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RESEARCH ARTICLE

REVISED Histories of sardine fisheries. architecture and environment in the Bay of Biscay (1846–1965)

[version 2; peer review: 2 approved]

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Abstract

Background

This study combines historical cartography and statistical analysis to examine France Atlantic's sardine fisheries across time (1846–1965) and spatial scales, from individual harbours to the continental shelf. It aims to use interdisciplinary methods to identify the relations between European sardine populations (*Sardina pilchardus*), climatic fluctuations, and the material structures associated with fishing—including vessels and coastal infrastructures. The underlying hypothesis is that long-term sardines fluctuations in landings influenced the way we built on land and, in turn, exerted pressures on sardines ecologies.

Methods

Historical data on fishing vessels, coastal infrastructures, sardine landings, territorial occupation by canneries, fishing grounds, and fisher censuses were compiled to reconstruct the temporalities of fishing landscapes. First, we quantified the spatial expansion of canneries and shoreline infrastructures. While canneries were the product of private industrial investment, shoreline infrastructures included both private and public developments. Given the limited availability of detailed funding records, subsequent analyses focused on publicly funded coastal works, for which investment amounts and construction timelines could be reconstructed and compared with profits derived from fish landings. Second, in the absence of

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consistent financial records or urban plans at the continental-shelf scale, population census data were used as a proxy for urban growth and related to fishing effort to identify areas of intensified pressure. These patterns were then compared with the spatial distribution of fishing grounds. Finally, sardine landings were analysed against environmental indices and vessel characteristics to assess their relative influence.

Results

The assessment revealed: (1) a long-term decline in sardine landings that does not seem to be influenced by environmental variability; (2) the continuing expansion of harbour infrastructures and vessels tonnage even when landing values declined; (3) trends toward the spatial concentration of fishing effort.

Conclusions

The findings suggest that harbour works were driven less by an objective awareness of ecological pressure than by latent development projects activated during fishing crises. Rather than serving as a passive backdrop to the history of fisheries, these infrastructures actively shaped the circulation of sardine landings, capital investment, and fishing activity along the coast.

Keywords
Fishing architecture, Fish landing records, Historical fisheries, Multiscalar research, Sardine, Statistical analysis (Granger Causality Test, Generalized Linear Model), Interdisciplinary research

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REVISED **Amendments from Version 1**

This revised version includes changes to the text, figures, and interpretation of the results. The manuscript now explicitly distinguishes the three analytical scales used in the study (Douarnenez, South Brittany, and the French Atlantic façade) and clarifies the role of harbor works, canneries, vessel tonnage, and census-based indicators in reconstructing the material infrastructure of the sardine fishery.

A new figure has been added comparing vessel tonnage (1846–1928) with the economic value of sardine landings. This analysis strengthens the comparison between investments in fishing capacity and investments in harbor infrastructures and is now discussed in the Results, Discussion, and Conclusion sections. The phased reconstruction of harbor works in Douarnenez has also been revised through the addition of color coding to improve readability.

Several methodological clarifications have been added. The revised manuscript now explains how sardine landings data function as a common comparative indicator across the different spatial scales and datasets analysed, allowing changes in infrastructure and fishing capacity to be related to fluctuations in the fishery's economy. Additional clarifications have also been made regarding the relationship between landing values and catch volumes, as well as the limitations associated with the available historical records.

The Results, Discussion, and Conclusion have been substantially revised to clarify the paper's central arguments. In particular, the argument is now structured around three main relationships: (1) sardine behavior and the geography of fishing harbors, (2) the relationship between fishing grounds and landing sites, and (3) the relationship between sardine fluctuations and investments in fishing capacity and shore-based infrastructures. A new subsection, "Following sardines' skin," examines historical descriptions of sardines' skin quality and their relationship to the geography of canning industries and fishing infrastructures.

These revisions strengthen the analysis of interactions between ecological and material landscapes and highlight the coexistence of multiple temporalities within the sardine fishery.

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Introduction

The historical relationship between fisheries and fish, including its impact on fish populations, has been the subject of research ranging from biology to oceanography (Pauly, 2019; Jackson et al., 2011). Yet such history has overlooked the connection between the fisheries and the associated dynamics on land. This paper addresses this gap by assessing the architectural and urban dynamics related to historical sardine fisheries in South Brittany, France. Sardine fisheries in the Bay of Biscay became one of the main sources of economic income for the French regions of the Atlantic coast at the turn of the twentieth century (Fichou, 2006; Binet, 1999). The activities helped shape not only the regional economies but also the shoreline, generating a variety of constructions that defined a specific landscape. However, understanding the historical exchanges between sardine populations and coastal societies requires an approach that addresses sardine fluctuations, fishing practices, and the structures that channelled fishing efforts all at the same time. In the Bay of Biscay, several studies (Binet 1986, 1999; Planque et al., 2004; Bellier et al., 2007) have explored the interplay between fish population dynamics and environmental fluctuations; however, the fishing pressure is frequently treated as secondary and is difficult to quantify in historical assessments. Le Floc'h's et al. (2023) work is one of the rare studies that engages directly with technical changes over the course of a century (1900–2017), tracing vessel size, gear shifts, and fleet structure. Although he mentions fishing pressure, he does not measure or quantify its effects. A more recent study by Lahellec et al. (2024) complements this by focusing on how pelagic fleets adapted between 2010 and 2018, combining landings, vessels, and fishers' knowledge. Both works highlight how regulations alongside economic and technological factors shape fishing effort.

In parallel, historical studies by Binet (1986, 1999) have sought to relate fluctuations in sardine landings to broader climatic and oceanographic changes. Binet's work used coastal archival data, such as harbour statistics, sailors' registers, and qualitative descriptions of annual yield (such as "good" or "poor" years). It correlates these materials with reconstructed temperature indices, like historical sea surface temperature.

A more recent body of work (Planque et al., 2007; Bellier et al., 2007) has focused on the ecological factors, mostly hydrography, to show how these factors influence sardines' spawning behaviours and distributions. These studies tend to examine ecological patterns in isolation from the industry that harvests them. Planque et al. (2004) developed the concept of "hydrological landscapes", identifying river plumes and oceanographic currents, such as the upwelling, as shapers of marine habitats where pelagic species may spawn and feed. A complementary study, by Bellier et al. (2007), uses ichthyoplankton surveys to demonstrate how spawning locations have shifted significantly between the late 1960s and early 2000s, likely in response to changing temperatures and salinity.

Building from this understanding of oceanographic structures, a growing body of ecological modelling work has quantified the spatial distribution of sardines in relation to environmental variables. Ecological niche models (Sillero et al., 2021) have been used to estimate potential spawning and feeding grounds by integrating sea surface temperature, salinity, chlorophyll concentrations, and other hydrographic indicators. For instance, Planque et al. (2007) has identified key thresholds of environmental conditions that influence sardine spawning habitat. The authors divided spawning habitat into three categories: "potential spawning habitat", which is defined by the hydrographic conditions suitable for spawning; "realized spawning habitat", the habitat where spawning actually occurs; and "successful spawning habitat", the habitat where recruitment has happened. Moreover, Hébert-Burggraeve (2023) and Quemper (2021) explored the integration of both commercial and scientific datasets into ecological models that estimate the spatio-temporal variations of small pelagic fish distribution. These modelling approaches not only deepen ecological understanding but also serve as strategic tools for protecting, or rather exploiting more efficiently, sardine populations in changing environmental conditions.

From technical changes to climatic correlations and ecological modelling, these approaches seemingly omit to address the role of built infrastructures in the history of fisheries. Hence, our hypothesis suggests looking at sardine fisheries as a shaper of both the marine and urban ecologies. Indeed, an intertwined process occurred in which the fisheries' infrastructures developed in response to sardines' biological traits, while in turn exerting new pressures on the fish and its habitat. It appeared to us that those structures—such as piers, auction houses, and canneries—have been looked at as a passive backdrop, where the fish is accessed, processed, and commodified. By adding the built environment as a layer, our approach aims to reframe the story of the fishing harbours, making architecture an active agent.

To a certain extent, we can argue that shore-based structures are a proxy measurement of fishing pressure, the latter increasing in relation to the growth of fish-processing facilities. In this paper, we explore the hypothesis that fluctuations in sardine landings influenced the ways we built on land. We discovered that this was not necessarily the case, since design and building practices relate to the agendas of a variety of agents other than fish, notably the state (in France through the *Ponts et Chaussées* technical offices). Nonetheless, we can identify a relationship between investment in construction works and reductions in landings, with an influx of public investment to cope with the decrease in fisheries profit. While landing values declined (and we try to establish the reason for this decline, be it environmental factors, overfishing, or circumstantial movements of fish populations, etc.), harbour infrastructures continued to expand. Rather than reacting to an objective awareness of the ecological and environmental factors that might have generated a decrease in landings, the design and construction of terrestrial infrastructure was driven by latent projects, previously unrealized projects whose construction was determined by the urgent need to respond to fishing crises. To address this tangle of reasons, factors, and evidence, this paper explores novel interdisciplinary methods, using the Bay of Biscay historical sardine fisheries as a testing ground.

Objectives

In this study, our objectives are threefold: firstly, to compile a dataset covering annual sardine landings, fishing effort, and environmental variables (1865–1965)—this dataset served as a basis for assessing fisheries' economics, climatic fluctuations, and urban transformations across multiple temporalities and scales; secondly, to analyse how the commodification of European sardines and how this process was shaped by the urban patterns and territorial occupation of coastal towns; and thirdly, to examine how the built environment, understood as part of the broader material infrastructure of the sardine fishery, may have reinforced fishing capacity and contributed to pressures on sardine populations.

Our historical data limit our ability to quantify the ecological impacts and to reconstruct the exhaustive material infrastructures of the sardine fishery. Beyond coastal works, canneries, and fishing vessels, sardine production depended on a wider network of shipyards, salt depots, net-drying racks, auction houses, and other facilities for which consistent historical records are lacking. Consequently, our analysis focuses on those dimensions of the fishery for which systematic spatial, temporal, and statistical data were available, including harbour works, canning facilities, vessel tonnage, and census-based indicators of fishing activity. Although these sources provide only a partial reconstruction of the fishery's material infrastructures, they allow us to examine how investments in harbour facilities and fishing capacity evolved in relation to fluctuations in sardine landings.

While comparing harbour construction work investment with the economic value generated by sardine landings, we observed a recurrent mismatch: even if landing values declined, harbour infrastructures continued to expand. This prompted us to examine the role of the *Corps des Ingénieurs des Ponts et Chaussées*, the state engineering body responsible for harbour works. Their planning practices (phased, anticipatory, and responsive to administrative constraints) help explain why architectural development responded indirectly to sardine fluctuations.

