The air we breathe: a study into the impact of historical socioeconomic changes on the respiratory health of past Dutch populations (ca. 470-1850 CE)

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CHAPTER 5

The Urban Sea: Cribra orbitalia, porotic hyperostosis, linear enamel hypoplasia, and sinusitis in three diachronic urban sites from the Dutch province of Zeeland (1030–1800 CE)

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Abstract

Until the 17th century, the Dutch coastal region of Zeeland ranked among Europe's most urbanized areas, driven by thriving international trade networks. People living in this time of flourishing economy benefitted enormously from it in terms of employment opportunities and working conditions, which were reportedly better than in the rest of the Low Countries. However, the rapid growth of Zeeland's urban centers likely presented increasing challenges for the population in terms of accessing essential resources, including food, clean water, and housing. In the 19th century, Zeeland's economy ultimately faced a significant downturn due to the decline in the maritime trade, leading to a substantial reduction in its urban population.

Examining patterns of urbanization and economic histories that differ from the commonly studied thriving industrial contexts in bioarchaeological research, as exemplified by Zeeland, is a crucial yet relatively underexplored facet in our efforts to understanding the human past. To address this gap, this study investigates the impact of urbanization on the health of Zeeland's inhabitants over time by analyzing non-specific stress markers (i.e., cribra orbitalia, porotic hyperostosis, and linear enamel hypoplasia) and chronic maxillary sinusitis in a sample of 246 individuals from three urban sites dating from 1030 to 1800 CE. Our analysis of skeletal remains reveals significant differences in the prevalence of porotic hyperostosis, linear enamel hypoplasia, and sinusitis between the medieval and post-medieval periods. These findings suggest that de-urbanization and economic decline adversely affected the health and wellbeing of the populations under study, influenced by factors such as working conditions and food availability. This study provides a new perspective on bioarchaeological approaches to urbanization, shedding light on the intricate realities of urbanization in Zeeland and offering important insights into its complexities.

Keywords: Netherlands; Non-specific stress indicators; Respiratory disease; Urbanization

5.1. Introduction

In recent years, osteoarchaeological studies on urbanization and its influence on the wellbeing of historical populations have witnessed a significant surge in scholarly interest. Through the application of an extensive array of research methodologies, our understanding on the impact urbanization and industrialization had on the health of past populations has significantly advanced to a point where it was never before. Yet, while ongoing studies on urbanization are continuously expanding our current understanding of past societies, archaeologists still struggle to address urbanization in most of its complexities (Betsinger & DeWitte, 2021).

The urbanization process (defined as a population shift from rural areas to cities) has influenced European history and culture for the past millennia (de Vries, 1984). Despite it being generally considered an ever-lasting and ever-growing phenomenon, urbanization has always been an extremely dynamic process, characterized by considerable variations in terms of both intensity, nature, and direction (Seto et al., 2015). In the past, many historiographical approaches have associated urbanization with industrial development, large-scale (factory) employment, and/or general negative effects on the health of the local population. However, it was recently argued that urbanization exhibits regional patterns rather than a single, uniform set of changes, and that various factors such as population composition, environment, local resources, types of labor, and economic disparities between urban sites in the same region or country can lead to vastly different experiences (Betsinger & DeWitte, 2020).

In the Netherlands, urbanization started as early as the 12th century, initially exclusively in the costal and northern regions and ultimately expanded to the hinterland during the 17th century (de Vries, 1984). Right from the outset of their urbanization process, Dutch cities exhibited remarkable heterogeneity. Some cities served as government seats, others primarily functioned as military centers or industrial hubs, while others (such as Amsterdam) focused the development of their economy and wealth on international trade (Brusse & Mijnhardt, 2011). While these remarkably different characterizations must have influenced people's lives and health in different ways, to date this has been only scarcely addressed in bioarchaeological research on Dutch urbanization (e.g., Casna & Schrader, 2022). While a considerable number of bioarchaeological studies have explored the lives of people residing in industrial (or proto-industrial) settings in other areas of Europe (e.g., Boyd, 2020; Western & Bekvalac, 2019; Yaussy, 2019), less industrialized (or rather "differently urbanized") environments have generally garnered limited attention (e.g., Davies-Barrett et al., 2021; Floreanova et al., 2020), leaving the life experiences of these inhabitants largely uncharted. To fill this gap, the present study aims to investigate the impact of urbanization on the health of three diachronic communities dating 1030-1800 CE whose urbanization history differs from the industrial/proto-industrial narrative, by analyzing prevalence rates of cribra orbitalia (CO), porotic hyperostosis (PH), linear enamel hypoplasia (LEH), and chronic maxillary sinusitis (CMS) across time. We aimed to test the hypothesis that (de) urbanization processes negatively impacted the health of Zeeuws people, resulting in increasing frequencies of both non-specific stress markers and sinusitis.

5.1.1. Urbanization in Zeeland

The coastal region of Zeeland is located in the southwestern corner of the Netherlands, bordering Belgium to both the south and west (Figure 5.1). Originally only comprising a group of small islands, starting from the 11th century Zeeland underwent significant transformations. Over the centuries, numerous areas in Zeeland were reclaimed from the water, and it is estimated that today almost 80% of Zeeland's landmass was originally submerged and later drained by local populations (van Cruyningen, 2012b). Historical records suggest that Zeeland's cold and wet climate has played a crucial role in shaping its maritime and economic history. This is evident not only in trade routes and in coastal infrastructure development, but also in the construction, spanning approximately ten centuries, of 429 kilometers of dikes, dams, dunes, and quays to protect cities against flooding (e.g., Dekker, 2023, Henderikx, 2012a, 2012b, 2012c). The name "Zeeland" itself translates to "Sea Land", a reflection of its close connection to water. Its unique geography has historically positioned Zeeland as a maritime powerhouse, thanks to its abundance of natural harbors and its strategic location along both the North Sea and the Scheldt River. In fact, throughout history Zeeland served as the first point of contact between the Netherlands and the world, acting as a gateway for international commerce and cultural exchange.

