Christian burials, known fasting communities • ~ f = 40% showed leprosy • Shows increased sub-adult morbidity • Increases in LEH and middle-ear disease

Czech Lands

Table E2: Czech Osteological Evidence (Trutmanice)

Site:	Source:	Represented Droughts N =	Represented Foodway Disruptions	Remains N =	Notes:
Trutmanice, South Moravia (13th–15th c.)	Račanská et al. (2023)	220	AD 1251–1254 1262–1264, 1266, 1272–1273, 1281–1282, 1307, 1312–1313, 1318, 1326, 1333, 1337, 1348, 1352, 1361–1362, 1368, 1371, 1415, 1417, 1440–1443, 1461, 1473–1474, 1479, and 1494	?	• Significant infantile scurvy indicating nutritional deficit

Table E3: Czech Osteological Evidence (Kutná Hora-Sedlec)

Site:	**Source:**	**Represented Droughts N =**	**Represented Foodway Disruptions**	**Remains N =**	**Notes**:
Kutná Hora-Sedlec (AD 1318 – late 14th century)	Brzobohatá et al. 2019	58 (Until AD 1400)	AD 1318, 1326, 1333, 1337, 1348, 1352, 1361–1362, 1368, 1371	2 mass graves with 1,200 skeletons + 600 individual burials	• Largest known medieval European mass burial • Began with drought-induced famine of 1318 and plague outbreak • Elevated osseous lesions and mortality crisis detected

Table E4: Czech Osteological Evidence (Church VI)

Site:	**Source:**	**Represented Droughts N =**	**Represented Foodway Disruptions**	**Remains N =**	**Dental Caries f =**	**LEH f =**	**Notes**:
Church VI, Mikulčice (9th–10th c.)	Jilková et al. 2019	61 (in 10th c.)	-	91 adults	78%	75%	• Christian fasting context • Suggests higher nutritional stress in urban areas than in hinterlands

Table E5: Czech Osteological Evidence (Prostějov and Jarošová)

Site:	**Source:**	**Represented Droughts N =**	**Represented Foodway Disruptions**	**Remains N =**	**LEH f =**	**Notes**:
Prostějov and Jarošová Burials (9th–10th c.)	Drtikolová Kaupová et al. 2020	61 (in 10th c.)	-	89	37.9%	• All remains represented individuals under 50 years old

Table E6: Czech Osteological Evidence (Czechia Collections)

Site:	**Source:**	**Represented Droughts N =**	**Represented Foodway Disruptions**	**Notes**:
2 Czechia Collections (9th–10th c.; 11th–14th c.)	Drtikolová Kaupová et al. 2020	61 (10th c.) 162 (11th–14th c.)	AD 1113, 1121, 1124, 1176–1177, and 1194	• Heightened early-onset arthritis, degenerative joint disease, and young morbidity

Poland

Table E7: Polish Osteological Evidence (Sypneiwo)

Site:	**Source:**	**Represented Droughts N =**	**Represented Foodway Disruptions**	**Remains N =**	**LEH f =**	**Notes**:
Sypniewo Cemetery (11th–13th c.)	Gawlikowska-Sroka et al. 2017	234	AD 1076–1077, 1113, 1166, 1262–1264, 1268, 1270–1271, and 1281–1282	126 skulls	**29%**	• **Evidenced deficiencies during formative childhood years**

Table E8: Polish Osteological Evidence (Śródka, Wodna, and Garbary Cemeteries)

Site:	**Source:**	**Represented Droughts N =**	**Represented Foodway Disruptions**	**Remains N =**	**LEH f =**	**Periosteal reaction in tibia f =**	**Notes**:
Śródka, Wodna, and Garbary Cemeteries (10th –13th c.)	Betsinger and DeWitte (2017)	292	1076–1077, 1113, 1166 + ?	164	75%	100%	• **Heightened death and decreased survivorship** • **Cribra orbitalia** • **developed across all social groups**

Appendix F
Additional Ichthyological Analyses

Poland
Gdańsk

Table H1: Sturgeon Declines in Gdańsk

Site and layer:	Sturgeon f =	Droughts Represented by Layers	Foodway Disruptions Represented by Layers	Notes:	Source(s):
Gdańsk (10th c.)	54%	291	AD 1076–1077, 1166, 1262–1264, 1268, 1270–1271, 1281, 1282 + ?	Bones also show reductions in size	Hoffman (1996; 2023a); Makowiecki (2001)
Gdańsk (13th c.)	12%				

Table H2: Freshwater Fish Declines and Cod and Herring Presence in Wrocław

Site and layer:	Droughts Represented by Layers	Foodway Disruptions Represented by Layers	Total Freshwater Bones n =	Freshwater Species Represented n =	Herring	Cod	Notes:	Source(s):
Wrocław (10th–13th c.)	357	AD 1076–1077, 1166, 1262–1264, 1268, 1270–1271, 1281, 1282, 1315–1321 + ?	**159**	**8**	**-**		• 375 km inland from the Baltic Sea • Ostrów Tumski neighborhood showed rapid freshwater decline	Kovalchuk et al. (2024)
Wrocław (10th–12th c.)			**3**	**2**	**Predominant**			
Wroclaw (14th c.)			-	-	**Predominant**	**Present**		

Table H3: General Freshwater Patterns at Szczecin Vegetable Market

Site and layer:	Droughts Represented by Layers	Foodway Disruptions Represented by Layers	Notes:	Source(s):
Szczecin Vegetable Market (10th–13th c.)	291	AD 1076–1077, 1166, 1262–1264, 1268, 1270–1271, 1281, 1282 + ?	Net declines in freshwater fish in consecutive layers	Chełkowski et al. (2005)

General Polish Patterns

- Dr. Robert Lenders (2016) and his collaborators (2017) cite milling as the cause for a 90% decline of Atlantic Salmon stocks on the Paleo-Rhine Catchment during the medieval and early modern eras.
- Sturgeon remains from seventeen southern Baltic sites reveal reductions in average size and consumption frequency from "70% of fish consumed during the 7th–9th centuries to only 10% during the 12th–13th" (Hoffmann 1996:649).