Methods and materials

1. Study area

Located along the Atlantic coast of France and northern Spain, the Bay of Biscay encompasses a continental shelf of approximately 220 000 km^2. Its morphology is characterized by a broad northern section (the *plateau armoricain*) that extends nearly 200 kilometres, and a tapering southern section (the *plateau aquitain*) that narrows to about 30 kilometres (Dessier, 2015). These contrasting shelf widths influence the circulation of water masses and nutrients, resulting in distinct ecological subregions (Planque et al., 2004). The Bay's hydrology is defined by the confluence of nutrient-rich river discharges with major oceanic currents. This combination creates a productive coastal ecosystem that supports small pelagic species such as *Sardina pilchardus* (European sardines).

Within this broader context, the study encompasses three scales. The harbour of Douarnenez serves as the local case study, where the most detailed reconstruction of harbour infrastructure was possible, while South Brittany provides a regional framework for examining fishing grounds and changes in vessel tonnage. The broader French Atlantic façade provides the largest geographical frame of analysis. These scales reflect the spatial extent of the historical sources available, and the different dimension of the sardine fishery examined in this study. Across all three scales, sardine landings data serve as a common comparative indicator, enabling us to relate changes in infrastructure, fishing capacity and fishing strategies to fluctuations in the fishery's economy.

2. Historical data source

2.1 Fishery data: Landings and fleet composition

To reconstruct long-term patterns in sardine exploitation, we first compiled one dataset covering the historical period 1865–1965. This dataset systematized historical records in order to look for fluctuations in sardine abundance in the Bay of Biscay. Titled "Brittany_1865–1965_landings", the data set is a collection of records on sardine landings derived from three different archives: Bibliothèque Nationale de France (1869, 1872–1875, 1880–1882, 1885–1906), Archives Nationales (1875, 1881–1882, 1898, 1900–1902, 1904–1905, 1910, 1913–1914), and Archimer (1866–1867, 1874, 1876–1880, 1883–1885, 1887, 1903, 1905, 1907–1909, 1911–1912, 1916–1965), which is the online archive of Ifremer (the French national research institute dedicated to the ocean and marine resources). The data set is composed of several time fragments, during which the recording methods and data organization remained consistent, facilitating intra-period comparisons despite an overall heterogeneity across the century (intra-periods 1865–1866; 1867–1874; 1875–1890; 1891–1893; 1894; 1895–1902; 1903–1912; 1913–1923; 1924–1937; 1938; 1945–1956; 1957–1958; 1959–1965).

These time fragments reflect the changing nature of data-collection practices over time. Throughout this century-long time span, the data show significant heterogeneity. Units of measurement vary from period to period, ranging from financial value (in francs) to the number of sardines caught, and later to weight—initially in kilograms and later in metric tons. For consistency, all quantities in weights have been standardized and expressed in kilograms. In some years, the official totals reported in the archival documents include additional fishing methods such as *pêche à pied* (literally "fishing on foot", a practice dependent on the tides and the use of various tools) or distant-water expeditions (e.g. to Iceland or Newfoundland). These totals have been preserved in the dataset for each year and harbour to contextualize the relative importance of sardine fishing within overall landings. However, when isolating sardine catches specifically, only quantities caught through coastal operations were retained; for instance, sardines caught via *pêche à pied* were excluded from that column when identified. The data is organized differently across periods—sometimes by maritime district, sometimes by harbour—making direct comparisons challenging. From the late nineteenth century onward, additional details such as number of fishers, vessels, tonnage, fishing gear, and the seasonality of sardine fishing were progressively introduced. For the purposes of this study, only data relating to sardine fishing along the "Région de l'océan" (excluding the English Channel and North Sea) were retained.

2.2 Filtering the dataset

Since the dataset differed across periods, we standardized the temporal and spatial frames to ensure continuity and enable statistical analysis. The first filtered dataset, covering the years 1895 to 1912, includes information on the quantity of fish caught (in kilograms), the total value (in francs), the number of boats, and their tonnage capacity across fifteen districts: Arcachon, Audierne, Auray, Bayonne, Belle-Île, Camaret-sur-Mer, Concarneau, Douarnenez, Le Croisic, Lorient, Quimper, Saint-Gilles, Île d'Oléron, Noirmoutier, and les Sables-d'Olonne. The second filtered dataset spans a longer period but is limited to data on sardine landings: specifically, the kilograms caught and their value in francs. It includes the districts of Arcachon, Audierne, Concarneau, Douarnenez, Le Croisic, Lorient, and Saint-Gilles-sur-Vie.

3. Digitizing built environment data

3.1 Comparative mapping (1879)

We found on the online catalogue of the Archives Départementales du Finistère (ADF) scanned maps of fishing harbours in France. These maps were extracted from a book, *Atlas des Ports de France* (1879) written by the technical body of *Ponts et Chaussées*.

The urban plans are represented using a consistent scale and cartographic convention, allowing comparison of shoreline organization and maritime infrastructures. The maps were an entry point in examining how the terrestrial dimension of sardine exploitation evolved in relation to fishing intensity. We digitized and assessed these maps, with a focus on three sardine harbours in South Brittany: Douarnenez, Audierne, and Concarneau.

The 1879 plans of Douarnenez, Audierne, and Concarneau were digitized as vectorial drawings on AutoCAD (such as Figure 1, representing only Douarnenez). These maps allowed us to delineate the main harbour docks and structures, such as slipways and breakwaters. We enriched these maps by locating canning factories as we cross-referenced maps produced by Jean-Christophe Fichou in his habilitation thesis (2006). This revealed how canneries positioned themselves within the harbour morphologies.

3.2 Temporal comparative mapping: Douarnenez, 1879 and 1909

To understand change over time, we focused on Douarnenez, for which additional detailed materials were available. A 1909 urban plan found at the Service Historique de la Défense (SHD) in a book written by two *Ponts et Chaussées* engineers (Corbeaux & Foucault, 1910), documents subsequent extensions and reconfigurations of the harbour areas, including the development of the Port de Rosmeur (fishing harbour) and Port-Rhu (commercial harbour). The construction of new docks and slipways, and the establishment of a bridge between Douarnenez and Tréboul to carry the railway (Figure 2). This 1909 plan was digitized and processed following the same annotation procedure as for the 1879 series.

The 1910 *Ponts et Chaussées* book also provides quantitative data on harbour use and investments. This data inform us of the number of fishing boats entering and leaving Douarnenez between 1880 and 1906, as well as tables of construction works completed (piers, docks, slipways, etc.) and their related cost. From this material, we reconstructed a chronological sequence of the waterfront development in seven phases, between 1800 and 1907 (Figures 3), indicating the economic value invested in each phase. It should be noted that fluctuations in the economic value of sardine landings do not directly reflect changes in catch volumes, as prices varied substantially depending on abundance, with scarcity driving prices upward and periods of abundance leading to price declines. An accompanying graph represents the value generated by sardine landings and how it was distributed across the phases (Figure 4).

4. Statistical analysis

By using the Granger causality test (Granger, 1969), a statistical method to determine if one time series can predict another time series, we analysed the time series of "landings" against "number of boats", "tonnage" and "value". The test assesses whether past values of one variable provide significant information about future values of another variable, indicating a predictive relationship rather than a direct causal one. The null hypothesis is that "landings" causes the "number of boats", "tonnage", or "values". As the test is asymmetrical, the comparisons were performed in both directions. We used the datasets from the two continuous periods (1895–1912 and 1895–1938) for "values" and a continuous dataset from 1895–1912 for "number of boats" and "tonnage".

We also analysed the influence of the environment and time over the "landings", with a Generalized Linear Model (GLM) using the dataset of 1895–1912. We did not use mixed models as there are no repeated measures for each year. Hence, the variable "year" cannot be used as a random effect because mixed models require grouping and repeated measures: random effects are designed to model variability between groups when there are multiple observations within each group (Wikle et al., 2019). Therefore, we compared landings against the environmental variables, such as sea surface salinity, sea surface temperature, surface upward latent heat flux, sea-level pressure, surface upwelling shortwave radiation, northward near-surface wind (respectively: sos, tos, hfls, psl, rsus, vas) and year as another fixed variable. We used a Gaussian distribution, as "landings" is a continuous variable. All variables were scaled, centred, and introduced in the model, as no variable pairs presented a correlation higher than 0.7 or a VIF (variable inflation factor) higher than 3 (Field et al., 2012). We performed all analyses in R 4.5.1.

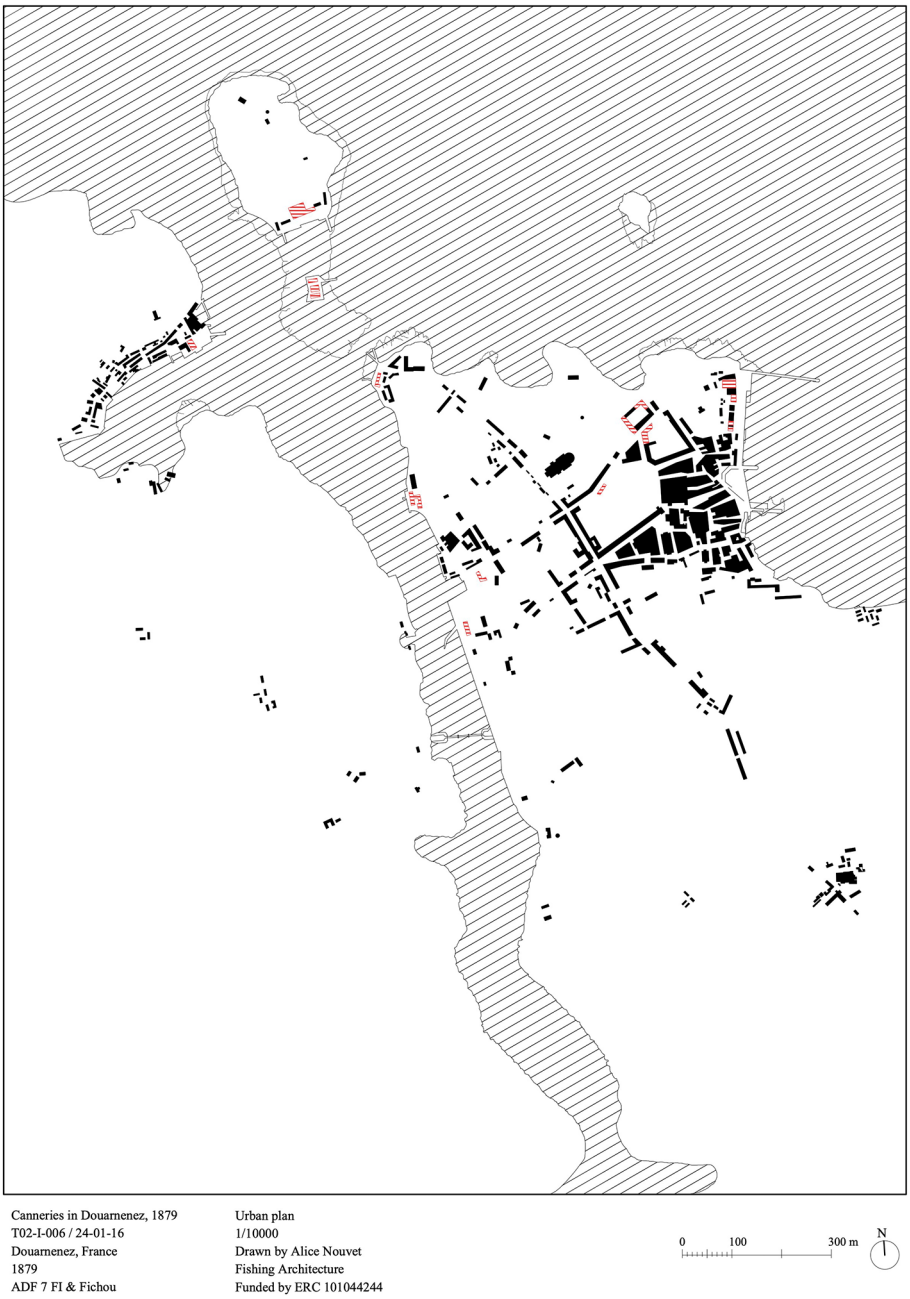

Figure 1. Urban plan, scale 1/10000, canneries of Douarnenez, 1879. Source: *Atlas des Ports de France*, Archives Départementales du Finistère, 7 FI.