Figure 5.1. Map of the Netherlands showing the location of the province of Zeeland. Image made by M. Casna.

While it is today the least populous region of the Netherlands, up until the 17th century Zeeland formed one the most urbanized areas in Europe, as opposed to the more rural inland whose proto-industrial economy was based on small freehold livestock farmers (Brusse & Mijnhardt, 2011). Unlike other urban realities in the Low Countries, Zeeuws cities were connected by a singular federal structure where the power sat in the hands of wealthy merchants and guilds (Enthoven, 1996; van Cruyningen, 2012a). This uniquely structured governance facilitated the growing importance of international trade starting from the 11th century, leading to the prosperity of several towns in Zeeland. Following the Middle Ages, private trading companies such as the Dutch West India Company (WIC) and the United East India Company (VOC) established large-scale shipyards in most Zeeuws harbors, propelling both the local shipbuilding industry and international trade networks to become some of the largest in the entire European continent (Brusse & Mijnhardt, 2011). Consequently, Zeeuws cities experienced rapid expansion, with at least 50% of the local population residing in urban centers by the early 18th century (Brusse & Mijnhardt, 2011). It was noted that salaries as well as living conditions in Zeeland were generally higher than in the rest of the Netherlands; however, it is likely that the rapid expansions of Zeeuws centers limited the population's access to various basic resources (e.g., proper housing, healthcare, food, drinking water) (van Laar, 1966; Wintle, 2000). In fact, according to Van Steensel (2012) 15th century Zeeuws citizens were particularly susceptible to death and disease because of their poor living conditions.

Zeeland's economy continued to flourish until around 1670 CE, when major cities, such as Middelburg and Vlissingen, stopped growing following the financial difficulties of the Dutch East India Company in maintaining its international routes (de Vries & van der Woude, 1997; van Cruyningen, 2012a). After 1730 CE, the fortunes of the VOC severely declined and, together with the rise of early industries in the hinterland and with the stop of maritime trade caused by the Batavian Revolution, in 1794 CE Zeeuws economy finally collapsed (Brusse & Mijnhardt, 2011; de Vries & Van der Woude, 1997). By 1815 CE, all urban centers in Zeeland had faced a sharp decline in population numbers (Brusse & Mijnhardt, 2011): in just one or two years, 75% of the working population of Zeeuws cities left, making local economies (and populations) dramatically poorer (Brusse, 2011).

5.1.2. Non-specific stress indicators and respiratory diseases in relation to urbanization

Because the presence within an individual of any non-specific stress indicator (e.g., cribra orbitalia, porotic hyperostosis, linear enamel hypoplasia) is not indicative of a particular cause of stress but rather suggestive of the fact that the individual experienced some physiological challenges during their lifetime, it was argued that the study of non-specific stress indicators may provide valuable insights into the health and life experiences of archaeological populations. While many of these markers are generally considered to be indicative of nutritional deficiencies (e.g., Brickley, 2018; Walker et al., 2009), more recent research has explored their etiologies, suggesting that factors such as parasitic diseases, trauma, and local inflammations might also contribute to the prevalence of these lesions (e.g., King et al., 2002; Schats, 2023; Wapler et al., 2004). Possibly due to the complex etiology of these markers, comparisons across several populations have yielded complicated results, with no clear pattern indicating whether urbanization negatively influenced the physiological stress of the populations under study (Betsinger & DeWitte, 2021). When examining the occurrence rates of cribra orbitalia, porotic hyperostosis, linear enamel hypoplasia, and periosteal reaction in a medieval Polish population, Betsinger and DeWitte (2017) noted that these skeletal indicators exhibited no significant changes as urbanization increased. Conversely, Zhang and colleagues (2016) investigated the same lesions in the Late Shang dynasty in China (1250-1046 BCE) and concluded that increasing urbanization did increase physiological stress within the population under study. Similarly, Roberts (2009) compared data from multiple studies regarding cribra orbitalia, linear enamel hypoplasia, and stature in various medieval populations from England (ca. 450–1500 CE), arguing that urbanization did indeed negatively impact the health of the analyzed populations.

Besides examining non-specific stress markers, in the past years bioarchaeologists have frequently studied the occurrence of respiratory diseases (i.e., sinusitis, ear infections, and lung diseases) in urban settings under the assumption that these diseases can serve as indicators of air quality, hence providing insights into how urbanization may have posed challenges to the respiratory health of residents (e.g., Collins, 2019; Davies-Barrett et al., 2021; Sundman & Kjellström, 2013). However, the investigation of respiratory diseases in urban contexts has always yielded varying results, and rarely revealed a direct correlation between urbanization and individual health (e.g., Boyd, 2020; Casna et al., 2021). In a recent study by Casna and colleagues (2023) on six Dutch populations dating 475-1866 CE, it was observed that sinusitis prevalence rates remained consistent between rural and urban populations. However, these rates showed a progressive increase over time in both settings, suggesting that the process of urbanization had a detrimental impact on the health of individuals in both rural and urban areas. On the other hand, prevalence rates of ear and pulmonary infection for the same study did not match this pattern, suggesting other factors are at play, such as exposure to cold climates, tobacco smoke, genetic predisposition, and more (Boyd, 2020; Casna et al., 2023; Davies-Barrett et al., 2023).