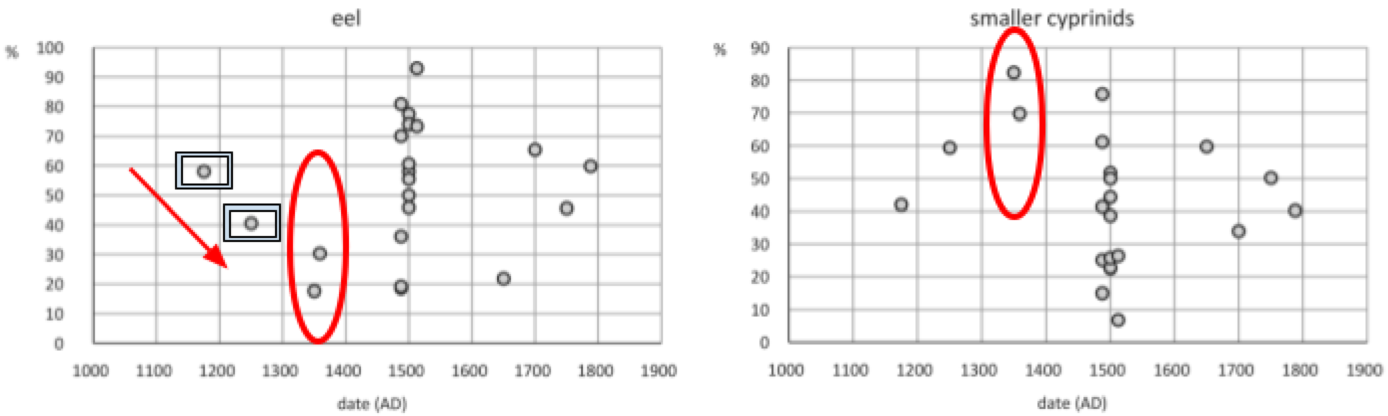
Further Research

Zygmunt Chełkowski, B. Chełkowska, Jaroslaw Filipiak, the authors of the Wolin-town study discussed in **section 5**, also partnered with M. Iwaszkiewicz in the 1950s–1970s for other Polish excavations (Chełkowski and Chełkowska 1966). Their additional work on medieval Szczecin, Kamień Pomorski, Ujście, Bnin, Lake Szczytno, and Lake Charzykowskie fish bone assemblages cannot be accessed online and is not kept by databases, and is therefore inaccessible to the author. Access to these articles should be acquired in future work.

Belgium

Aalst, Flanders (Louis D'Haeseleerstraat and Stadhuis)

Variance among all assemblages excavated by and included in Wouters et al.'s (2021) work is illustrated in **Figure H1**: AD 1300–1400 eel declines, consistent *cyprinidae* contributions, and marine influxes are annotated in red. **Belgium experienced at least 68 Summer droughts between AD 1100–1200, 52 in the 13th century, and 138 AD 1300–1500.** The assemblages also reflect foodway disruptions in AD 1106, 1113, 1125, 1143, 144–1148, 1153–1155, 1166, 1191, 1195–1198, 1204–1206, 1211, 1219–1222, 1257–1258, 1281, 1282, 1315–1321, 1318, 1406, 1437–1438, 1440–1441, 1480, 1482, 1491–1492, 1521–1523, 1592–1531, 1540. Stadhuis represents a cesspit and refuse midden. Louis D'Haeseleerstraat represents a sand and loam extraction pit. The Jans Household represents the known home of Christoffels Jans, a common crossbow maker.



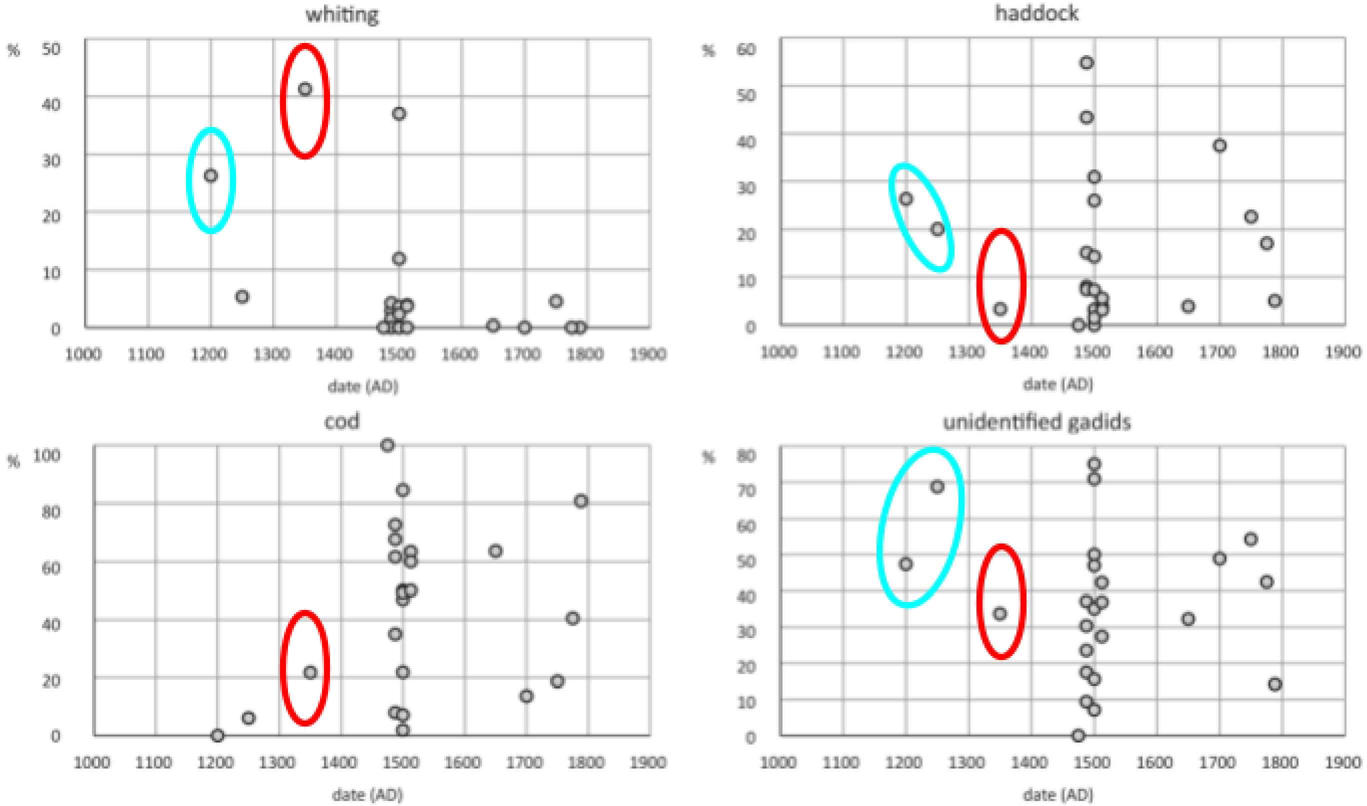

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Figure H1: Freshwater and marine fish assemblage data from Aalst showing eel declines, cyprinidae variance, and marine fish influxes (After: Wouters et al. 2021:7–9)

