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A long-term (1667–1860) perspective on impacts of fishing and environmental variability on fisheries for herring, eel, and whitefish in the Limfjord, Denmark

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Abstract

This investigation reconstructs the development of major fisheries for herring, eel and whitefish in the Limfjord estuary, Denmark ca. 1667–1860, and then evaluates how their long-term dynamics have been influenced by some key fishery and environmental developments. The commercially most important fishery was for herring, *Clupea harengus*, which spawned in the Limfjord. This fishery underwent large changes in these centuries. High landings occurred in two periods in the early 18th and again in the early 19th centuries, when 4000–8000 metric tonnes were caught annually. In 1830, the fishery collapsed and landings were <1000 tonnes until the 1910s. Even during the 20th century using modern fishing techniques, the herring fishery never exceeded 7000 tonnes. The collapse was most likely due to unsustainable fishing practices (direct impacts on adults, juveniles, larvae and eggs). The second most important fishery of the Limfjord was the eel fishery. Eel, *Anguilla anguilla*, seems to have fled the fjord after a winter storm in 1825 broke the narrow Agger Tange isthmus which used to separate the Limfjord from the North Sea, and permanently increased the salinity in the western part of the Limfjord from 8 psu to 33 psu. The, so-called *pulse seine* fishery for eel declined rapidly following the salt water intrusion, and the population needed at least one to two generations to even partly recover. One possible technological reason for the recovery of the fishery was the 1848 invention of a new type of gear in the Limfjord which today is known as the *Danish seine*. However, the commercial eel fishery in Limfjord ceased by the 1980s coincident with the overall decline in European eel populations. The third fishery analyzed is the fishery for common whitefish, *Coregonus lavaretus*. A local population formed the basis of a substantial seasonal fishery, but the whitefish did not survive the salinity obstacle presented by the salt water intrusion in 1825. This study documents both the effects of fishing and environmental variability on collapses of different Limfjord fish species.

Keywords: Historical ecology; Fisheries; Herring; Eel; Whitefish; Limfjord

1. Introduction

The Limfjord is an estuary in northern Denmark (Fig. 1) which has supported commercial fisheries for centuries. This situation has changed drastically because commercial fishing activity, except for cultured shellfish, in the early 21st century is at a very low level (Hoffmann, 2005; Christiansen et al., 2006). This paper presents a reconstruction of time series of the historical fisheries of the Limfjord in the pre-industrial era from ca. 1667 to 1860 based on archival studies of historical fishing licenses, custom records and the catch records of individual fishers. In doing so, this paper highlights the phenomenon known as the *shifting baseline syndrome*, whereby the time frame in scientific analyses is partly determining baseline perceptions of how large fish abundances have been or can become (Pauly et al., 1998; Jackson et al., 2001; Pitcher, 2001). The reconstruction of these historical fisheries can potentially serve as an example of the importance of the implementation of longer time scales in fisheries science. During the last decade an increasing number of studies have called for a general shift of the baseline of scientific investigation going back centuries, in order to understand the interplay between man and the sea (Alheit and Hagen,

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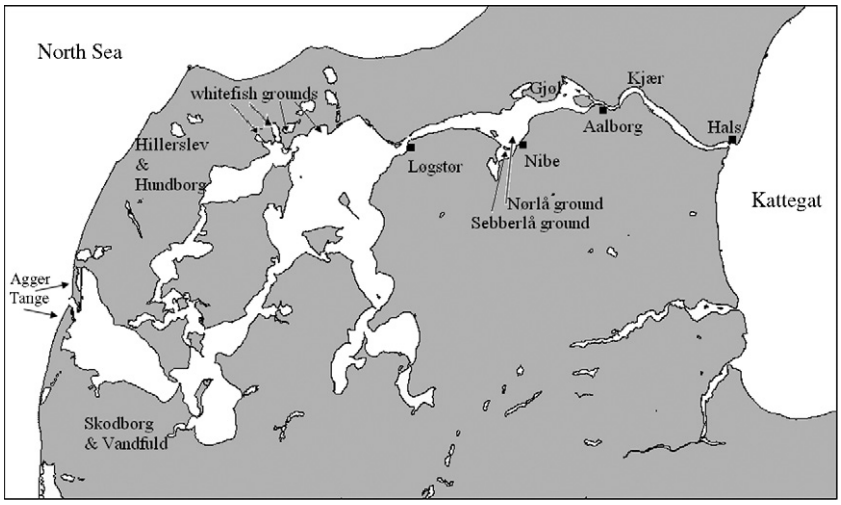

Fig. 1. Map of present day Limfjorden, with the breached Agger Tange in the west. Until 1825 the only entrance to the Limfjorden was from Kattegat at the town of Hals. Fishing grounds, towns and districts mentioned in the text, are all mapped.