5. Continental shelf cartographies of the census and landings data

A series of maps was created to represent the 1928, 1931, and 1932 fishing grounds, found respectively in the scientific reports of Jean Le Gall, Gérard Belloc, and Pierre Desbrosses (Figure 5). The study of Jean Le Gall (1928) portrays the best-known fishing grounds along Brittany's coast. He notes that sardine shoals appear later in the year as one moves northwards. According to Le Gall, this has led to a probably premature conclusion that the sardine is a migratory fish, moving from south to north. The study by Belloc (1932) followed the sardine fishing campaign of 1931 between the rivers Loire and Gironde. It also records the main fishing grounds. Belloc writes that each fishing ground is exploited for four to six months and observes the same pattern as Le Gall, with fish moving progressively from south to north. Desbrosses (1933) recorded the fishing grounds off the coast of Brittany in 1932. In each map, we juxtaposed the landing values per year to assess relations between the places and the numbers.

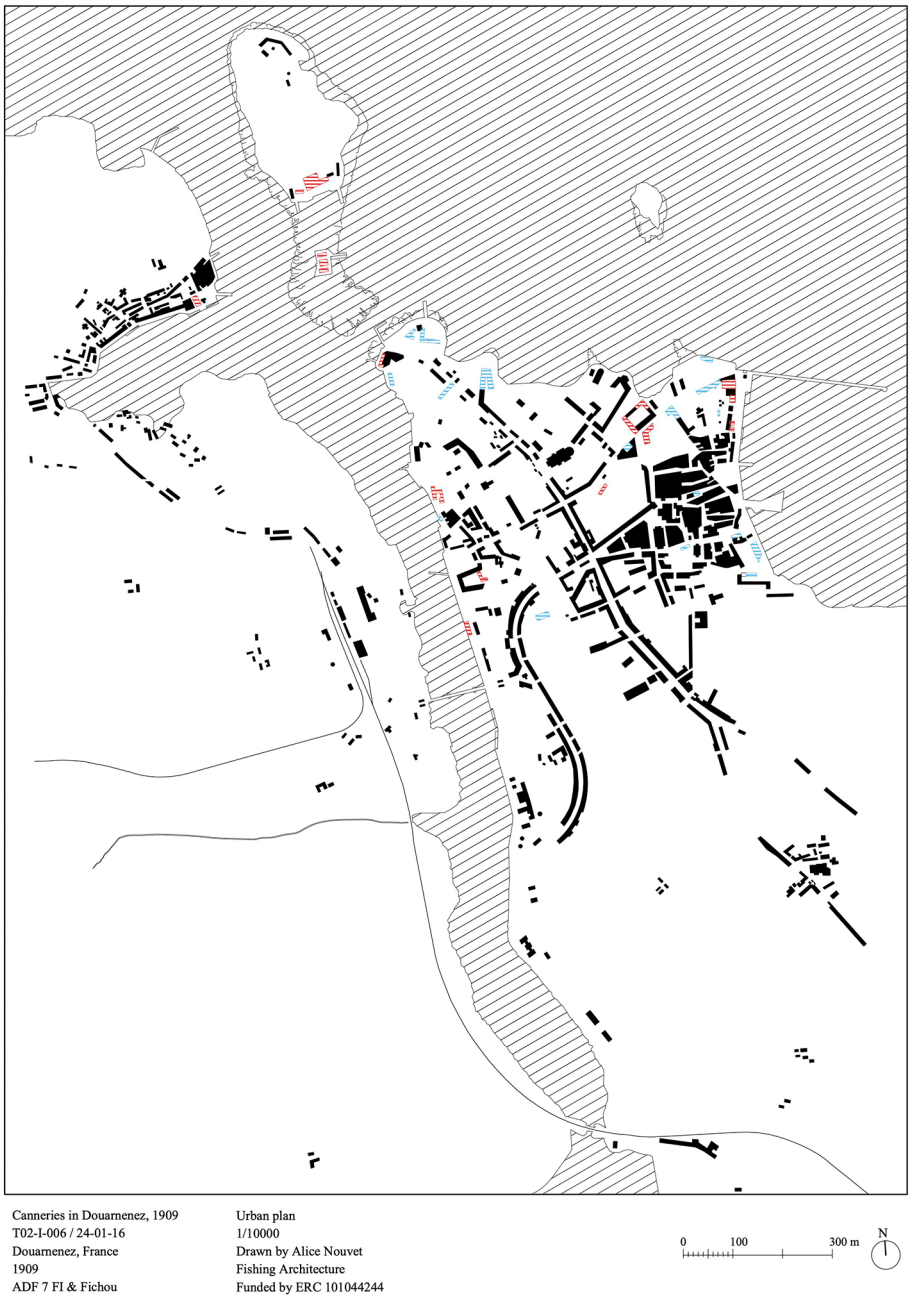

Figure 2. Urban plan, scale 1/1000, canneries of Douarnenez, 1909. Source: *Ports Maritimes de la France*, Service Historique de la Défense.

Enlarging the frame of study, in order to address the development of coastal settlements, we assembled a dataset combining the number of fishers and the total population for each harbour on the total extent of the French Atlantic coast. This dataset drew on two sources: the population census from INSEE and the landings statistics, which include counts of fishers. Only harbours reporting the number of fishers were retained in the census subset. For each harbour, we calculated the proportion of fishers within the total population for the years 1896, 1901, 1906, and 1911 (Figure 6). In parallel, we visualized the landings dataset (1895–1912) for the same four reference years (1896, 1901, 1906, and 1911), ensuring consistency with the census-based temporal slices. We restricted the representation to harbours for which comparable observations of both landings and fisher counts were available. Sardine revenues are represented through symbol colour, and landed quantities through symbol size (Figure 7). Brest was excluded from the figure because it is only represented in 1896 and cannot be consistently integrated into the subsequent temporal comparisons.

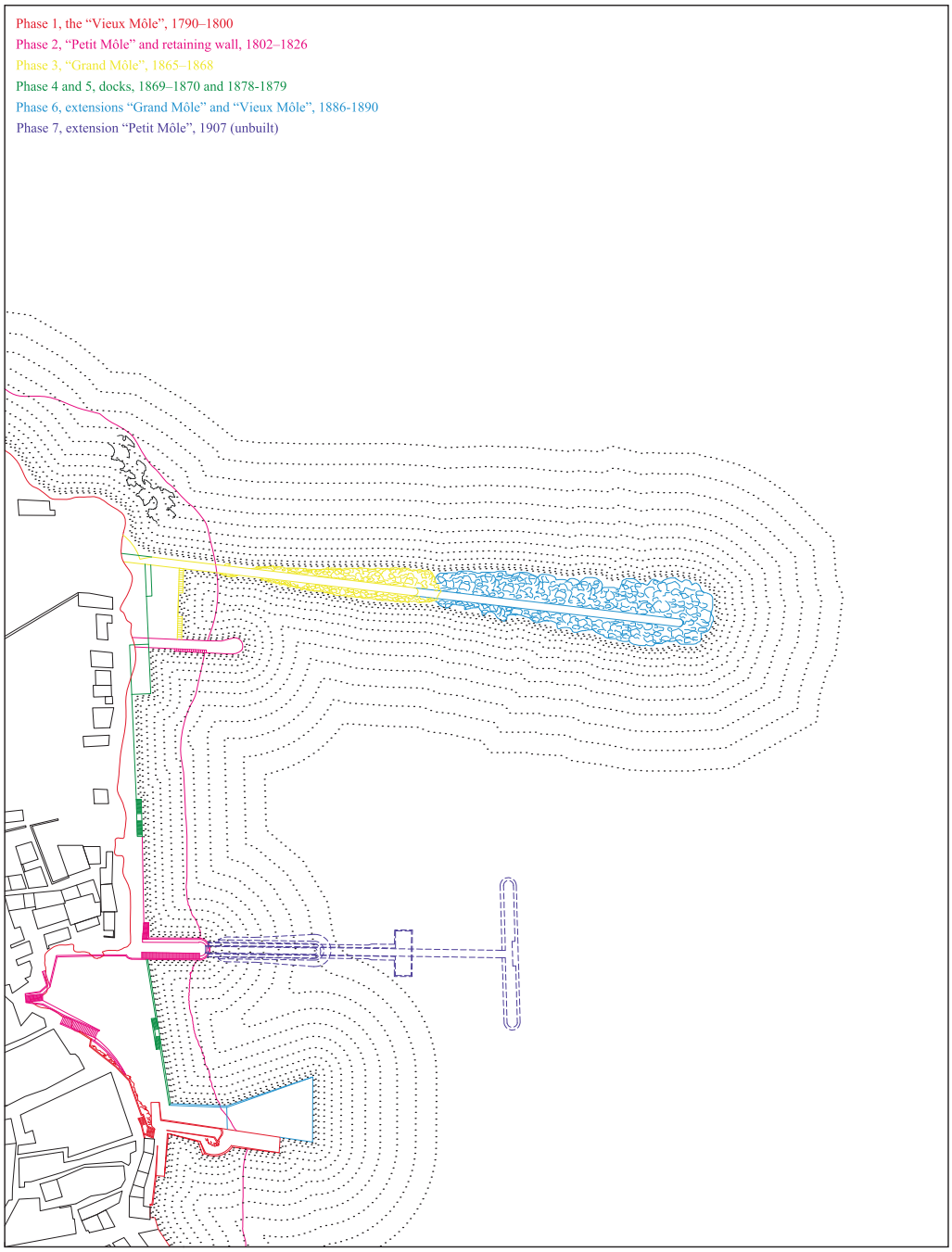

Figure 3. Urban plan, scale 1/2000, fishing harbor of rosmeur, Douarnenez. Phase 1, the "Vieux Môle", 1790–1800; Phase 2, "Petit Môle" and retaining wall, 1802–1826; Phase 3, "Grand Môle", 1865–1868; Phase 4, docks "Port de Rosmeur", 1869–1870; Phase 5, docks "Grand Port", 1878-1879; Phase 6, extensions "Grand Môle" and "Vieux Môle", 1886-1890; Phase 7, extension "Petit Môle", 1907. Source: Denis Geraads.