Table H4: Diachronic Comparison of Aalst, Belgium Assemblages

Site and layer:	Total Fish N =	Combined Freshwater and Migratory Fish NISP + f	Herring NISP + f * site not sieved for small bones	Cod NISP + f	*Gadidae* NISP + f	Whiting NISP + f	Haddock NISP + f	Flatfish, Flounder, Plaice, Batoidea, and Dabs NISP + f	Carp NISP + f	Greater Weever NISP + f *elite delicacy	Source:
Stadhuis (12th c.)	83	65 (f = 78.3%)	13 (f = 15%)	1 (f = 1.2%)	2 (f = 2.4%)	-	-	-	-	-	Wouters et al. (2021)
Stadhuis (12th–13th c. transition)	61	11 (f = 18%)	3 (f = 5%)	-	18 (f = 29%)	10 (f = 16%)	10 (f = 16%)	7 (f = 11.5%)	-	-	Wouters et al. (2021)
Stadhuis (13th c.)	577	182 (f = 31.5%	37 (f = 6.4%)	16 (f = 2.8%)	182 (f = 31.5%)	14 (f = 2.4%)	53 (f = 9.2%)	88 (f = 15.25%)	-	-	Wouters et al. (2021)
Stadhuis (mid-14th c.)	296	42 (f = 14.2%)	139 (f = 47%)	20 (f = 6.7%)	31 (f = 10.5%)	38 (f = 12.8%)	3 (f = 1%)	22 (f = 7.4%)	-	-	Wouters et al. (2021)
Stadhuis (mid-16th c.)	9,251	2,327 (f = 25%)	1,269 (f = 13.7%)	156 (f = 1.6%)	(f < 1%)	(f < 1%)	(f < 1%)	2,162 (f =22.7%)	5 (f < 1%)	2,696 (f = 29%)	Wouters et al. (2021)
Louis D'Haeseleerstraat (14th–15th)	136	33 (f = 24.3%)	58 (f = 42.6%)	7 (f = 5.15%)	7 (f = 5.15%)	-	-	39 (f = 28.7%)	17 (f = 12.5%)	-	Wouters et al. (2021)
Louis D'Haeseleerstraat (15th c.)	101	0	37 (f = 36.6%)	64 (f = 62.4%)	0	0	0	0	0	0	Wouters et al. (2021)
Louis D'Haeseleerstraat (15th–16th c.)	540	81 (f = 15%	110 (f = 20%)	188 (f = 34.8%)	54 (f = 10%)	-	-	79 (f = 14.4%)	7 (f = 1.3%)	-	Wouters et al. (2021)
Jans Household (median date AD 1490)			> 25 taxa present	Mostly marine fish > 60%	F.W. and migratory fish < 20%	Herring dominate data set, along with flatfish	Lack of catfish, sturgeon, salmon, large pike				Hoffmann (2023c)

Brussels

Table H4: Diachronic Comparison of Brussels, Belgium Café assemblages

Site and layer:	Total Fish N =	Cod NISP + f	Herring NISP + f	Flounder NISP + f	Eel NISP + f	Carp NISP + f	*Cyprinidae* NISP + f	Source:
Café Cesspits 1+2 (14th–15th c.)	10,974	1,596 (f = 14.5%)	3,636 (f= 33%)	817 (f = 7.4%)	1,740 (f = 15.8%)	254 (f = 2.3%)	1,096 (f = 9.9%)	De Cupere et al. (2022)
Café Cesspit 2 (16th–17th c.)	2,668	206 f = 7.7%)	1,611 (f = 60.4%)	196 (f = 7.3%)	479 (f = 17.9)	72 (f = 2.7%)	208 (f = 7.8%)	De Cupere et al. (2022)

<u>The Netherlands</u>

Eindhoven Castle

Table H5: Summary of Eindhoven Castle Evidence

Site and layer:	Notes:	Source:
Eindhoven Castle (Mean AD 1490)	• 60% marine fish, half of which were Cod. • 33% freshwater fish, 10% of which were carp	Hoffmann (2023c)

Germany

Elisenhof and Itzhoe

Table H6: General comparison between Elisenhof and Itzhoe

Site:	Represented Droughts	Represented Foodway Disruptions	Sturgeon NISP	Source:
Elisenhof Eider River Estuary (AD 700–1000)	238 (between AD 900–1200)	AD 942, 1004, 1005–1006, 1012, 1013, 1016, 1019, 1022, 1032, 1035, 1038, 1041, 1043–1046, 1051, 1052–1054, 1056, 1058, 1069–1070, 1073, 1076–1077, 1083, 1088, 1090, 1093–1094, 1097–1098, 1099–1102, 1113, 1115, 1124, 1128, 1135, 1137, 1144–1148, 1149–1150, 1150–1151, 1153–1155, 1166, 1173, 1175, 1176–1177, 1194, 1195–1198 (between AD 900–1200)	120	Nikulina and Schmölcke (2016)
Itzehoe Elbe River Site (70 km inland) (AD 1100–1200)			15	

Haithabu and Menzlin

Table H7: General comparison between Haithabu and Menzlin

Site:	Herring f =	Perch f =	Pike f =	*Gadidae* f =	Source:
Menzlin (9th–10th c.)	Dominant	Present	Present	Dominant	Enghoff (1999)
Haithabu (9th–11th c.)	38.6%	24.9%	11.1%		Enghoff (1999)
Menzlin (16th c.)	> 90%	-	-	-	Enghoff (1999)

Schleswig

Table H8: Diachronic Comparison of Schleswig Assemblages

Site:	Total Fish N =	Marine Fish NISP + f	Freshwater and Migratory Fish NISP + f	Source:
Schleswig (11th–12th c.)	1,064	660 (f = 62%)	404 (f = 38%)	Enghoff (1999)
Schleswig (13th–14th c.)	-	Cod prevalent	-	Küchelmann (2019)
Schleswig (15th–16th c.)	2,119	1,133 (f = 53%)	986 (f = 47%)	Enghoff (1999)

Bremen

Table H9: Diachronic Comparison of Bremen Assemblages

Site:	Represented Droughts	Represented Foodway Disruptions	*Gadidae* f =	Herring and *Clupeidae* f =	Flatfish and Dabs f =	Source:
Bremen Altmarkt (late-13th c.)	220 (AD 1250–1540)	AD 1253–1254, 1255, 1257–1258, 1262–1264, 1268, 1270–1271, 1272–1273, 1275, 1276, 1281, 1282, 1294, 1301–1304, 1310, 1312, 1313	>30%	41%	10%	Van Neer and Ervynck (2016)
Bremen (11th–12th c.)		1315–1321, 1318, 1338–1339, 1343, 1352, 1361, 1363, 1370, 1386–1387, 1389, 1397, 1406, 1419, 1420, 1425, 1430, 1433, 1437–1438, 1440–1441, 1442–1443, 1446–1448, 1451–1452, 1456	25%	-	-	Küchelmann (2019)
Bremen (13th c.)		1459–1461, 1471, 1472, 1473, 1474, 1480, 1482,	52.2%	-	-	Küchelmann (2019)

		1485, 1489, 1491–1492, 1495, 1501, 1503–1504, 1511, 1512–1514, 1515, 1516–1518				
Bremen (~ AD 1300)		1521–1523, 1529–1531, 1534, 1536, 1540	44.4%	-	-	Küchelmann (2019)
Bremen (16th c.)			94.1% (of NISP = 1,537)	-	-	Küchelmann (2019)