5.2. Materials

For this study, the total sample was composed of three different populations from the Dutch province of Zeeland, dating 1030-1200 CE, 1300-1590 CE, and 1600-1800 CE, respectively (Figure 5.2). They were selected because they represent a diachronic window into urban life in the province of Zeeland across the medieval and post-medieval periods.

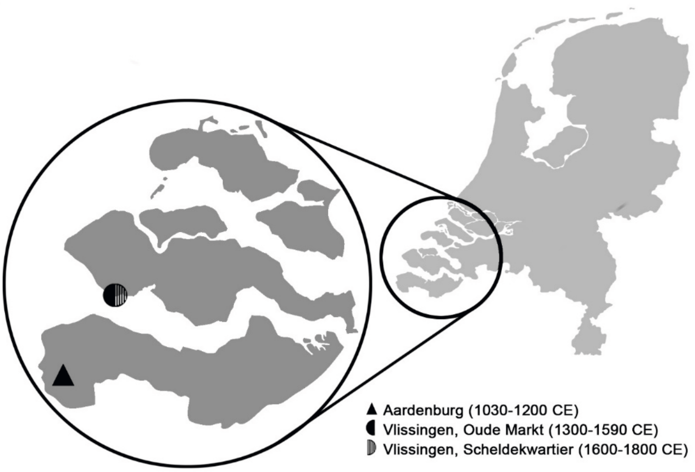

Figure 5.2. Map of the Netherlands showing the location of the sites under study. Image made by M. Casna.

5.2.1. Aardenburg (1030-1200 CE)

The skeletal collection of Aardenburg was excavated in 1948 from the Sint-Baafskerk, one of the city's oldest buildings (Forbes, 1953). Because these burials were discovered following the structural damages that the Second World War caused to the church, no excavation reports were produced at the time and, therefore, no information is available on how many skeletons were originally recovered. Similarly, the dating of these burials (i.e., 1030-1200 CE) remains uncertain, and was based on the interpretation of the symbols adorning the burial vaults (Cornelis, 1951; Haakma Wagenaar & van den Brink, 2011).

Formerly known as Rodanburg, Aardenburg was among the first Dutch cities to acquire city rights in 1187 CE (Henderikx, 2012d). HHowever, the area was already inhabited around the 8th century and quickly flourished thanks to the pre-existing infrastructures (e.g., pavemented roads; urban hydraulic systems) left by the Romans when they abandoned the settlement in the 5th century (de Pooter et al., 2000). Around 1000 CE, Aardenburg experienced a significant transformation with the emergence of the wool industry (Polderman, 2001). Initially solely relying on domestic wool, the city gradually shifted its focus and began importing wool from England. The imported wool became then a preferred choice for crafting opulent textiles, while the use of domestic wool continued for the creation of more modest clothing (Henderikx, 2012a). However, despite the flourishing wool industry, the primary source of employment for migrants seeking work in Aardenburg was centered around freight shipping, with merchants hiring skippers and occasionally fishermen to transport goods abroad (Henderikx, 2012a). In fact, thanks to its strategic position on the North Sea, already in 1000 CE Aardenburg extended its economic trade not only to England, but also to the Baltic coast, Northern Spain, and Italy, where they exported textiles, clothes, salt, food grains, and fish (de Pooter et al., 2000; Henderikx, 2012e). As a result of the expanding international market, the population of Aardenburg was estimated

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to be already around 3,500 inhabitants by the end of the 12th century (Henderikx, 2012b). While this figure may appear modest in comparison to flourishing urban centers like Bruges with 40,000 inhabitants, Ghent boasting 60,000, and London at 80,000, Aardenburg's demographic size held its own against major Dutch centers like Dordrecht, which counted around 5,000 inhabitants by 1200 CE (Henderikx, 2012b).

5.2.2. Vlissingen, Oude Markt (1300-1590 CE)

The skeletal assemblage of Vlissingen, Oude Markt was excavated in 2005 from the cemetery of Vlissingen's former main church and comprised a total of 716 individuals of mixed skeletal sexes and age groups (Koning & Wattenberghe, 2007). Because of their location within the church cemetery, these individuals are thought to be representative of the middle-to-lower socioeconomic class, possibly workers involved with either the sailing or fishing industry (Claeys et al., 2010).

Between 1315-1322 CE, exceptionally adverse weather conditions caused almost all of Western Europe to experience a widespread decline in population attributed to famine resulting from crop failures and livestock losses (van Steensel, 2012). Subsequently, from 1347-1351 CE, the whole continent faced an additional decline due to the devastating impact of the plague (Blockmans, 1980). While the historical documentation for the population development of Zeeland during this period is particularly limited, indications suggest that Zeeland encountered a less significant population decrease compared to its neighboring countries, together with a much faster repopulation in the 15th century (van Steensel, 2012). In Vlissingen alone, population size grew from 500 inhabitants in 1417 CE to 4,000 in just a century (van Steensel, 2012). This significant rise in population during the late Middle Ages in Vlissingen can be attributed to the city's pivotal role as the sole port linking the North Sea to the Dutch hinterland. Already in 1400 CE, Vlissingen was one of Zeeland's most important cities, as it operated as a key hub for several companies trading with Southern Africa and Eurasia (van Cruyningen, 2012a). Constant increase in commercial routes led to an expansion of the original harbor in 1443 CE financed by the city management (Claeys et al., 2010). From there and until the end of the 16th century, Vlissingen was in full development: new governmental buildings were built as well as two more ports, and the settling of several important characters in the Dutch cultural landscape led to the foundation of the Zeeland Society of Sciences (de Ridder, 2002). Between 1572 and 1600 CE, the power of Vlissingen had risen so high that the city was able to cut off both Middelburg and Antwerp (two of the most powerful trade hubs in the area) from their supply roads (van Cruyningen, 2012a).