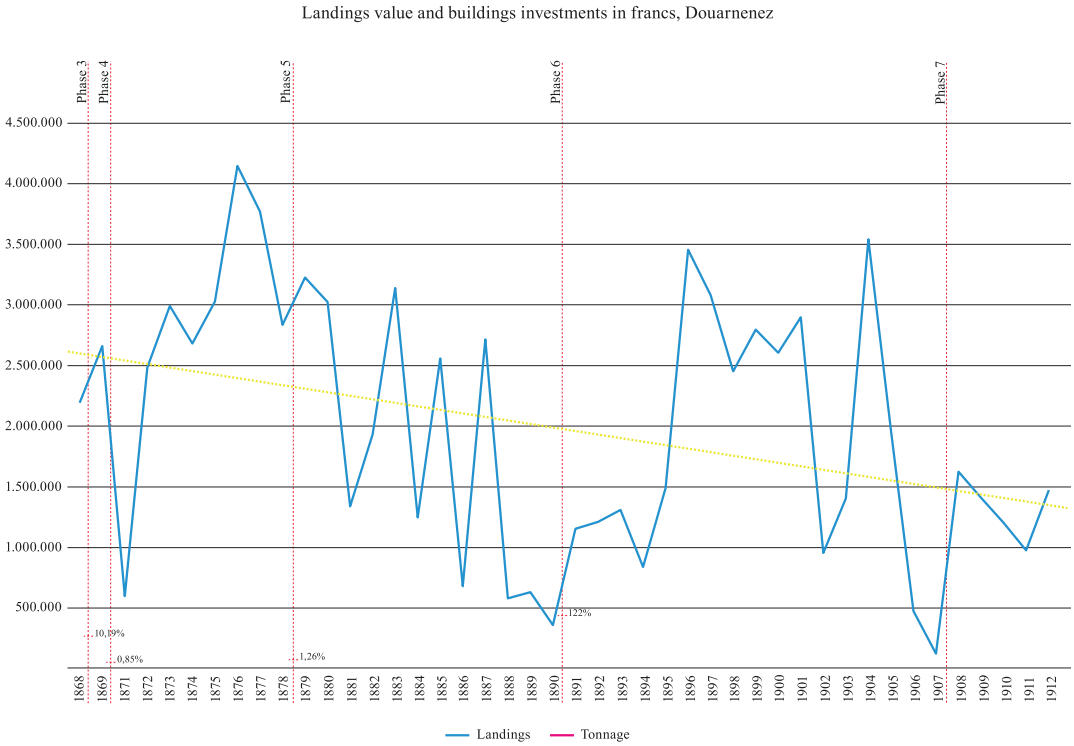

Figure 4. Graph with the values in francs of landings vs. phased investment harbour work. Source: Archimer and Service Historique de la Défense.

Results

1. Canneries' urban occupation

Digitizing the built environment data of Audierne, Douarnenez, and Concarneau from 1879 allowed us to calculate the proportion of canneries within the total built-up area of each harbour. It indicated for Douarnenez a result of 6.19 per cent, for Concarneau 7.87 per cent and for Audierne 9.36 per cent. Yet, these percentages cannot be directly compared because the harbours differ in total built-up area, the absolute number of canneries, and their spatial distribution. The assessment was confined to the area covered by the *Ponts et Chaussées* drawings. For example, Audierne has the smallest built-up area (40,889 m² of urban footprint, including canneries, housing and other buildings) and the fewest canneries (five), followed by Douarnenez (90,925 m²; seventeen canneries), and Concarneau (110,269 m²; twenty canneries). Thus, while Concarneau has both the largest built-up area and the most canneries, Audierne has a higher proportion of its built environment devoted to canneries. Since there are no landings data, nor information on the workforce or vessels operating in these locations prior to 1882, our assessment is limited to the relationship between the urban footprint and the number and area of canneries.

The complementary materials we had for Douarnenez for the year 1909, allowed us to track its transformation between 1879 and 1909. A few aspects are very visible first hand: the arrival of the railway, the expanding built area (from 90,925 m^2 to 161,709 m^2) and the growing number of canneries (from seventeen to thirty-nine). Yet, the total annual value of sardine landings (expressed in current francs in the source statistics) declined by about half, from 3,208,579 francs in 1879 to 1,406,000 francs in 1909. This indicator reflects the aggregate monetary value of landings and therefore combines both changes in catch volumes and price fluctuations. This decline aligns with the literature on the sector's economic crisis (Dubois, 2004) and underscores the role of public investment in coastal infrastructures to mitigate it.

2. Shoreline infrastructures: value per square metre

The drawing representing the seven stages (Figure 3) of coastal infrastructure in Douarnenez allowed to measure the surface of moles, docks, and slipways that were built to accommodate more fishing vessels. Only constructions expanding from the shoreline were measured. Due to inconsistencies in the representations of foundations and underwater works, our measurements were restricted to the visible surface elements. Hence, the figures represent minimum estimates of the real expansions. Having information on the value in francs invested for the building stages 3, 4, 5, and 6, we calculated the value per square metre of these infrastructures. The result was that for the establishment of

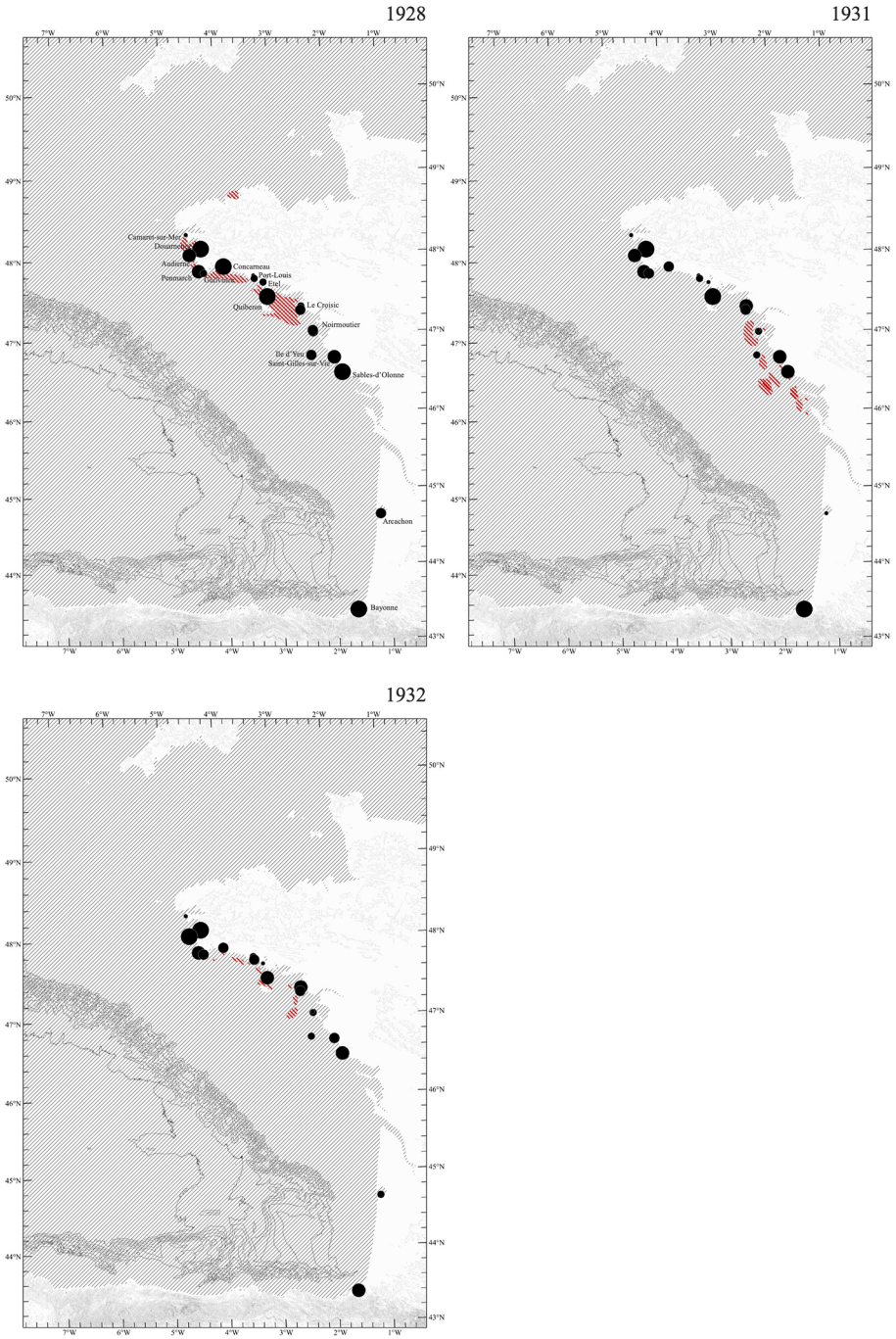

Figure 5. Series of cartography. Comparing fishing grounds and landings years 1928, 1931, and 1932. Source: Archimer.

the Grand môle between 1865 and 1868, with a surface of 1,785 m^2, the value per square metre was equal to 124.77 francs. The dock built to link the Grand môle to the Petit môle between 1868 and 1870, with a 1,702 m^2 surface, had a square metre value equal to 13.22 francs. The dock built to link the Petit môle to the Vieux môle between 1878 and 1879, with a surface of 3,409 m^2, had a square metre value of 10.41 francs. Finally, the two extensions of Grand and Vieux môle between 1886 and 1890 cost 221.39 francs/m^2. The variation is too large to be taken at face value. Moreover, moles required the extensive use of stone, whereas docks only needed a retaining stone wall and gravel and sand as fillers for the ground, thus becoming significantly less expensive.