Cod concentrations in Bremen, Lübeck, Wismar-Wendorf, Kiel, Erfurt, Stralsund, Schleswig, Göttingen, Halberstadt, Hameln, Höxter, Koln, Lüneberg, Magdeburg, and Osnabrück, tended to increase from roughly f = 40–60% in the 12th–13th centuries to > 80% by 15th century contexts

Göttingen and Duisburg

Table H10: Diachronic Comparison of Göttingen and Duisburg Assemblages

Site:	Represented Droughts	Total Fish N =	*Gadidae* NISP + f	Source:
Duisburg (12th–13th c.)	231	80	60 (f = 75%)	Küchelmann (2019)
Göttingen (AD 1270–1345)		55	44 (f = 80%)	

AD 1100–1345 saw foodway disruptions in: AD 1099–1102, 1113, 1115, 1124,1126, 1135, 1137, 1144–1148, 1149–1150, 1150–1151, 1153–1155, 1166, 1173, 1175, 1176–1177, 1194, 1195–1198, 1204–1206, 1217–1218, 1223–1224, 1225–1227, 1229, 1233, 1224, 1245–1246, 1253–1254, 1255, 1257–1258, 1262–1264, 1268, 1270–1271, 1272–1273, 1275, 1276, 1281, 1282, 1294, 1301–1304, 1310, 1312, 1313, 1315–1321, 1318, 1338–1339, 1343

Martin Luther Family Home (Mansfeld)

Table H11: Analysis of Martin Luther Family Home Assemblage

Site:	Represented Droughts	Represented Foodway Disruptions N =	Total fish N =	Herring f =	Traded fish f =	Freshwater fish f =	Source(s):
Martin Luther Home, Mansfeld (~AD 1490)	109 (1400–1540)	35 Fish kills noted in AD 1442–1443	1,304	25–33%	57% (3% preserved cod)	40%	Hoffmann (2023c); Tambora

Denmark

Selsø-Vestby

Table H12: Northern Industry Growth Evidenced by Diachronic Comparison of Selsø-Vestby Assemblages

Site:	Represented droughts	Herring f =	Source:
Viking Pit Houses and Village (9th–10th c.)	122	3% (of NISP = ~1,150)	Enghoff (1996)
Viking Pit Houses and Village (11th c.)	(AD 900–1100)	42%	

Birkely

Table H13: Birkely Fish Bone Evidence

Site:	Total Fish N =	Marine Fish f =	Freshwater Fish f =	Source:
Birkely (8th–11th c.)	1,066	618 (f = 58%)	488 (f = 42%)	Enghoff (1999)
Birkely (AD 1300)	**Freshwater fish almost irrelevant**			

Austria and Hungary

Vienna Basin, Danube Bank- Austria

Analysis includes 14 Austrian and 19 Hungarian sites dating to the Medieval (9th–13th centuries) and Late/Post-Medieval (14th–16th centuries) periods (Galik et al. 2015). Galik et al. (2015) sorted data from the Austrian sites into “Vienna Basin tributary” and “Danube Bank” categories, and compiled data from the Hungarian compiled into “upstream” (towards Visegrád) and “downstream” (towards Budapest) categories. All assemblages came from hand-collection, other than four of the Austrian sites– Mauerbach, Salzburg, St. Pölten, and Vienna Stallburg– where soil sieving occurred. The interval between the late/post-medieval periods of most pattern change– the 13th–14th centuries– saw ~150 Summer droughts and foodway disruptions in AD 1217–1218, 1225–1227, 1257–1258, 1277–1278, 1281–1282, 1312, 1315–1321, 1366, and 1394 (Tambora). The AD 1465 “Fisch Preis Taxe in Eger,” records the mass importing of salted marine fish to compensate for an under-supply of resources (Galik et al. 2015). Summer droughts are documented and reconstructed in AD 1465 Hungary and elsewhere, and 20 consecutive years of Summer and seasonal drought events preceded AD 1465.

Table H14: Austria Vienna Basin and Danube Fish Bone Data

Site:	Represe nte-d Drough ts	Identified Fish N =	Unidentifie-d Fish N =	Sturgeo -n NISP + f	Carp NISP + f	*Cyprinidae* NISP + f	Pike NISP + f	Trout NISP + f	Bullhead and Loach NISP + f	Other F.W. NISP + f	Herring NISP + f	*Gadidae* NISP + f	Flatfish and Dabs NISP + f	Source:
Vienna Basin (9th–13th c.)		1,153	1,868	35 (f = 3%)	317 (f =27.5 %)	295 (f = 25.6%)	328 (f = 28.4%)	120 (f = 10.4 %)	22 (f = 1.9%0	-	1 (f < 1%)	-	-	
Vienna Basin (14th–16th c.)	482	2,222	683	31 (f = 1.4%)	309 (f = 13.9 %)	440 (f = 19.8%)	158 (f = 7.1%)	204 (f = 9.2%)	548 (f = 24.6%)	74 (f = 3.3%)	132 (f = 5.9%	85 (f = 3.8%)	73 (f = 3.2%)	Galik et al. (2015)
AustriaDanube (9th–13th c.)		77	121	-	16 (f = 20.7 %)	34 (f = 44%)	10 (f = 13%)	-	-	-	-	-	1 (f = 1.3%)	
Austria Danube (14th–16th c.)		3,856	4,493		65 (f = 1.6%)	1,527 (f = 39.6%)	324 (f = 8.4%)	43 (f = 1.1%)	748 (f = 19.4%)	877 (f = 22.7 %)	131 (f = 3.4%)	1 (f < 1%)	-	

Upstream, Downstream- Hungary

Table H15: Hungarian Fish Bone Data Displaying Freshwater Fish Declines

Site:	Represented Droughts	Identified Fish N =	Unidentified Fish N =	Sturgeon NISP + f	Carp NISP + f	*Cyprinidae* NISP + f	Pike NISP + f	Catfish NISP + f	Source:
HungaryUpstream (5th–7th c.)	265 (AD 900–1300) 177 (AD 1300–1540)	31	63	-	10 (f = 32.3%)	7 (f = 22.6%)	9 (f = 29%)	-	Galik et al. (2015)
Hungary Upstream (9th–13th c.)		100	23	37 (f = 37%)	47 (f = 47%)	4 (f = 4%)	8 (f = 8%)	-	
Hungary Upstream (14th–16th c.)		43	273	9 (f = 20.9%)	15 (f = 39.4%)	-	5 (f = 11.6%)	-	
Hungary Down-stream (9th–13th c.)		42	14	10 (f = 23.8%)	20 (f = 47.6%)	1 (f = 2.4%)	5 (f = 11.%)	6 (f = 14.3%)	
Hungary Down-stream (14th–16th c.)		207	53	41 (f = 19.8%)	63 (f = 30.4%)	41 (f = 19.8%)	45 (f = 21.7%)	9 (f = 4.3%)	