5.2.3. Vlissingen, Scheldekwartier (1600-1800 CE)

This skeletal assemblage was excavated in 2003 and comprised a total of 128 individuals dating 1600-1800 CE. Dating was estimated based on the analysis of grave goods, including pottery, glass, smoking pipes, leather and textiles, metal, and surrounding building materials (Claeys et al., 2010). Unlike in Oude Markt, grave goods recovered in Scheldekwartier varied significantly in terms of quality, quantity, and provenance, potentially indicating a more heterogenous social composition of the sample (i.e., both merchants and harbor workers may have been interred there) (Claeys et al., 2010).

By the year 1600 CE, Vlissingen had transformed into a bustling international hub, boasting a diverse population and thriving trade connections (Claeys et al., 2010). While many were employed in supplying companies (i.e., shipbuilding, sail making, rope making, etc.), hundreds of people relocated to Vlissingen to work in the fishing industry, which continued to offer stable incomes and opportunities until the end of the 18th century (van Cruyningen, 2012a).

Vlissingen's economic prosperity began to wane in the late 1600s, as a financial stall of the Dutch East India Company coupled with mounting religious and political tensions inflicted significant damage to the city's administrative structures (de Ridder, 2004). This turbulent environment, characterized by growing instability and dwindling employment prospects, prompted both families and skilled laborers to leave Vlissingen as early as the late 17th century to relocate either towards burgeoning industrial centers inland, or back to the countryside (Brusse, 2011; Brusse & Mijnhardt, 2011). The resulting rapid decline in population was so pronounced that, as Brusse and Mijnhardt (2011) suggest, it must have been directly observable (and deeply concerning) to the residents of that era. The economic collapse of Vlissingen ultimately happened in 1795 CE, when the presence of the French army in the city forced all trading activities to cease.

5.3. Methods

For every individual, skeletal sex was estimated based on the observation of morphological features on the skull (i.e., nuchal crest, mastoid process, supraorbital margin, prominence of glabella, and mental eminence) and os coxae (Buikstra & Ubelaker, 1994; Phenice, 1969). Age estimations were made using morphologic characteristics of the pubic symphysis according to Brooks & Suchey (1990) and of the auricular surface (Buckberry & Chamberlain, 2002). Age groups were defined as young adult (approx. 20-34 years), middle adult (approx. 35-49 years), and old adult (50+ years), according to Buikstra and Ubelaker (1994). In order to be included in the final sample, each individual had to have an age-at-death ≥20 years old, and at least two among these features were required to be ≥25% complete: orbital roofs, cranial vaults, maxillary sinuses, and/or both upper and lower dentition (Casna & Schrader, 2022).

The presence of each lesion (i.e., cribra orbitalia, porotic hyperostosis, linear enamel hypoplasia, and chronic maxillary sinusitis) (Figure 5.3) was assessed macroscopically for all skulls and noted as either "absent" or "present" according to accepted criteria (Boocock et al., 1995; Waldron, 2008; Walker et al., 2009). Details on how each lesion was assessed are published in Casna and Schrader (2022). As dental disease (i.e., severe caries lesions, abscesses, and granulomas) can affect and/or potentially cause sinusitis (Patel & Ferguson, 2012), individuals presenting periapical lesions in the upper molars were excluded from this analysis. In case of complete skulls, the presence of maxillary sinusitis was assessed through observation with a flexible medical endoscope (Pentax model: FNL-10RBS, ø=4mm; view angle=30°).