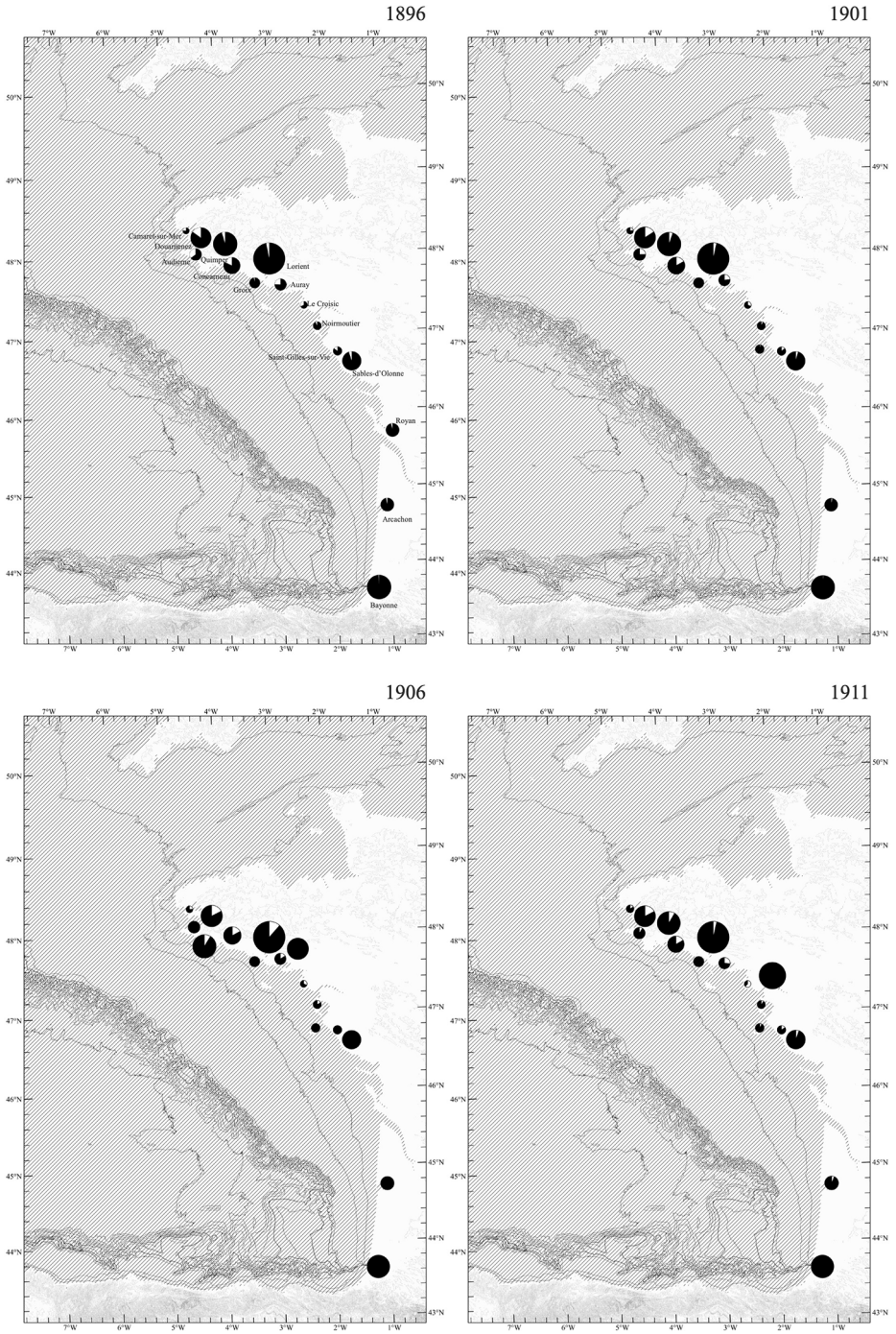

Figure 6. Series of cartography. Comparing fisher density within population density in fishing harbours, 1896, 1901, 1906, and 1911. Source: INSEE and Archimer.

3. Statistical analysis

The Granger causality test showed significant results only in the comparisons of "landings", "tonnage", and "values" (Table 1). The comparison of "landings" and "number of boats" was marginally significant. The rest of the comparisons were not significant. Therefore, "values" depended on "landings", and "landings" depended on "tonnage". The number of boats has a minimum influence on landings as it mixes boats of different sizes: having more boats does not guarantee a larger catch. The GLMs comparing "landings" against the environmental variables and "year" for both periods reflected a

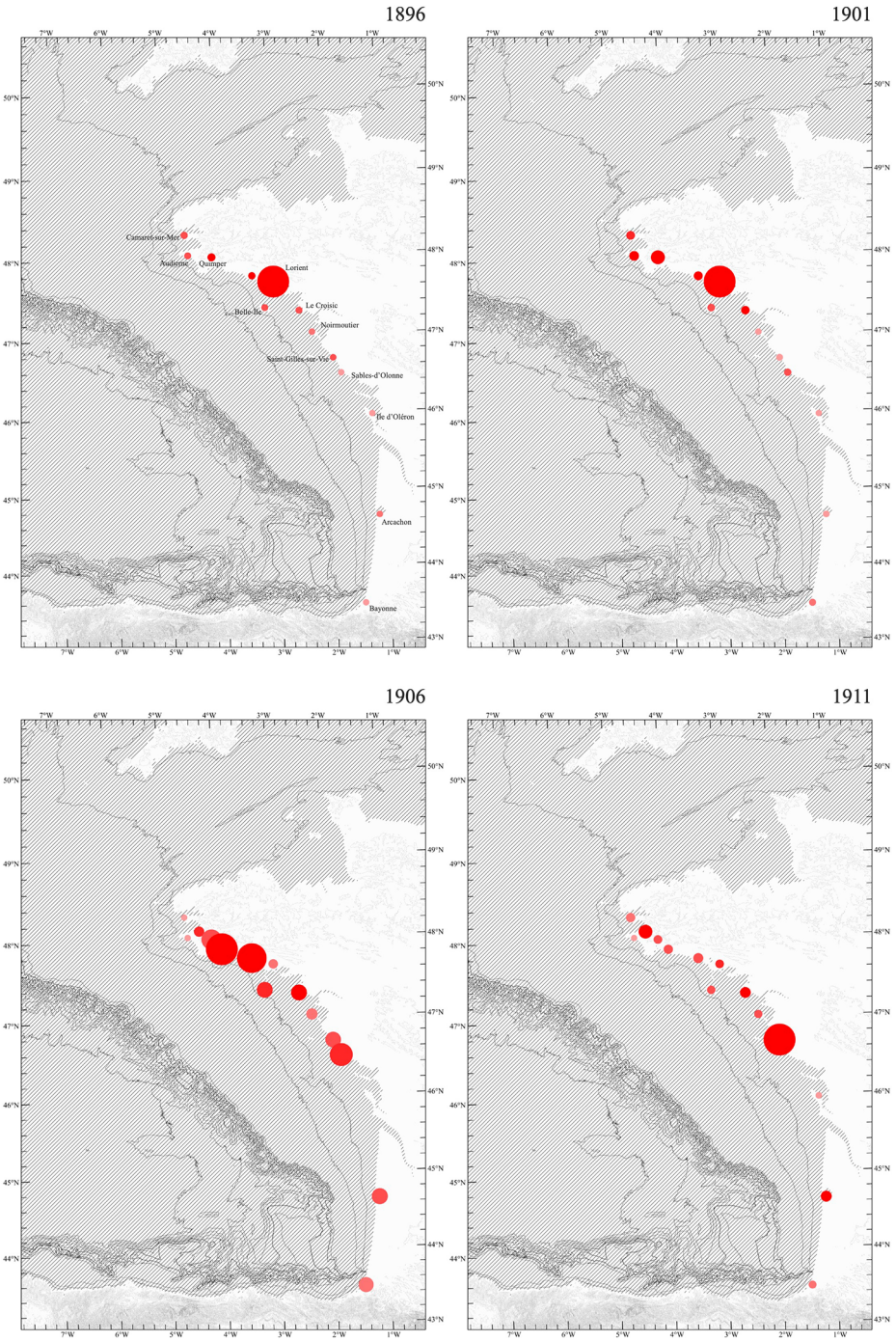

Figure 7. Series of cartography. Landings in kilograms and values, years 1896, 1901, 1906, and 1911. Source: Archimer.

lack of significance in almost all variables and intercepts (Table 2): only the variable "year" and the intercept for the period 1895–1912 had a significant p-value (0.025).

4. More fishing pressure in the *plateau armoricain* than the *plateau aquitain*?

There is a similar spatial distribution between the 1928, 1931, and 1932 maps of fishing grounds (Figure 5). In all three years, fishing pressure was concentrated on the *plateau armoricain* and limited to areas shallower than the 50-metre bathymetric line. This may partly result from a bias in the available sources, which are available for this region and may

Table 1. Granger causality test results. As the test is asymmetrical, the comparisons were performed in both directions: variable 1 vs. variable 2 and vice versa. DF is degrees of freedom; F is the statistical test metric. Significant p values are indicated with an asterisk (*).

Period	Variable 1	Variable 2	DF	F	p-value
1895–1912	Landings	N boats	−1	4.8126	0.046
1895–1912	N boats	Landings	−1	0.2275	0.641
1895–1912	Landings	Tonnage	−1	5.5799	0.033*
1895–1912	Tonnage	Landings	−1	0.4537	0.512
1895–1912	Landings	Values	−1	0.2178	0.648
1895–1912	Values	Landings	−1	0.1468	0.707
1895–1938	Landings	Values	−1	1.112	0.298
1895–1938	Values	Landings	−1	5.8256	0.020*

Table 2. Results of the generalised linear models (GLM) between landings and environmental variables for the periods 1895-1912 and 1895-1938. It is indicated the estimate, the standard error, the value of the statistic T, and the p-value. sos: Sea Surface Salinity; tos: Sea Surface Temperature; hfls: Surface Upward Latent Heat Flux; psl: Sea Level Pressure; rsus: Surface Upwelling Shortwave Radiation; vas: Northward Near-Surface Wind.