Esztergom

Table H16: Summary of Esztergom Fish Bone Data

Site:	Notes:	Source
Esztergom (12th–15th c.)	Assemblages evidence increasing carp, pike, and perch aquaculture at Hyppolite d'Este, the Archbishop of Esztergom's residence	Bartosiewicz (2021)

Estonia

Order Castle, Kivimägi, Suusahüppemagi, Tallinn, Tartu, Pärnu, and Viljandi

Table H17: Comparative NISP data in Order Castle Sites (Kivimägi, Suusahüppemagi, Order Castle Wall), and general patterns

Site:	Droughts Represented	Pike NISP =	Perch NISP + f	Bream NISP + f	Roach NISP + f	*Cyprinidae* NISP + f	Source:
Kivimägi (10th c. – AD 1233)	258 (10th–13th c)	59	72	30	18	36	**Enghoff (1999)**
Suusahüppemagi (12th c. – early-13th c.)		30	68	2	3	28	
Order Castle Wall (13th c.)		3	1	2	0	2	

Marine fish account for > 20% of samples in 13th–16th c. Tallinn, Tartu, Pärnu, and Viljandi

Lithuania

Vilnius Lower Castle

Table H18: Freshwater fish declines at Vilnius Lower Castle

Site:	Droughts Represented	Total Fish N =	Pike NISP + f	Perch NISP + f	Catfish NISP + f	Bream NISP + f	Source:
Vilnius Lower Castle (14th–15th c.)	164 (AD 1300–1540)	164	66 (f = 40.2%)	29 (f = 17.7%)	12 (f = 7.3%)	15 (f = 9.1%)	Piličiauskienė and Blaževičius (2019)
Vilnius Lower Castle (15th c.)		66	20 (f = 30.3%)	10 (f = 15.2%)	4 (f = 6.1%)	5 (f = 7.6%)	

Switzerland

Basel

While marine fish do not eclipse freshwater taxa in Swiss records, freshwater fish frequencies still decline between the 11th–13th centuries. Urban Swiss areas engaged in long-distance freshwater fish trade with more sparsely populated and cleaner mountainous areas, rather than immediately turning to marine trade. Evidence of freshwater fish trade comes from bullhead and salmonid trout remains in urban areas, which prefer the cold, fast-running, high-oxygen, low-nutrient water of the Alpine posterior Rhine. Diachronic comparison of each canton reveals 11th–13th century declines, and influxes of traded freshwater fish. Remains showed consistent shrinking in size to < 10 cm. Atlantic cod stockfish became a staple in Basel by AD 1435, though no remains appeared in excavations. **Switzerland experienced 82 Summer drought years in the 11th century, 77 in the 12th century, 64 in the 13th century, and 71 in the 14th. Foodway disruptions are recorded in AD 1005–1006, 1043–1046, 1073, 1099–1102, 1113, 1144–1148, 1150–1151, 1166, 1195–1198, 1217–1218, 1225–1227, and 1282.**

Table H19: Diachronic comparison of Basel Assemblages

Site:	**Total Fish N =**	**Pike NISP + f**	**Perch NISP + f**	***Salmonidae* NISP + f**	***Cyprinidae* NISP + f**	**Bullhead NISP + f**	**Herring NISP + f**	**Source:**
Altenberg Castle (11th c.)	1,107	165 (f = 14.9%)	20 (f = 1.8%)	164 (f = 14.8%)	693 (f = 62%)	56 (f = 5%)	6 (f < 1%)	Häberle and Hüster Plogmann (2018)
Schnabeltasse Neighborhood (12th c.)	14,042	9 (f < 1%)	5,203 (f = 37%)	1,397 (f = 9.9%)	5,524 (f= 39.3%)	1,703 (f = 12.1%)	160 (f = 1.1%)	
Bäumleingasse Neighborhood (13th c.)	2,959	f < 1%	95 (f = 3.2%)	292 (f = 9.8%)	380 (f = 12.8%)	2,166 (f = 73%)	22 (f < 1%)	
Martingasse Neighborhood (14th c.)	575	min.	159 (f = 27.6%)	120 (f = 20.8%)	157 (f = 27.3%)	139 (f = 24.2%)	Present	
Wildensteiner Hof Neighborhood 14th c.)	3,046	min.	860 (f = 28.2%)	689 (f = 22.6%)	755 (f = 24.8%)	731 (f = 24%)	Present	

Schaffhausen

Table H20: Diachronic comparison of Schaffhausen assemblages

Site:	**Total Fish N =**	**Pike NISP + f**	**Perch NISP + f**	***Salmonidae* NISP + f**	***Cyprinidae* NISP + f**	**Bullhead NISP + f**	**Herring NISP + f**	**Source:**
Allerheiligen Monastery (12th c.)	277	33 (f = 11.9%)	23 (f = 8.3%)	137 (f = 49.4%)	77 (f = 27.8%)	f < 1%	-	Häberle and Hüster Plogman (2018)
Stein am Rhein Hospital (13th–14th c.)**	425	f < 1%	268 (f = 63%)	27 (f = 6.3%)	40 (f = 9.4%)	74 (f = 17.4%)	-	

** Many perch remains at Stein am Rhein Hospital measured < 10 cm, but archival information suggests that small fish, even if illicitly caught, were believed to be beneficial for one's health and recovery, and more desirable (Häberle and Hüster Plogman 2018). Recovering mostly small fish makes contextual sense at a hospital site

Serbia

Table H21: Summary of Serbian Data	Source:
• Cod and Herring trade is archivally confirmed in 15th century Serbia • Freshwater fish and carp trade is evidenced by 14th century assemblages ○ 14th–15th c. midden context at Studenica Monastery revealed carp and sturgeon bones provenanced to the Zeta River in Modern Montenegro • Serbia experienced 21 Summer droughts in the 10th century, 64 in the 11th, 61 in the 12th, 47 in the 13th, 53 in the 14th, and 55 in the 15th • Potential compelling evidence of even earlier marine fishing and fish trade in Serbia comes from a 13th century fresco from Gračanica Monastery (Figure H2), in which an octopus and a potential member of the Teleost fish family are depicted	Živaljević et al. (2019)

Figure H2: A 13th century fresco showing boat and net fishing at the at Gračanica Monastery in Serbia, and a 14th century fresco depicting the known fish taxa on the same site, including marine, migratory, and freshwater fish, (From: Živaljević et al. 2019:182–183)