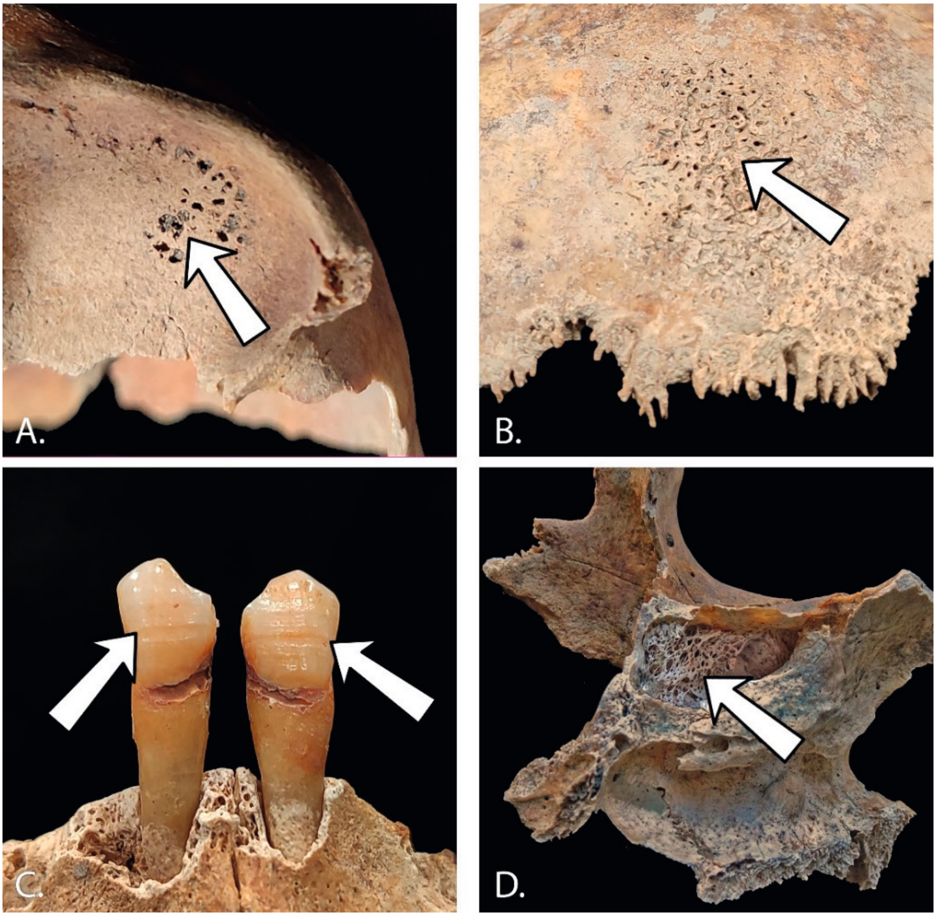

Figure 5.3. Lesions observed in this study and indicated by white arrows. A: Cribra orbitalia; B: Porotic hyperostosis; C: Linear enamel hypoplasia; and D: Chronic maxillary sinusitis in the form of "spicule-type bone formation", according to Boocock et al. (1995). Photographs by M. Casna.

Statistical analysis of the results was performed utilizing SPSS for Windows, version 29.0. To assess the significance of the relationship between various population groups and the presence of stress markers and chronic maxillary sinusitis, Chi-squared tests were employed. In instances where the expected cell count fell below 5, Fisher's exact test was used instead. A *p*-value ≤0.05 was considered as statistically significant.

5.4. Results

The total sample consisted of 246 adult individuals (Table 5.1). Figure 5.4 displays the observed prevalence of cribra orbitalia, porotic hyperostosis, linear enamel hypoplasia, and chronic maxillary sinusitis between the three populations under study.

Table 5.1. Demographic composition of the sample included in this study.

	Males				Females			
	Young adult (20-34 years) (%)	Middle adult (35-49 years) (%)	Old adult (50+ years) (%)	Total	Young adult (20-34 years) (%)	Middle adult (35-49 years) (%)	Old adult (50+ years) (%)	Total
Aardenburg (1030-1200 CE)	25 (42.4)	26 (44.1)	8 (13.5)	59	32 (72.7)	9 (20.5)	3 (6.8)	44
Vlissingen, Oude Markt (1300-1590 CE)	19 (70.4)	5 (18.5)	3 (11.1)	27	14 (56.0)	9 (36.0)	2 (8.0)	25
Vlissingen, Scheldekwartier (1600-1800 CE)	31 (68.9)	10 (22.2)	4 (8.9)	45	28 (60.9)	7 (15.2)	11 (23.9)	46
Total	75 (57.2)	41 (31.3)	15 (11.5)	131	74 (64.3)	25 (21.7)	16 (14.0)	115

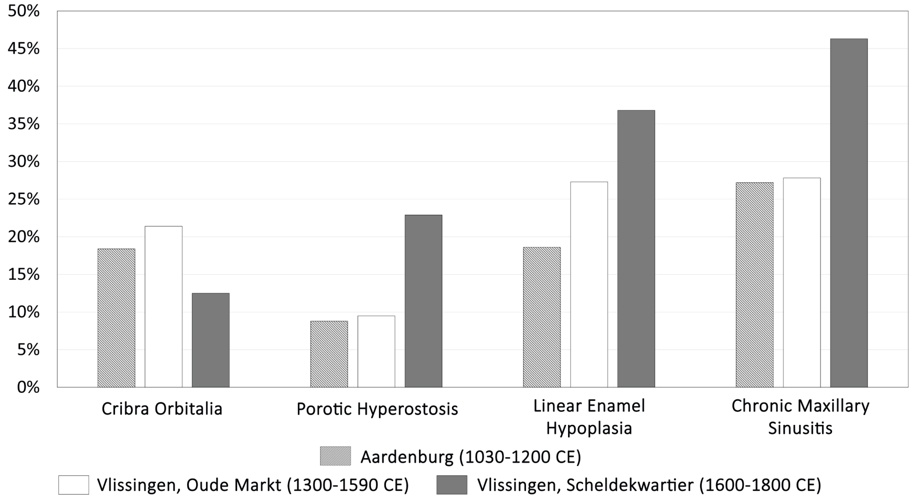

Figure 5.4. Prevalence of Cribra Orbitalia, Porotic Hyperostosis, Linear Enamel Hypoplasia, and Chronic Maxillary Sinusitis for all samples under study.

All lesions increased in prevalence through time, except for cribra orbitalia which was lower in Vlissingen, Scheldekwartier than it was in both Aardenburg and Vlissingen, Oude Markt. Statistically-significant increases were observed between Aardenburg and Vlisingen, Scheldekwartier for the prevalence rates of porotic hyperostosis, linear enamel hypoplasia, and chronic maxillary sinusitis (Table 5.2).

Table 5.2. Summary of Chi-Squared Test Results, per site.