Period 1895–1912				
Variable	**Estimate**	**Standard error**	**T value**	**p-value**
Intercept	205.1879	78.0536	2.629	0.025*
sos	−0.0702	0.2423	−0.289	0.776
tos	0.2762	0.2417	1.143	0.280
hfls	0.1363	0.2980	0.457	0.657
psl	0.0183	0.3528	0.052	0.960
rsus	−0.2260	0.2827	−0.800	0.443
vas	−0.3933	0.2762	−1.424	0.185
year	−0.1078	0.0410	−2.629	0.025*
Period 1895–1938				
Variable	**Estimate**	**Standard error**	**T value**	**p-value**
Intercept	37.4562	30.7625	1.218	0.231
sos	0.0239	0.1647	0.145	0.886
tos	0.1587	0.1953	0.813	0.422
hfls	−0.0221	0.1903	−0.116	0.908
psl	−0.0071	0.2617	−0.027	0.979
rsus	0.0603	0.1997	0.302	0.765
vas	−0.2751	0.1818	−1.513	0.139
year	−0.0195	0.0161	−1.218	0.231

unbalance the figures between north and south. However, the same imbalance also appears in the national landings dataset and fishermen census, which shows a concentration of fishing activity along the coast facing the *plateau armoricain.*

The census and sardine landings datasets assembled during this research share data for eleven harbours in four years (1896, 1901, 1906, and 1911). Within the *plateau aquitain*, only two coastal towns, Arcachon and Bayonne, appear in the dataset. In these, the proportion of fishers within the total population is extremely small and barely visible in the figures, though present in the census records (Bayonne: 1886, 0.25%; 1901, 0.55%; 1906, no info; 1911, 0.38%; Arcachon: 1886,

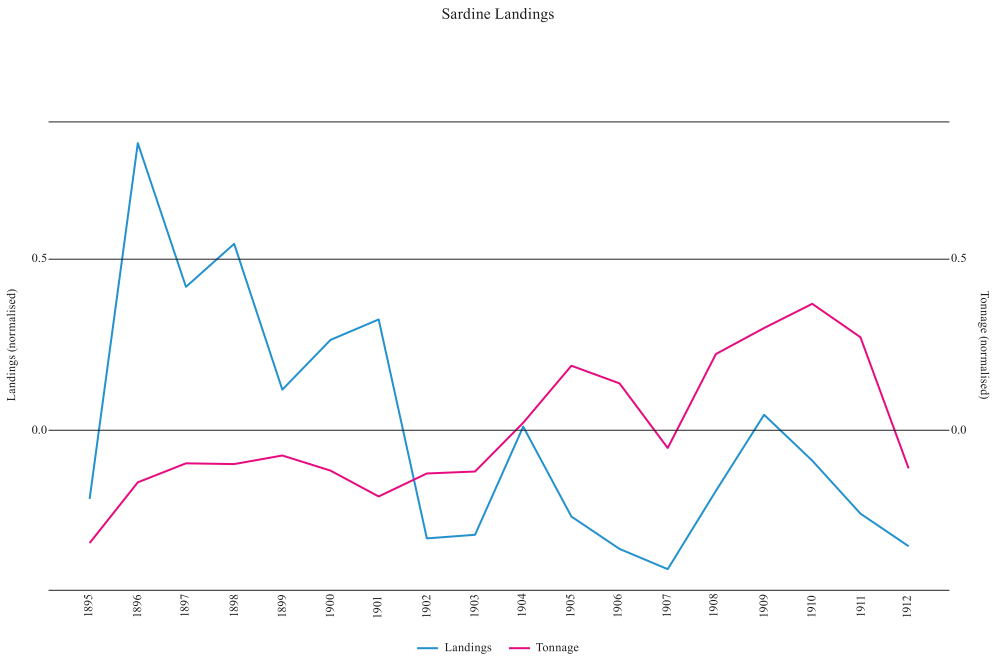

Figure 8. Graph comparing landing values and vessels tonnage. Source: Archimer.

0.29%; 1901, 0.60%; 1906, no info; 1911, 1.31%). Landings data reflect the same trend, showing very low sardine volumes and economic value. By contrast, the coastal towns bordering the *plateau armoricain* present higher proportions of fishers (often approaching one quarter of the total population) and their landing records show a corresponding concentration of sardine activity.

5. Continuous average decline and public investment

The clearest result of the data analysis was the continuous decline of the landings throughout the study period (see trend line in Figure 4). Major public investments were deployed both for vessels (Figure 8) and coastal works after or during years of significant fisheries collapse. In general, they recovered the sardine economy, but profits remained weaker than in previous years. It is also blatant that the public sums invested represented a tiny percentage of the global sardine business value. Since we did not obtain the years nor the values of private investment in construction and transformation of canneries and their equipment, there was no comparison possible between public and private investment within the sardine economy of the period.

Discussion

The results show three broad patterns: a long-term decline in sardine landings that does not seem to be the influenced by environmental variability; the continuing expansion of harbour infrastructures and vessels tonnage even during periods of fluctuating catches; and a spatial concentration of fishing effort on the *plateau armoricain.*

1. Latency and misalignment in harbour work

Built forms such as moles, breakwaters, slipways and docks organized the circulation of vessels, fish, and labour, thereby structuring how value could flow between marine ecosystems and terrestrial landscapes. However, the relationship between architectural investment (both in vessels and coastal works) and sardine landings appears oblique: construction works often occurred shortly after periods of decline in landing values. While we cannot state that these were intentional responses, this temporal coincidence suggests that, in the case of harbour facilities, public investment took place during periods of social unrest and instability within the sardine economy. These investments may therefore be understood as part of a broader state effort to stabilize and maintain fishing activities, rather than profit-driven actions. Yet, the Ponts et Chaussées book (Corbeaux & Foucault, 1910) shows us that the harbour work followed an open and pre-established plan drawn up by administrative bodies as part of long-term programmes, which reinforces the idea that investments did not necessarily match the realities of the fisheries.

The plans made by the *Ponts et Chaussées* did not introduce fixed forms, only proposals as dotted lines, with scope for adaptation. These proposals were sometimes abandoned or postponed and picked up years later by the new engineers in

charge. For example, the sequential transformations of Port de Rosmeur were dictated by constant programmes of repair. As Zitouni & Tellier (2013) argue, the dotted lines in the drawings are a deliberate strategy of latency: by inscribing possible futures in advance, the technical body delimits and conditions the range of transformations that will later "appear feasible", thereby producing a future that is already partly foreclosed. This insight is particularly relevant as these pre-shaped harbour configurations ended up creating the conditions in which fishing pressure on sardine populations intensified. And ultimately, the "open plan" left a long-term mark within the territory: more than a century later, what can be seen today in Douarnenez's shore is the result of the successive milestones chosen and designed by the *Ponts et Chaussées.*

2. Anthropic drivers of sardine landings

The statistical analyses show that the variable "landings" were influenced by the variable "tonnage" for the period of 1895–1912. And the variable "values" were influenced by the variable "landings". Landings increased because the boat capacity increased as well, and values increased with landings over time. In our analysis, the "landings" were not influenced by the environmental variable; thus, the changes in the landings over time were influenced by anthropic pressure rather than climatic factors. In fact, after strong decreases in landings, the increase in boat capacity ("tonnage") made landings bounce back, although the quantity did not get back to the initial values of the period (Figure 4). The lack of relationship between landings and the number of boats confirms that the influencing factor was the increase in boat capacity ("tonnage") and not the increase in the number of boats, which might include small and large fishing boats. There was an important but temporary increase in the number of boats after 1905, but that did not translate into a substantial increase in landings. Profits ("value") substantially increased after 1920, despite the small increase in landings. And the fish price increased because fish became a rare commodity. This last aspect is supported by existing literature (Dubois, 2004).

As the landings data does not directly reflect the actual abundance of European sardine populations in the Bay of Biscay but rather serves as a proxy in our analysis, we cannot rule out the possibility that the fish had simply moved further offshore, beyond the reach of the fishing vessels. In this case, the fishing vessels may have continued to intensively exploit nearshore areas that were already being deserted by migrating sardines.

Moreover, while the influence of tonnage on landings does not present itself as a causality, it does point to a relationship in which coastal architectures and vessels may have reinforced each other over time. Larger vessels required deeper mooring and extended moles, and, in return, harbour expansions facilitated more and larger vessels operations (Fichou, 2003).

3. Architecture as a material conduit

The figures representing the landings across time show that they did not follow a consistent spatial distribution, which could be explained by the movement of sardines. Yet, existing literature suggests an interesting hypothesis: landings were often concentrated in harbours with favourable infrastructure, more accessible docks, and multiple canneries, regardless of their proximity to rich fishing grounds (Fichou, 2006). This spatial mismatch highlights the influence of industrial geographies for fishers at sea. Fishers landed where processing capacity, buyers, and harbour facilities could handle their catch with certainty. Architecture, in this sense, greatly influenced the economic system of sardines and the locations where economic opportunities materialized. It did not determine an immediate increase in catches, but it shaped when and where sardines entered the economic circuit, with architecture becoming a material conduit for sardine value.

4. Following sardines' skin

The figures for landings and fishing grounds reinforce the idea of architecture as a material conduit as they reveal an odd imbalance between south and north. Early observers interpreted this spatial pattern as a south–north sardine migratory movement (Un pêcheur, 1864), linking the progression of the fishing season to the movement of both fisherfolk and sardines. The sardine fishing season opened between February and March on the southern coasts and advanced northward over the course of the year, ending in October/November in the bay of Douarnenez. Fishing activities shifted accordingly, with boats and crews moving from harbour to harbour as catches declined in the south and increased further north. This displacement of fishing effort was understood as the result of sardines themselves migrating northward, growing and changing as they moved. This interpretation, based on the directional migratory pattern, is no longer supported today. Sardine movements are now understood as responses to environmental conditions that shape spawning and feeding areas (Bellier et al., 2007; Planque et al., 2007). Sardines are opportunistic feeders and batch spawners, reproducing through successive spawning events rather than in a single episode (Dessier, 2015). Spawning and feeding zones may therefore overlap at certain times while remaining separate at others. This could help explain earlier observations of mixed size classes within the same fishing grounds, where larger and smaller sardines were sometimes seen together, without implying a linear growth trajectory from south to north.

However, in De la pêche de la sardine et des industries qui s'y rattachent (1864), the description of sardines' skin provides an explanation for the northward concentration of canning factories. The text describes southern sardines as small, tender, fragile fish, with soft skin and flesh that made them difficult to conserve—particularly when it came to preserving the oil. Further north, sardines are described as larger and firmer, reaching what was considered an optimal state for the canning industry, especially between Concarneau and Douarnenez. Canneries required sardines that met both size and texture thresholds—neither too small and fragile, nor too large and oily—thus, fishing pressure tended to concentrate in areas where these conditions were most often encountered.

If these observations accurately reflect the requirements of the nineteenth-century canning industry, they also emphasize that the geography of fishing harbours cannot be understood solely through the physical characteristics of the coastline. The northern shoreline is generally more indented and rockier than the beach-dominated southern coast, suggesting that fishing infrastructures may have been more driven by the sardine skin qualities sought by canneries.

5. Limitations

Because preliminary archival work across municipal, regional, and national archives was constrained by time, additional sources are still to be found and may yet complement the datasets assembled here. More continuous records of coastal transformations, together with documentation of other building typologies (such as salt depots, auction houses, shipyards, etc.) and information on private investments in canning factories, would allow a systemic reconstruction of the economic and political choices that shaped the sardine industry. Such materials could extend the research on Douarnenez and allow the methods to be transposed to other fishing harbours. This would reduce the reliance on population censuses as proxies for fishing activity. Nevertheless, further archival discoveries are unlikely to resolve the principal limitation of this study: the absence of historical scientific observations capable of reconstructing sardine abundance independently from landing records.