Appendix G

***Terminus Post Quem* entry of traded marine fish in Central Europe**
(written account in Appendix E)

Country	Herring Entry Date (or *TPQ*) →	Recent Drought years (~prior 10 years)/Drought years Per Century or Time Span	Recent Foodway Disruptions (~prior 10 years)/ Disruptions Per Century or Time Span	Cod Entry Date (or *TPQ*) →	Recent Drought years (~prior 10 years)/ Drought years Per Century or Time Span	Recent Foodway Disruptions (~prior 10 years)/ Disruptions Per Century or Time Span
Germany	Coastal: 9th century; Inland: 10th–11th century	AD 900–910, 914–929, 933–935, 941–946, 949, 952–957, 960–965, 969–971, 973–974, 977–979, 981–984, 988–990, 993–995, 997–998, 1000, 1003, 1005–1007, 1009–1010, 1014–1016, 1018–1020, 1022–1029, 1031–1039, 1042–1051, 1053–1055, 1059–1094, 1096–1100 (**153 total** from AD 900–1100)	AD 942, 1004, 1005–1006, 1012, 1013, 1016, 1019, 1022, 1032, 1035, 1038, 1041, 1043-1046, 1052–1054, 1056, 1058, 1069–1070, 1073, 1076–1077, 1083, 1088, 1090, 1093–1094, 1097–1098, 1099–1102 (**38 total recorded** from AD 900–1100)	AD 1100–1250	AD 1100–1121, 1123–1135, 1137–1139, 1142–1143, 1146–1147, 1150, 1152–1156, 1159–1186, 1188–1189, 1191–1194, 1197–1200, 1202–1205, 1207–1209, 1211–1241, 1243–1245, 1247, 1250 (**134 total** from AD 1100–1250)	AD 1113, 1115, 1124, 1128, 1135, 1137, 1144–1148, 1149–1150, 1150–1151, 1153–1155, 1166, 1173, 1175, 1194, 1195–1198, 1204–1206, 1217–1218, 1223–1224, 1225–1227, 1229, 1233, 1234, 1245–1246 (**41 total recorded** from AD 900–1100)
Czech Lands (Including Slovenia est. AD 1991)	Late 10th–11th century	AD 952–957, 960–965, 969–971, 974, 977–979, 981–984, 988–990, 993–995, 997–998, 1000, 1003, 1005–1007, 1009–1010, 1014–1016, 1018–1020, 1022–1029, 1031–1039, 1042–1051, 1053–1055, 1057–1094, 1095, 1097, 1099–1100 (**117 total** from AD 950–1100)	? Scarce Czech archival material prior to 12th century	AD 1371	AD 1360, 1361,1368, 1369 1370, 1371 (In prior ~ 10 years)	AD 1361, 1362, 1368, 1371 (In prior ~ 10 years)
Poland	Coastal: 9th century; Inland: 10th–11th century	AD 901, 907–908, 914, 916, 917, 919–920, 922, 925–926, 928, 934–935, 941–942, 944, 946, 949, 952–957, 960–962, 964–965, 969–971, 973–974, 977–979, 982–984, 988–990, 993–994, 997–998, 1000, 1005–1007, 1009–1010, 1014, 1016, 1018, 1019, 1023–1026, 1028–1029, 1031,	AD 1076–1077 + ? (Archival evidence scarce)	13th century	AD 1150, 1152–1165, 1160–1182, 1184–1185, 1188–1189, 1191–1192, 1197, 1202, 1204–1205, 1207–1209, 1211–1135, 1238, 1240–1241, 1243–1244, 1247, 1250–1254, 1255–1263, 1265,	AD 1262–1264, 1268, 1270–1271, 1281–1282 + ? (Archival evidence scarce)

		1034–1039, 1042–1051, 1053–1055, 1058–1094, 1096–1100 (**127 total** from AD 900–1100)			1267, 1270, 1272, 1274, 1276–1278, 1280–1281, 1283–1289, 1292–1294, 1296–1300 (**121 total** from AD 1150–1300)	
Austria	10th–11th century	AD 901–905, 908–910, 914–929, 933–935, 941–946, 949, 952–957, 960–965, 964–970, 974, 977–979, 981–984, 988, 990, 993–995, 997–998, 1000, 1003, 1005–1007, 1009–1010, 1016, 1018, 1020, 1022–1029, 1031–1039, 1042–1046, 1048–1051, 1053–1055, 1057–1094, 1096–1100 (**144 total** from AD 900–1100)	AD 1005–1006, 1043–1046, 1099–1102 + (Archival evidence scarce)	Mid-14th century	AD 1300–1314, 1315, 1317–1320, 1322–1326, 1328, 1331–1336, 1346, 1351–1337, 1376–1379 (**70 total** from AD 1300–1380)	AD 1312, 1313, 1315–1321, 1360 +
Hungary	14th century	AD 1250–1263, 1265–1268, 1270, 1272–1274, 1276, 1279–1281, 1284–1285, 1287–1289, 1292–1293, 1298–1309, 1311–1314, 1317–1320, 1322–1328, 1330, 1332–1337, 1348–1349 (**69 total** from AD 1250–1350)	AD 1282, 1315–1321 + ? (Archival evidence scarce)	15th century	AD 1353–1373, 1376–1379, 1381–1386, 1389–1391, 1393, 1395–1397, 1400–1427, 1429, 1431–1435, 1437–1440, 1442–1448 (**83 total** from AD 1350–1450)	AD 1362, 1437–1438, 1440–1441
Switzerland	11th century	AD 952–957, 960–965, 970–971, 973–974, 977–979, 981–984, 988–990, 993–995, 997–998, 1000, 1003, 1005–1007, 1009–1010, 1014–1016, 1018–1020, 1022–1028, 1031–1039, 1042–1050 (**69 total** from AD 950–1050)	AD 1005–1006, 1043–1046 + ? (Archival evidence scarce–Disruptions are recorded in neighboring Austria and Germany)	AD 1435	1425–1427, 1429, 1431–1435 (In prior ~ 10 years)	? (Archival evidence scarce–Disruptions are recorded in neighboring Austria and Germany in AD 1426–1427, 1430, 1433)
Liechtenstein	?	-	-	?	-	-
Luxembourg	?	-	-	?	-	-