	Cribra orbitalia				Porotic Hyperostosis †				Linear Enamel Hypoplasia				Chronic Maxillary Sinusitis			
	N	***n* (%)**	**χ^2**	***p***	**N**	***n* (%)**	**χ^2**	***p***	**N**	***n* (%)**	**χ^2**	***p***	**N**	***n* (%)**	**χ^2**	***p***
Aardenburg (1030-1200 CE)	103	19 (18.4)	1.893	0.388	102	9 (8.8)	8.369	**0.015***	70	13 (18.6)	5.729	0.057	103	28 (27.2)	8.069	**0.018***
Vlissingen, Oude Markt (1300-1590 CE)	42	9 (21.4)			42	4 (9.5)			33	9 (27.3)			36	10 (27.8)		
Vlissingen, Scheldekwartier (1600-1800 CE)	80	10 (12.5)			83	19 (22.9)			68	25 (36.8)			80	37 (46.3)		

Cribra orbitalia		
	Vlissingen, Oude Markt (1300-1590 CE)	Vlissingen, Scheldekwartier (1600-1800 CE)
Aardenburg (1030-1200 CE)	χ^2=0.170, *p*=0.680	χ^2=1.194, *p*=0.275
Vlissingen, Oude Markt (1300-1590 CE)		χ^2=1.1670, *p*=0.196
Porotic Hyperostosis		
	Vlissingen, Oude Markt (1300-1590 CE)	Vlissingen, Scheldekwartier (1600-1800 CE)
Aardenburg (1030-1200 CE)	† χ^2=0.018, *p*=1.000	**χ^2=7.051, *p*=0.008***
Vlissingen, Oude Markt (1300-1590 CE)		χ^2=3.319, *p*=0.068
Linear Enamel Hypoplasia		
	Vlissingen, Oude Markt (1300-1590 CE)	Vlissingen, Scheldekwartier (1600-1800 CE)
Aardenburg (1030-1200 CE)	χ^2=1.011, *p*=0.315	**χ^2=5.722, *p*=0.017***
Vlissingen, Oude Markt (1300-1590 CE)		χ^2=0.896, *p*=0.344

Table 5.2. Summary of Chi-Squared Test Results, per site. (continued)

Chronic Maxillary Sinusitis		
	Vlissingen, Oude Markt (1300-1590 CE)	Vlissingen, Scheldekwartier (1600-1800 CE)
Aardenburg (1030-1200 CE)	χ^2=0.005, p=0.945	**χ^2=7.146, p=0.008***
Vlissingen, Oude Markt (1300-1590 CE)		χ^2=3.515, p=0.061

N=total of individuals with observable feature; *n*= total of individuals showing lesions.
*=Statistically significant at 95 percent confidence level.

The distribution of lesions among skeletal sex groups was investigated for all populations under study (Table 5.3). While most lesions were evenly distributed among sex categories, in Vlissingen, Scheldekwartier males showed significantly higher rates of porotic hyperostosis than females. Porotic hyperostosis in males from Vlissingen, Scheldekwartier was also observed to be significantly higher than in males from both Aardenburg ($p<0.001$) and Vlissingen, Oude Markt ($\chi^2=6.368$, $p=0.018$) (Table S1). Furthermore, female individuals from Vlissingen, Scheldekwartier had significantly higher rates of CMS than female individuals from Aardenburg ($\chi^2=5.607$, $p=0.027$). All other associations among sex categories were observed to be non-significant.

The distribution of lesions among age-at-death groups was investigated for all populations under study. Among all samples, young adults (20-34 years) generally had the highest occurrence rates for every lesion. In Aardenburg and Vlissingen, Oude Markt old adults (50+ years) almost displayed no presence of cribra orbitalia, porotic hyperostosis, and linear enamel hypoplasia. When investigated statistically, no significant associations were observed between presence of lesions and age-at-death (Table S2).

Table 5.3. Summary of Chi-Squared Test Results, per sex groups.

		Cribra Orbitalia				Porotic Hyperostosis				Linear Enamel Hypoplasia				Chronic Maxillary Sinusitis			
		n	N (%)	X2	*p*	n	N (%)	X2	*p*	n	N (%)	X2	*p*	n	N (%)	X2	*p*
Aardenburg (1030-1200 CE)	Males	59	13 (22.0)	1.181	0.315	59	7 (11.9)	n/a	*0.296†*	39	8 (20.5)	0.219	0.761	59	14 (23.7)	0.833	0.380
	Females	44	6 (13.6)			43	2 (4.7)			31	5 (16.1)			44	14 (31.8)		
Vlissingen, Oude Markt (1300-1590 CE)	Males	21	5 (23.8)	n/a	1.000†	21	2 (9.5)	n/a	1.000†	17	6 (35.3)	n/a	0.438†	18	3 (16.7)	2.215	0.264
	Females	21	4 (19.0)			21	2 (9.5)			16	6 (35.3)			18	7 (38.9)		
Vlissingen, Scheldekwartier (1600-1800 CE)	Males	39	3 (7.7)	n/a	0.313†	42	17 (50.5)	14.895	**<0.001***	36	13 (36.1)	0.014	1.000	40	14 (35.0)	4.073	0.072
	Females	41	7 17.1)			41	2 (4.9)			32	12 (37.5)			40	23 (57.5)		

N=total of individuals with observable feature; *n*= total of individuals showing lesions.
†=Fisher’s exact test. *=Statistically significant at 95 percent confidence level.

5.5. Discussion

The aim of this study was to investigate patterns of health and respiratory disease across time in an urban context that differs greatly from the industrial framework on which most bioarchaeological studies on urbanization have focused so far (i.e., international maritime trade hubs).