Conclusion

The materials collected in archives pushed this work to engage with two complementary scales: a detailed analysis of a single harbour and a broader comparison across multiple fishing towns distributed along the continental shelf of the Bay of Biscay. The evidence assembled here reveals several important patterns. First, the geography of sardine fishing harbours cannot be explained solely on the basis of the physical characteristics of the coastline. The concentration of canneries and harbour infrastructures along the rocky shores of Brittany is not self-evident when compared with the sandy coasts further south. Historical descriptions repeatedly distinguished sardines according to their size, texture, and skin quality, describing the sardines of Brittany as particularly suited to the requirements of the canning industry. If these observations accurately reflect industrial preferences, the geography of fishing infrastructures was shaped not simply by the natural features of the shore but also by the qualities of the fish themselves. In this sense, the geography of the sardine's architecture followed the fish before it followed the shore.

Second, the comparison of fishing grounds, landing records, and harbour developments suggests a distinction between where sardines were caught and where their economic value was realized. Fishers continued to follow productive fishing grounds, but they did not necessarily land their catches in the nearest harbour. Instead, catches tended to be landed in harbours equipped with moles and canneries capable of purchasing and processing the fish with certainty. In other words, the geography of fishing grounds did not fully determine the geography of landings. Architecture therefore acted as more than a passive backdrop of fisheries. Equipped harbours attracted and channelled catches from a wider maritime territory.

Third, the study documents a persistent divergence between declining landings and continued material investment. Sardine landings followed a long-term downward trend throughout the period under study, yet vessel tonnage increased and harbour infrastructures continued to expand. The evidence suggests that these interventions formed part of broader efforts to sustain regional economies under pressure. In the case of harbour infrastructures, many projects had already been anticipated within the plans of the Ponts et Chaussées and were subsequently activated, resumed, or accelerated during periods of instability. The built environment therefore responded less to immediate ecological conditions than to longer-term development trajectories embedded within administrative and technical practices.

Taken together, these findings point toward the coexistence of multiple temporalities within the sardine fishery. Sardines responded to daily movements through the water column, seasonal cycles, and longer-term oceanographic variations. Fishing grounds shifted according to interannual and multidecadal environmental conditions. Vessels were repaired, enlarged, and replaced over successive decades, while harbour infrastructures and canneries were conceived as investments intended to endure for generations. The concentration of canneries in Brittany, the attraction exerted by equipped harbours, and the persistence of investment despite declining landings can all be understood as consequences of interactions between processes operating at different speeds.

By bringing together marine biology and architectural history, we can understand how ecological and material landscapes jointly produce each other and how their histories continue to structure coastal territories today.

Ethics and consent

Ethical approval and consent were not required.

Data availability

Zenodo. Three Historical Data Sets on Sardine (*Sardina pilchardus*) Fisheries and Climate in the Bay of Biscay (1846–1965): Landings, Vessels, and Environmental Variables. https://doi.org/10.5281/zenodo.15719564 (Nouvet, A., et al. 2025).

This project contains the following underlying data:

- Brittany_1865-1965_landings.xlsx (This is an excel file on European sardines (*Sardina pilchardus*) landings on the Atlantic coast of France, from Brest to Saint-Jean-de-Luz, between 1865-1965)
- Brittany_1865-1965_landings_and_climate.xlsx (This is an excel file on European sardines (*Sardina pilchardus*) landings, from Brest to Saint-Jean-de-Luz and climate variables of the Bay of Biscay between 1865-1965)
- Brittany_1846-1928_sardine_fishing_vessels.xlsx (This is an excel file on the launch and years of operations of sardines fishing vessels in South Brittany between 1847-1928)
- netcd2tif_v4.py (This is the python script to read the CMIP6 netCD files)
- year_sos_tos_table.R (This is R script to extract sea surface temperature and salinity variables)
- year_winds_table.R (This is R script to extract wind related variables)

Data is available under the terms of the CC-BY-4.0

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Version 2

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✔ **Jack Bouchard**
Rutgers University, New Brunswick, NJ, USA

I think that the revisions are effective and address my main concerns. I yield to the authors regarding the scope and goals of the piece, which are better articulated in this version. I think it should be indexed as it is and thank the authors for producing such an interesting study.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Fisheries history, premodern (XV-XVII centuries); Marine environmental history

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 1

Reviewer Report 11 May 2026

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✔ **Christy Anderson**
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The most original claim in Nouvet et al. is that architecture is not a passive backdrop to fisheries history but a "material conduit" through which sardine value flowed and through which fishing pressure was channelled. The piers, moles, slipways, docks, and cannery footprints of Douarnenez, Audierne, and Concarneau organised where fish entered the economic circuit, and the seven-phase reconstruction of the Port de Rosmeur shows with quiet authority how state engineering practice accumulated, decade by decade, into the shoreline we still see today. This is a genuinely architectural argument made on architectural evidence, and it deserves to be defended as such. The reviewer is right that the paper's hedging language ("to a certain extent we can argue," "we discovered that this was not necessarily the case") undercuts the force of the finding. The finding itself is bold: the built environment shaped the sardine economy more decisively than the sardines did.

What weakens the architectural argument is not its substance but its narrow material range. The paper treats moles, docks, slipways, and canneries, the heavy stone, brick, and timber fabric of the harbour edge, but stops there. Sardine fishing was made possible by a much wider architectural and material world that the paper leaves out: the seines and drift nets, the cordage and rigging, the tarred lines, the wooden hulls and iron fastenings, the salt and oil and tin and solder that moved through the canneries, and the women who worked them. Each of these had its own architectures on land. Ropewalks, sail lofts, cooperages, tin-plate works, salt depots, and fish-meal sheds were as terraqueous as the moles. To argue that architecture organised the sardine economy is to argue that this whole infrastructural fabric, not just its masonry edge, did the organising. Alison Bashford's "Terraqueous Histories" (*The Historical Journal*, vol. 60, no. 2, 2017, pp. 253–272) is useful here only because she names the conceptual move the paper is already making, collapsing the land/sea couplet into a single material world. The architectural case stands on its own, and would stand more firmly if the building types under analysis were broader.

The strongest single observation in the paper is that infrastructure investment continues, and even accelerates, while landings decline. This is an architectural finding with serious implications for how we read coastal landscapes. The Ponts et Chaussées drawings, with their dotted lines and phased proposals, show that the harbour was never the product of any one moment's economics. The mole built in the crisis of 1886 had been imagined twenty years earlier and would shape the harbour for a century after. Architecture on the shore therefore operates at a different temporality from the sea it serves. Sardines move in seasons; vessels in years; landings in decades; but moles and canneries in centuries. The paper has the evidence to make this temporal argument explicit and is one rewrite away from doing so. The reviewer's call for "clearer, more forceful argumentative language" applies most of all here.

What the architectural framing also makes possible, and what the paper has not yet claimed, is a connection between the building on land and the vessel at sea. The Granger test result that landings depend on tonnage is not merely a statistical finding; it is an architectural one. Larger vessels needed deeper moorings, longer moles, wider slipways, and the harbour transformations of the 1880s and 1890s answered those needs while also enabling the next generation of larger vessels. The mole and the boat shaped each other. This reciprocal building, on water and on land, is what gives the paper its claim to a maritime architectural history rather than a coastal one. The vessels dataset that the authors compiled but barely use (1846 to 1928) is the bridge they have not yet crossed: the boat is also a building, and reading the boat alongside the mole would let the architectural argument finally span the shoreline.

Bashford's "terraqueous" is one term for what this paper is reaching toward, and the reviewer is right to feel that something like Westerdahl's Maritime Cultural Landscape is missing. But the deeper point is that the architectural history of the sea is still being written, and Nouvet et al. have made a real contribution to it. Their evidence (the 1879 atlas, the 1909 plan, the seven-phase reconstruction, the cannery footprints, the vessel registers) is exactly the material from which such a history must be built. What the paper needs is the confidence to claim that ground openly: to treat the architecture of the harbour, the cannery, the ropewalk, and the vessel as a single object of study, and to argue that this architecture, not the fish and not the climate, organised the sardine century.

Is the work original in terms of material and argument?
Yes

Does it sufficiently engage with relevant methodologies and secondary literature on the topic?
Yes

Is the work clearly and cogently presented?
Yes

Is the argument persuasive and supported by evidence?
Yes

If any, are all the source data and materials underlying the results available?
Yes

Does the research article contribute to the cultural, historical, social understanding of the field?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: architectural history, early modern maritime history, European trade and economic history

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 25 Jun 2026

Alice Nouvet

Dear Reviewer, We are grateful for the careful reading of the manuscript and the insightful and constructive comments. The remarks have been helpful in clarifying and strengthening the framing of our contribution.

Comment 1: “The reviewer is right that the paper’s hedging language (‘to a certain extent

we can argue', 'we discovered that this was not necessarily the case') undercuts the force of the finding. The finding itself is bold: the built environment shaped the sardine economy more decisively than the sardines did. (...) What the paper needs is the confidence to claim that ground openly: to treat the architecture of the harbor, the cannery, the ropewalk, and the vessel as a single object of study, and to argue that this architecture, not the fish and not the climate, organized the sardine century."
Response: We appreciate this observation and agree that our earlier wording may not have sufficiently clarified our position regarding the relationship between sardines and coastal architectures. Our aim was not to adopt a framework in which architecture alone determines the organization of the sardine economy independently of marine life. Instead, our approach explores the correlations between ecological and material landscapes. The introduction of the notion of "sardine skin" in the discussion section of the revised manuscript is intended to address this point. Historical sources consistently describe how variations in the size, texture, and skin quality of sardines influenced their suitability for canning and therefore affected the spatial distribution of landing and processing activities. Sardines participate in shaping coastal infrastructures as biological entities whose qualities actively condition industrial choices.

Comment 2: "What weakens the architectural argument is not its substance but its narrow material range. The paper treats moles, docks, slipways and canneries, the heavy stone, brick and timber fabric of the harbor edge but stops here. Sardine fishing was made possible by a much wider architectural and material world that the paper leaves out: the seines (...). To argue that architecture organized the sardine economy is to argue that this whole infrastructural fabric, not just the masonry edge, did the organizing."
Response: Regarding the conceptual framing of architecture and its relation to wider maritime material artefacts, we fully agree with the observation that the infrastructures discussed in the paper exist within a broader terrestrial and maritime assemblage. In the revised version, we state more explicitly that these elements are part of a broader maritime material world, both in the objectives and in limitations sections. Nonetheless, they are not the primary objects of analysis in this paper. This is not meant to exclude their importance but is rather a methodological delimitation necessary to maintain a coherent and comparable longitudinal dataset focused on harbor-based infrastructures, which are the elements consistently traceable across space and time in our sources.