Lithuania (Including Belarus est. AD 1991)	Late 13th–14th century	AD 1250–1254, 1257–1263, 1267, 1270, 1272–1274, 1276–1281, 1283–1289, 1292–1294, 1296–1300 (**38 total** from AD 1250–1300)	? (Archival evidence scarce)	Late 13th–14th century	AD 1250–1254, 1257–1263, 1267, 1270, 1272–1274, 1276–1281, 1283–1289, 1292–1294, 1296–1300 (**38 total** from AD 1250–1300)	? (Archival evidence scarce)
Latvia	Early 13th century	AD 1180–1186, 1888–1195, 1197, 1199–1200, 1202, 1204–1205, 1207–1209, 1211–1212, 1216–1217, 1219, 1221–1237, 1240–1242, 1244–1245, 1247, 1250–1255, 1257–1260 (**62 total** from AD 1180–1260)	AD 1256 + ? (Archival evidence scarce)	14th century	AD 1250_1255, 1257–1263, 1267, 1272–1274, 1276–1280, 1283–1289, 1292–1294, 1296–1299, 1301, 1304–1311, 1314–1315, 1318–1320, 1322–1328, 1330–1332, 1337, 1339, 1346–1349 (**53 total** from AD 1250–1350)	? (Archival evidence scarce)
Belgium	Local trade: 10th century; International trade: 11th century	AD 952–957, 960–965, 969–971, 973–974, 977–978, 981, 983–984, 988–990, 993–995, 997–998, 1000, 1005–1006, 1010, 1014–1016, 1018–1020, 1022–1029, 1031–1036, 1038–1039, 1042–1050 (**65 total** from AD 950–1050)	AD 1005–1006, 1050–1051 + ?	12th century	AD 1050, 1053–1054, 1057–1066, 1069–1081, 1083–1084, 1086–1087, 1090–1091, 1094, 1096, 1099, 1100 (**36 total** from AD 1050–1100)	AD 1051, 1061, 1069–1070, 1090, 1095 + ?
Serbia	14th–15th century	AD 1303–1309, 1311–1315, 1317–1318, 1320, 1322–1328, 1334–1335, 1337, 1349, 1354–1369, 1371, 1373, 1378–1379, 1382–1386, 1391, 1400 (**46 total** from AD 1300–1400)	AD 1315–1321 + ? (Archival evidence scarce)	15th century	AD 1354–1369, 1371, 1373, 1378–1379, 1382–1386, 1391, 1400–1405, 1409–1410, 1412–1415, 1417–1418, 1420–1424, 1426–1427, 1429, 1431–1435, 1438–1440, 1442–1444, 1449–1450 (**61 total** from AD 1350–1450)	? (Archival evidence scarce)
Croatia	?	-	-	?	-	-

Estonia	11th century	AD 955, 963–965, 969–970, 974, 977, 982–984, 988–990, 993, 995, 998, 1000, 1003, 1005–1007, 1009–1010, 1014, 1018–1020, 1022–1029, 1031–1039, 1042–1050 (**54 total** from AD 950–1050)	? (Archival evidence scarce)	13th century	AD 1150, 1153, 1160–1186, 1188–1195, 1197, 1199–1200, 1202, 1204–1205, 1207–1209, 1211–1212, 1216–1217, 1219, 1221–1225, 1227–1237, 1240–1241, 1243–1245, 1250 (**73 total** from AD 1150–1250)	AD 1233 + ? (Archival evidence scarce)
Romania	?	-	-	?	-	-
Bulgaria	?	-	-	?	-	-
The Netherlands	11th century elsewhere; Trade from Dutch shores begins by 12th century	AD 1051, 1053–1054, 1057–1066, 1069–1081, 1083–1087, 1090–1091, 1094, 1096, 1099–1100 (**37 total** from 1050–1100)	AD 1051, 1061, 1069–1070 +	14th–15th century	AD 1300–1308, 1310–1311, 1317–1320, 1322–1326, 1330–1337, 1339, 1346–1348, 1351–1354, 1360–1361, 1367–1373, 1375–1377, 1381, 1384–1385, 1389–1397 (**60 total** from AD 1300–1400)	? (Archival evidence scarce)

Appendix H

***Terminus Post Quem* of Aquaculture in Central Europe**
(written account in Appendix E)

Country	Date of First Record of Aquaculture or Pond Building	Recent Droughts (~prior 10 years)/ Droughts Per Century or Time Span	Recent Foodway Disruptions/ Disruptions Per Century (~prior 10 years)
Germany	AD 1220, likely 11th–12th century	AD 1210–1220 (In prior ~ 10 years)	AD 1204–1206, 1217–1218; Hardship is recorded in neighboring Belgium and the Netherlands in AD 1211 and 1219
Czech Lands	AD 1119–1125	AD 1109–1121, 1123–1125 (In prior ~ 10 years)	AD 1113, 1121, 1124
Poland	14th century	AD 1250–1253, 1255–1263, 1265, 1267, 1270, 1272, 1274, 1276–1281, 1283–1289, 1292–1294, 1296–1300 (**39 total** from AD 1250–1300)	AD 1262–1264, 1268, 1270–1271, 1281–1282 +
Austria	12th century	AD 1050–1051, 1053–1055, 1057–1094, 1096–1100 (**45 total** from AD 1050–1100)	AD 1043–1046, 1099–1102 + ? (Archival evidence scarce) Hunger/hardship is recorded in neighboring Germany and Switzerland in AD 1052–1054, 1058, 1073, 1076–1077, 1083, 1088, 1090, 1093–1094, 1097–1098
Hungary	11th century	AD 952, 956, 960–962, 964–965, 970–971, 978–979, 981–984, 988, 990, 993–995, 998 (**21 total** from AD 950–1000)	? (Archival evidence scarce)
Liechtenstein	?	-	-
Luxembourg	?	-	-
Latvia	13th century	AD 1150, 1153, 1155, 1160–1186, 1188–1195, 1197–1198, 1200 (**31 total** between AD 1150–1200)	? (Archival evidence scarce)

Switzerland	14th–15th century	AD 1300–1309, 1311–1314, 1317–1320, 1322–1328, 1330–1334, 1336–1340, 1340–1349, 1351–1357, 1360–1361, 1363, 1367–1368, 1370–1373, 1375–1377, 1379, 1381–1382, 1384–1386, 1389–1397, 1400 (**80 total** from AD 1300–1400)	AD 1318, 1363, 1315–1321 + ? (Archival evidence scarce) Hunger/hardship is recorded in neighboring Austria in AD 1312–1313, 1360, 1394, 1403–1405, and in Germany in 1301–1304, 1310, 1338–1339, 1352, 1361, 1370, 1386–1387, 1389, and 1397
Lithuania	14th century	AD 1250–1254, 1257–1263, 1267, 1272–1273, 1276–1279, 1281, 1283–1289, 1292–1294, 1296–1298 (**33 total** from AD 1250–1300)	? (Archival evidence scarce)
Belgium	Mid-14th century	AD 1300–1308, 1310–1311, 1317–1320, 1322–1326, 1330–1337, 1339, 1346–1348, 1351–1354, 1357, 1360 (**38 total** from AD 1300–1360)	? (14th century archival evidence scarce)
Serbia	13th century	AD 1150, 1152–1156, 1159–1165, 1167–1186, 1189–1190, 1193–1195, 1197–1198 (**40 total** from AD 1150–1200)	? (Archival evidence scarce)
Croatia	Roman	–	–
Estonia	13th century	AD 1160–1186, 1188–1195, 1197, 1199, 1200 (**38 total** from AD 1150–1200)	? (Archival evidence scarce)
Romania	Late 14th century	AD 1346, 1348–1349, 1351–1371, 1375–1386, 1389–1392, 1394–1397, 1400 (**45 total** from AD 1340–1400)	? (Archival evidence scarce)
Bulgaria	Roman	–	–
The Netherlands	14th century	AD 1251–1252, 1259–1262, 1267–1268, 1270, 1272–1273,1276–1278, 1284–1289, 1292–1293, 1296–1300 (**25 total** from AD 1250–1300)	AD 1245–1246, 1248–1249, 1257–1258, 1268, 1272–1273 + Hunger/hardship is recorded in neighboring Belgium and Germany in AD 1253–1255, 1262–1264, 1270–1271, 1275–1276, 1281–1282, 1294