Even if living and working in harbors and on ships was undoubtably physically very demanding (Claeys et al., 2010), it was noted that Zeeland's economic growth in the medieval period brought substantial welfare to all citizens, both in terms of access to basic resources (e.g., food and clean water) and of salaries, which historical records attest were higher than in the rest of the country (Brusse & Mijnhardt, 2011). This is partially reflected in our results, as rates of non-specific stress indicators and sinusitis did not show significant variation between Aardenburg (1030-1200 CE) and Vlissingen, Oude Markt (1300-1590 CE), suggesting that these populations were somehow protected by the flourishing economic situation in the region. Inversely, we observed statistically-significant increases in porotic hyperostosis, linear enamel hypoplasia, and chronic maxillary sinusitis prevalence rates between Aardenburg and Vlissingen, Scheldekwartier (1600-1800 CE). While this may be indicative of living conditions (e.g., limited access to food resources) harshening with Zeeland's economic collapse in the 18th century, it is still very interesting to note that the largest increase in both stress indicators and sinusitis did not occur in times of intense urban growth, but rather during significant de-urbanization. As already mentioned, Zeeland's dramatic economic decline reportedly affected the wellbeing and health of people and caused many families to relocate by the end of the 17th century (Brusse & Mijnhardt, 2011). It is likely that the first dissolution of the Dutch West India Company in 1674 CE severely impacted the Zeeuws population both in terms of employment opportunities and of financial wellbeing (Klein, 1965), possibly making it harder to afford certain foods, leading to vitamin/nutrient deficiencies and an increase in cases of malnutrition among workers and the poorest members of society. Therefore, we argue that people from Vlissingen, Scheldekwartier underwent significant physiological stress in response to the declining economic environment in which they were living.

We argue that the effects of Zeeland's economic decline on the health of Zeeuws people are further reflected in our sinusitis results, as CMS prevalence rate was significantly higher in Vlissingen, Scheldekwartier than in Aardenburg and almost significantly higher in Vlissingen, Scheldekwartier than in Vlissingen, Oude Markt (p=0.061). In the past, most bioarchaeological studies focusing on respiratory diseases associated higher rates of sinusitis to overcrowding and exposure indoor/outdoor to air pollution (e.g., Bernofsky, 2010; Casna et al., 2021; Sundman & Kjellström, 2013). However, recent research has started to acknowledge the diverse and intricate etiology of sinusitis, shedding light on the challenges linked to pinpointing the particular factors that could be responsible for the fluctuations in prevalence rates within different archaeological populations (e.g., Boyd, 2020; Casna et al., 2023; Davies-Barrett et al., 2023). While changes in risk factors such as working and living conditions, food resources availability, and access to healthcare are usually addressed in most publications on chronic maxillary sinusitis, others such as exposure to adverse weather conditions, genetic predisposition, and cultural habits (e.g., smoking) have revealed to be very difficult to address in archaeological settings despite them being extremely prevalent in most populations (Casna et al., 2023; Davies-Barrett et al., 2023; Sundman & Kjellström, 2013). For example, as most specialized workers (e.g., shipbuilders, cobblers, and merchants) left Vlissingen following its economic downturn (Brusse, 2011; Brusse & Mijnhardt, 2011), it is likely that the population of Scheldekwartier primarily consisted of non-specialized laborers engaged in activities such as construction, fishing, or ship loading. These individuals generally undertook extremely physically demanding tasks and were exposed to harsh weather conditions, potentially impacting their susceptibility to infectious diseases such as sinusitis. These results reflect those of Casna and colleagues (2023) who compared rates of CMS across three diachronic (i.e., early-medieval, late-medieval, and post-medieval) populations from the Netherlands and observed that prevalence rates significantly increased with time, concluding that urbanization may have impacted negatively the respiratory health of past Dutch populations.

As historical records indicate that Zeeland's maritime industry was run by both men and women (Stuurman, 2023), we did not expect significant differences between sex groups as we considered them to be equally exposed to socioeconomic changes. However, while no differences were observed in cribra orbitalia, linear enamel hypoplasia, nor sinusitis rates, significantly higher rates of porotic hyperostosis were noted in males compared to females in Vlissingen, Scheldekwartier. Moreover, PH prevalence rates in males from Vlissingen, Scheldekwartier were significantly higher than those in males from both Aardenburg and Vlissingen, Oude Markt. Despite its etiology being debated, in the past porotic hyperostosis has been linked to a synergy between poor hygienic conditions, infectious diseases, and diets lacking in vitamin B12 (Walker et al., 2009). Even if men and women were equally contributing to the maritime industry, their roles and expectations differed greatly (e.g., men working on ships, women running markets or making fishing nets at home) (Stuurman, 2023; Wintle, 2000). Working at sea for long periods, likely with limited access to food, clean water, and healthcare, may have drastically and increasingly impacted the health of men, especially during the post-medieval period when basic resources became even more limited.