Comment 3: "Sardines move in seasons; vessels in years; landings in decades; but moles and canneries in century. The paper has the evidence to make this temporal argument explicit and is one rewrite away from doing so."
Response: We are grateful for the remarks on temporality, which proved particularly helpful in clarifying a dimension that had remained implicit in earlier versions of the manuscript. As observed, the argument gains strength when the different temporalities at play are made explicit. The revised conclusion now explicitly distinguishes ecological, operational, and infrastructural temporalities. The way the review addressed this issue was especially helpful in guiding this revision, and we have used it to hone the argument that architectural operations often persist independently of ecological fluctuations.

Comment 4: "What the architectural framing also makes possible, and what the paper has not yet claimed, is a connection between the building on land and the vessel at sea. The

Granger test result that landings depend on tonnage is not merely a statistical finding; it is an architectural one. (...) The vessels dataset that the authors compiled but barely use (1846 to 1928) is the bridge they have not yet crossed: the boat is also a building, and reading the boat alongside the mole would let the architectural argument finally span the shoreline"
Response: We agree that the vessel dataset provides an important link between terrestrial infrastructures and fishing activity at sea, and that the relationship between vessel capacity and harbour development deserved further attention. In response, we have substantially expanded our use of the vessel dataset (1846–1928). A new figure now compares vessel tonnage with the economic value of sardine landings (figure 5), complementing the existing analysis of harbor-work investments. This comparison reveals a pattern similar to that observed for harbor infrastructures: vessel tonnage continued to increase despite declining landing values. We have incorporated this result into both the Results and Discussion sections. These additions allow us to draw a stronger parallel between investments in vessels and investments in harbor works. Rather than responding directly to short-term fluctuations in the fishery, both forms of material investment appear to follow longer temporalities and development trajectories. We therefore revised the Discussion and Conclusion to emphasize that fishing capacity was reinforced through both maritime and terrestrial infrastructures, thereby extending the architectural argument beyond the shoreline. At the same time, while we recognize the value of approaching vessels as architectural objects, a more complete analysis of their design, construction, and material evolution would require a different body of evidence than that assembled in the present study.

Competing Interests: No competing interests were disclosed.

Reviewer Report 30 April 2026

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Jack Bouchard
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This is an interesting piece which makes a small but useful contribution to our understand of historical fisheries. It is coming at the problem from the perspective of architecture, rather than fisheries studies, which offers a fresh perspective and the potential for more interdisciplinary thinking. I think that the question which the authors identify - what is the relationship between fishing, marine ecologies, and the built human coastal environment - is a worthwhile and provocative line of inquiry. (I am surprised, actually, that they do not invoke Westerdahl's idea of the Maritime Cultural Landscape - that seems to be, arguably, what the authors are interested in reconstructing). The last line - about treating coastal architecture not as passive but active -is well

substantiated by the research.

In some ways, this is an interesting historical and anthropological problem which is limited by the scientific approach of the authors. The emphasis on quantitative methods rather than spending time with the archival material, especially from the French state's perspective, means that we only have a partial answer to the hypotheses posed at the beginning (as I think the authors acknowledge). I get the sense the authors did not quite find what they expected, but to their credit they use this to propose future lines of inquiry, and I think they have set up a set of conclusions which could be explored in other historical contexts.
The data generated by this study will nonetheless be useful to fisheries historians in the future. The author's conclusion that sardine landing declines does not have to do with environmental variability is a revealing and useful point, contributing to our global understanding of fisheries fluctuations in the past.

Although overall this is a good article, a few thoughts and suggestions. The article could be improved by a number of revisions, most of which serve to strengthen what the authors have already achieved.:
- The authors ought to be much clearer about the limitations (self-imposed) on the study. This isn't really a study of the Bay of Biscay, it is a study of one part of southern Brittany. In some places, it is more or less a study of one port. If they wish for southern Brittany to be a proxy for all of the Bay of Biscay then they will have to do more to make that case. Likewise, the focus on the sardine canning industry means that it would be hard to generalize the article's conclusions beyond the modern period. Unfortunately, these choices are not foregrounded in the study, and are not brought up much in discussing the conclusions.
- I think that the most interesting conclusion they develop is that infrastructure investment lags behind actual fluctuations in catches - that there is more intensive investment during periods of decline. (This tracks with Brian Payne's observations about state-backed advertising in the Canadian fishing industry, which intensified even as demand was plummeting). This opens some worthwhile lines of future research, and is a conclusion which can be tested in other settings around the Atlantic basin.
This conclusion also suggests that fisheries historians should be paying more attention to politics - a point which the authors unfortunately don't lean into. But it would be worthwhile to reconstruct the decisions, lobbying, and debates which led to increasing French state investment in the sardine industry in the wake of declining catches. This suggests that rather than strictly focusing on coastal landscapes, we should be paying attention to archives of state power.
- At times, the argument becomes muddled across the article. The way the piece is structured it keeps coming back to conclusions, so that it feels a tad repetitive. But at times the authors have trouble committing to one or two clear arguments. Emblematic are some sentences at the start: "To a certain extent, we can argue that shore-based structures are a proxy measurement of fishing pressure, the latter increasing in relation to the growth of fish-processing facilities. In this paper, we explore the hypothesis that fluctuations in sardine landings influenced the ways we built on land. We discovered that this was not necessarily the case, since design and building practices relate to the agendas of a variety of agents other than fish, notably the state (in France through the *Ponts et Chaussées* technical offices). " These hedge and go back and forth, and dilute what are some useful observations. Clearer, more forceful argumentative language throughout would strengthen the piece.

Is the work original in terms of material and argument?

Yes

Does it sufficiently engage with relevant methodologies and secondary literature on the topic?
Yes

Is the work clearly and cogently presented?
Partly

Is the argument persuasive and supported by evidence?
Yes

If any, are all the source data and materials underlying the results available?
Yes

Does the research article contribute to the cultural, historical, social understanding of the field?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Fisheries history, premodern (XV-XVII centuries); Marine environmental history

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 25 Jun 2026

Alice Nouvet

We are grateful for the careful reading of the manuscript and the constructive comments. We greatly appreciate this assessment, which opens up further interdisciplinary lines of inquiry. In revising the manuscript, we have taken the remarks into account, focusing on three main points.

Comment 1 : "I am surprised, actually, that they do not invoke Westerdahl's idea of Maritime Cultural Landscape – that seems to be, arguably what the authors are interested in reconstructing."
Response: Regarding the suggested idea of engaging with Westerdahl's concept of the Maritime Cultural Landscape, we agree that this framework is relevant to broader debates in maritime history. Our work shares with this perspective an interest in the relationships between maritime activity and the transformation of coastal environments. However, our study does not aim to reconstruct a maritime cultural landscape in the broader anthropological sense proposed by Westerdahl, encompassing navigation practices, toponymy, and the wider cultural dimensions of coastal communities. Rather, our focus is

more specifically directed toward the material dimensions of coastal transformation, particularly the relationship between fluctuations in sardines' population, fisheries shore-based infrastructure, and state-mediated investment in the built environment. In this sense, architecture is approached as a measurable and historically situated interface between marine exploitation and public policy. The goal is to incorporate biological marine histories—if not an animal perspective—within architectural history: hence the conscious effort to depart from terrestrial and anthropological approaches.

Comment 2: "The authors ought to be much clearer about the limitations (self-imposed) on the study. This isn't really a study of the Bay of Biscay, it is a study of one part of southern Brittany. In some places, it is more or less a study of one port."
Response: We appreciate this observation and have revised the manuscript to clarify the spatial scope of the study. The analysis operates across three spatial scales that reflect the availability and nature of the historical sources: the harbour of Douarnenez, South Brittany, and the broader French Atlantic façade. These scales are now presented more explicitly in the Methods and materials sections. We also clarify in the Conclusion that the objective is not to provide an exhaustive reconstruction of the Bay of Biscay as a whole, but rather to examine relationships between sardine landings, fishing capacity, and coastal investment through a set of interconnected case studies and datasets operating at different spatial scales.

Comment 3: "If they wish for southern Brittany to be a proxy for all of the Bay of Biscay then they will have to do more to make that case."
Response: We agree that this point required clarification. South Brittany is not intended as a proxy for the entire Bay of Biscay. Rather, different spatial scales were examined using different datasets and methods. Detailed information on harbour infrastructures, fishing grounds, and vessel capacity was available for South Brittany and Douarnenez, whereas broader demographic and fisheries statistics were available at the scale of the French Atlantic façade. We have revised the Methods and materials sections to make this multi-scalar approach more explicit and to clarify the distinct role played by each dataset.

Comment 4: "(...) the focus on sardine canning industry means that it would be hard to generalize the article's conclusions beyond the modern period."
Response: We agree with this observation. The study is intentionally bounded by the temporal coverage of the available datasets, which span the period from the mid-nineteenth century to the mid-twentieth century. Our objective is not to generalize these conclusions beyond the modern period, but rather to use this historical case study to explore relationships between marine resources, fishing capacity, and coastal infrastructures.

Comment 5 "This conclusion also suggests that fisheries historians should be paying more attention to politics – a point which the authors unfortunately don't lean into. But it would be worthwhile to reconstruct the decisions, lobbying, and debates which led to increasing French state investment in the sardine industry in the wake of declining catches. This suggests that rather than strictly focusing on coastal landscapes, we should be paying attention to archives of state power."
Response: We greatly appreciate this suggestion and agree that the political dimensions of

fisheries management and public investment deserve further investigation. Indeed, the role of state institutions emerges repeatedly throughout our analysis, particularly through the activities of the Ponts et Chaussées. However, a detailed reconstruction of political decision-making, lobbying processes, and administrative debates falls beyond the scope of the present article. Our objective here was to assess the relationships between sardine fluctuations, fishing capacity, and shore-based infrastructures using a combination of spatial and quantitative evidence.

Comment 6: "At times, the argument becomes muddled across the article. The way the piece is structured it keeps coming back to conclusions, so that it feels a tad repetitive. But at times the authors have trouble committing to one or two clear arguments."
Response: We appreciate this comment and have revised the manuscript accordingly. In the revised version, we have sought to make the central arguments more explicit and to reduce repetition across sections. In particular, we now structure the argument around three main relationships:
(1) sardine behavior and the geography of fishing harbors,
(2) the relationship between fishing grounds and landing sites, and
(3) the relationship between sardine fluctuations and investments in fishing capacity and shore-based infrastructures.
These themes are now articulated more consistently throughout the Results, Discussion, and Conclusion sections.

Competing Interests: No competing interests were disclosed.