Appendix I

Known Hanseatic Cog Wreck Information and Drought and Foodway Disruption Analysis

Shipwreck and Location	Dendrological Year Approx	Dendrological Wood Provenance	Recorded and Reconstructed Droughts in Prior 2 years (or in time span approx.) in Provenance Location	Recorded Foodway Disruptions in Prior 2 years (or in time span approx.) in Provenance Location	Source(s)
Kollerup Cog (N. Jutland, Denmark)	AD 1155	Baltic coast S. of Jutland	AD 1153	? 1153–1155 in Belgium and Germany	van de Moortel 2011
Kolding, E. Jutland, Denmark	AD 1188–1189	Baltic coast S. of Jutland	AD 1188–1189	?	van de Moortel 2011
Skagen, N. Jutland, Denmark	AD 1195	Frisian coast of S. Jutland	? Potential drought in AD 1194 (Severe drought is recorded in Germany)	-	van de Moortel 2011
Kuggmaren 1 (Stockholm Archipelago, Sweden)	AD 1215	Denmark	AD 1213–1215, (+ Many consecutive years prior)	?	van de Moortel 2011; von Arbin 2023
Dyngö III (Fjällbacka archipelago, Sweden)	AD 1233–1240	Lower Saxony - NW Germany	AD 1231–1236	AD 1233–1234	von Arbin 2023
Kronholmen Cog (Västergarn, Gotland)	AD 1245–1251	Kalmar Region, SE Sweden	AD 1243, 1251	?	von Arbin 2023
A57 Rutten, (Zuyderzee, Netherlands)	AD 1265–1275	NE Germany	AD 1263, 1265, 1267–1268, 1270, 1272	AD 1262–1262, 1268, 1270–1271, 1272–1273, 1275	van de Moortel 2011
Bossholmen Cog (N. Oskarshamn, SE Sweden)	After AD 1270	East Skåne, Sweden	AD 1270, 1272	?	von Arbin 2023

0Z43 Nijkerk (Zuyderzee, Netherlands)	AD 1275–1300	?	? Dendrological origin unknown	? Dendrological origin unknown	van de Moortel 2011
M61 Dronten (Zuyderzee, Netherlands)	After AD 1296	?	? Dendrological origin unknown	? Dendrological origin unknown	van de Moortel 2011
Darss Cog (German Baltic)	AD 1298–1313	Baltic Coast	AD 1296–1301, 1304–1310	AD 1301–1304, 1310, 1312–1313	van de Moortel 2011
Pärnu Harbor Cog (Pärnu, Estonia)	AD 1300	?	? Dendrological origin unknown	? Dendrological origin unknown	van de Moortel 2011
Q75 Ens (Zuyderzee, Netherlands)	AD 1300–1325	?	? Dendrological origin unknown	? Dendrological origin unknown	van de Moortel 2011
Rostock-Hohe Düne (German Baltic)	After AD 1304	?	? Dendrological origin unknown	? Dendrological origin unknown	van de Moortel 2011
OG77 Swifterbant (Zuyderzee, Netherlands)	AD 1305	Netherlands	AD 1303–1305	? Likely experienced similar conditions to Germany	van de Moortel 2011
Doel 1 (Scheldt River, Belgium)	AD 1325–1326	Aller/Weser, Germany	AD 1323–1326	?	van de Moortel 2011
Doel 2 (Scheldt River, Belgium)	AD 1325–1335	?	? Dendrological origin unknown	? Dendrological origin unknown	van de Moortel 2011
N5 Dronten (Zuyderzee, Netherlands)	AD 1325–1350	?	? Dendrological origin unknown	? Dendrological origin unknown	van de Moortel 2011
CZ76 Oostvaarders (Zuyderzee, Netherlands)	After AD 1327	Netherlands	AD 1325–1326	?	van de Moortel 2011

0Z36 Nijkerk (Zuyderzee, Netherlands)	AD 1336	?	? Dendrological origin unknown	? Dendrological origin unknown	van de Moortel 2011
Helgeandsholmen II (Stockholm, Sweden)	After AD 1330	?	? Dendrological origin unknown	? Dendrological origin unknown	von Arbin 2023
Varberg 1 (Central Varberg, W. Sweden)	After AD 1346	Netherlands, Belgium, NE France	AD 1346–1348	?	von Arbin 2023
NZ42 Spakenburg (Zuyderzee, Netherlands)	AD 1350–1400	?	? Dendrological origin unknown	? Dendrological origin unknown	van de Moortel 2011
Varberg 2 (Central Varberg, W. Sweden)	AD 1355–1357	N. Poland	AD 1353–1354	?	von Arbin 2023
Lille Kregme (Roskilde Fjord, Denmark)	AD 1358	Baltic	AD 1357–1358 (Lithuania, Latvia, Estonia)	?	van de Moortel 2011
Lootsi Cog (Tallinn, Estonia)	AD 1360	?	? Dendrological origin unknown	? Dendrological origin unknown	Estonian Maritime Museum
Mollösund II (Orust, NW Sweden)	AD 1365	Funen/Zealand/W. Denmark/ N. Germany	AD 1363	AD 1362	von Arbin 2023
Vejby Cog (N. Coast Sealand, Denmark)	AD 1372	Baltic	AD 1370–1372	AD 1370 (Germany)	van de Moortel 2011
M107 Marknesse/ Emmeloord (Zuyderzee, Netherlands)	AD 1375–1400	?	? Dendrological origin unknown	? Dendrological origin unknown	van de Moortel 2011
Bremen Cog (Weser River, Germany)	AD 1378	Weser	AD 1376–1377	?	van de Moortel 2011

Skanör Cog (Skanör, Sweden)	After AD 1382	SE Baltic	In the Baltic Littoral: AD 1379	In the Baltic Littoral: -	von Arbin 2023
NZ43 Spackenberg (Zuyderzee, Netherlands)	AD 1402–1414	Netherlands/ Westphalia	AD 1405, 1407–1409, 1411–1414	AD 1406	van de Moortel 2011
Almere (Zuyderzee, Netherlands)	AD 1410	?	? Dendrological origin unknown	? Dendrological origin unknown	van de Moortel 2011
IJsselcog (Kampen, Netherlands)	AD 1415–1420	Netherlands	AD 1413–1420	?	Waldus et al. 2019
Wismar-Wendorf Cog (Wismar Harbor, Germany)	AD 1476	German Baltic	AD 1474, 1476	AD 1473–1474	Heinrich 2012
R1 Kuinre (Zuyderzee, Netherlands)	?	?	-	-	van de Moortel 2011