When looking at the distribution of lesions among age-at-death categories, no significant differences were observed. Although it is important to acknowledge the potential influence of our limited sample size on these findings, the uniform distribution of lesions across all adult age-at-death categories suggests that the factors influencing the health and wellbeing of the three populations under study may have uniformly impacted all groups, thereby posing a pervasive risk independent of age. On the other hand, despite there not being any statistically significant association, older adults from both Aardenburg and Vlissingen, Oude Markt did generally show the lowest occurrence rates of all non-specific stress indicators (in most cases, old adults showed no cribra orbitalia, porotic hyperostosis, nor linear enamel hypoplasia). While it is unlikely that any of the risk factors outlined in this paper affected older populations less than their younger counterparts (or rather, the risk was not present during the early life of old adults), it is possible that the presence of these indicators in the samples under study marks more fragile individuals who died before old adults. Previous research on enamel hypoplasia identified a link between the presence of LEH and premature mortality, suggesting that early-life stress may be strongly associated with mortality in the younger-adult life stage (e.g., Amoroso et al., 2014; Stutz et al., 2021). While this would fall within the concepts of hidden heterogeneity and selective mortality as outlined by Wood and colleagues (1992), the lack of data on subadults demographic profiles for the populations under study makes it difficult to thoroughly deal with the osteological paradox (DeWitte & Stojanowski, 2015). However, the uniform distribution of lesions across age-at-death categories potentially supports a "non-paradoxical" view of results (DeWitte & Stojanowski, 2015; Krenz-Niedbała & Łukasik, 2020). This implies that our observed prevalence rates may indeed reflect the life experiences of the individuals included in this study, and hence provide with a deeper understanding of Zeeland's past.

5.5.1. Limitations of the study

While our findings provide valuable insights into the impact of urbanization and economic collapse on the health of Zeeuws citizens during the post-medieval era, it is imperative to acknowledge the presence of several limitations, such as disparities in sample sizes among different assemblages, and difficulties in addressing every risk factor for the health of the individuals under study (e.g., climate). To date, the impact that the natural environment had on the health of past populations has received almost no attention from bioarchaeologists, despite it likely playing a significant role in the wellbeing of many past societies (Casna et al., 2023; Davies-Barrett et al., 2023; Roberts, 2016). In the Netherlands (and in Zeeland specifically) climate has always been heavily impacted by the North Sea (Wintle, 2000). Cold temperatures, strong winds, and frequent floodings must have impacted negatively the health of past Dutch populations, regardless of the time period (Zijlmans, 2017). However, while weather conditions are extremely difficult to address archaeologically, comparisons of different populations from different climatic regions may help addressing the role of climate on past human health. In this framework, Schats (2023) recently underscored the significance of incorporating the natural environment into the interpretation of porous lesions, as high prevalence rates of cribra orbitalia can serve as a potential indicator of malaria in skeletal remains from regions with high malaria endemicity. It is worth noting that, even if historical sources explicitly mention malaria in Zeeland only from the 16th century onward, it has been argued that it may have been highly prevalent even during the medieval period (Heide, 1988; Schats, 2015). In our results, cribra orbitalia prevalence rates indicate minimal variation over time, suggesting that the factors contributing to it were not influenced by (de)urbanization in the studied area. Consequently, the enduring consistency of cribra orbitalia in our samples may indeed hint at malaria's substantial impact on the health of the populations under investigation, even if more research would be needed to confirm this hypothesis.

An additional limitation in our research stems from the heterogeneity of the investigated populations (Wood et al., 1992). Despite our best efforts to account for all relevant factors shaping the lives of the individuals under study, our data originates from cemeteries that were in use for several centuries. This temporal expanse poses a challenge in addressing factors associated with temporal variations, such as climate change, natural calamities, epidemics, and wars, which could have impacted both human health and frailty. Furthermore, the dimension of mobility within the populations under investigation also potentially impacted our results. Although it is unlikely that a significant influx of immigrants occurred in Vlissingen during the post-medieval period, both Aardenburg and Vlissingen, Oude Markt experienced substantial prosperity in medieval times, likely attracting diverse newcomers with different backgrounds. The absence of an inquiry into migration is undoubtedly a confounding factor for our analysis, as we are unable to identify individuals with a mobility background, nor to make assumptions regarding their living and working conditions before they moved to the cities. While a few bioarchaeological studies on Dutch populations have addressed migration through isotope analysis (e.g., Kootker et al., 2016, 2018, 2019), there is currently no systematic study that has specifically examined the potential confounding effects of demographic non-stationarity in Dutch samples. Examining different populations would aid in assessing how human mobility could have influenced the health patterns of urban populations, especially the ones with significant migration history.

5.6. Conclusions

This study aimed to examine patterns of health and disease in several urban contexts in the Dutch region of Zeeland, whose economy was based on international maritime trade. While historical urban prosperity is reflected in our findings from the 11th to the 16th century by low, unchanging rates of cribra orbitalia, linear enamel hypoplasia, and chronic maxillary sinusitis, in the post-medieval period (i.e., during times of urban and economic decline) we observed a significant increase in porotic hyperostosis, linear enamel hypoplasia, and chronic maxillary rates. Furthermore, we observed how in the post-medieval period porotic hyperostosis was more frequent in males, suggesting that decreasing job opportunities and financial stability impacted men more than women.

Overall, our findings emphasize the necessity of examining each urban context individually, recognizing unique historical patterns and distinct influences on its inhabitants. We argue that, as we progress in our understanding of past urban populations, it is vital to address the multifaceted aspects of urbanization that have contributed to the health of our ancestors, delving into factors such as economic variability, gender differences in socioeconomic change, and historical climates. By doing so, we can aim to attain a more comprehensive and nuanced understanding of both urbanization, its diverse elements, and of how they have contributed to the wellbeing of past communities.

Supporting information

Supplementary materials for this paper are available on the publisher's website: https://doi.org/10.1002/oa.3302

Data availability statement

The datasets generated and analyzed during the current study are available at Casna, Maia, 2023, "Data for: "The urban sea"", https://doi.org/10.17026/AR/DOHGI1, DANS Data Station Archaeology.

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