1997; Holm et al., 2001; Jackson et al., 2001; Pitcher, 2001; MacKenzie et al., 2002, 2007; Rose, 2004; Rosenberg et al., 2005; Myers and Worm, 2003; Lotze et al., 2006; Lotze, 2007; Poulsen et al., 2007). From a marine ecology perspective it is of major interest to know how marine ecosystems functioned in an era before intensive fishing affected fish stocks and indirectly other trophic levels in ecosystems.

The results in this paper give new information on the magnitude of the main fisheries and the timing of large changes in targeted species and species composition in the Limfjord, which took place in this period. The reasons for the change in species composition are discussed in light of changes in exploitation and environmental conditions of the fjord.

2. Material and methods

2.1. Area description

The Limfjord is one of the most intensively surveyed marine areas in Denmark. Scientific studies have been carried out here since the late 19th century (Christiansen et al., 2006). Today, there is an inflow of salt water from the North Sea into the Limfjord from west to east, with the flow being ca. 8–9 km^3 annually (Anonymous, 2000). The inflow is controlled by the dominant westerly winds (Christiansen et al., 2006). The fjord has been open to salt water from the North Sea since February 1825 when a large winter storm cut through the narrow stretch of land, Agger Tange, in the west which previously had sealed off the western end of the fjord from the sea (Fig. 1). Analyses of sediment cores from the Limfjord have enabled a reconstruction of the historical fauna of the last 3000 years (Christensen et al., 2004). Faunal remains document different levels of salinity in the Limfjord. Until ca. 1100–1200 A.D. the Limfjord was a strait with salinity levels of 33 psu, close to the salinity level in the North Sea. Thereafter, the Agger Tange was formed and the Limfjord turned into a brackish fjord, whose only connection to the open sea was through a narrow eastern entrance to the Kattegat at Hals. A minor rise in salinity to ca. 20 psu occurred some time between 1500 and 1700 (Christensen et al., 2004). A couple of breaches of Agger Tange are mentioned in the historical records of this period, but the most likely breach to have led to this increase in salinity took place in 1624 (Berntsen, 1650–1656). The Danish topographer, Arent Berntsen, who visited the Limfjord in the 1630s, reported how the fresh water fish were dying and washed ashore due to the influx of saline water, which in turn brought in cod, *Gadus morhua* and plaice, *Pleuronectes platessa*. However, the breach was only short lived, and the isthmus at Agger rebuilt itself again in the mid 1630s (Berntsen, 1650–1656). The focus of this paper is the historical fishery of the brackish period between 1700 and 1825 and of the first period of the salt water regime until ca. 1900.

2.2. Historical context

Herring, eel and plaice were the dominant commercial species in the 1900s, until the early 1980s when commercial fishing became profitable only for mussel dredging (Anonymous, 2000). For the period before ca. 1890, no quantitative investigation of the Limfjord fisheries has been undertaken.

In the brackish period, the main Limfjord fisheries were for herring, eel and whitefish (Rasmussen, 1968). In the period from the breach of Agger Tange until the advent of modern fisheries statistics (1825–1889), eel, plaice and herring were the most common fisheries (Johansen, 1929). In 1848, a technological innovation of major importance took place, when farmer-fisher, Jens Væver invented the so-called *snurrevod*, which became known in the English speaking world as the *Danish seine* (Hjort Rasmussen, 1991). This gear was first used for plaice and later also eel fishing.

Not much is known about the herring, which was caught in the Limfjord before 1889. What was consistent though in the brackish period of the fjord was that the autumn months usually marked the first arrival of herring entering the Limfjord from the east, while the high season was in the months of April to June, when the herring spawned on the shallow grounds from Nibe Bredning and Haverslev Bredning to Løgstør

Grunde. The herring, known as *Aalborgsild*, therefore seem to have been spring spawning herring (Johansen, 1929). The name *Aalborgsild* comes from the main town in the Limfjord area, Aalborg (Rasmussen, 1968).

The dominant race of herring since the breach of Agger Tange has arrived from the North Sea through the western entrance, and it is not known whether this is a separate race from the Aalborgsild (Johansen, 1929).

2.3. Data sources

A systematic registration of the size of the Danish fisheries began only in the late 19th century; however different kinds of proxy-data can be used as indicators of the fluctuations that occurred in the fisheries in earlier years. In terms of the time period covered in this study, we are limited by the availability of historical source material, the quality of which is best from the late 17th century onwards. The size and species composition of the modern fisheries in the Limfjord from the late 19th century onwards has already been recorded in contemporary published fisheries statistics (Johansen, 1929; Anonymous, 1930–2000; Hoffmann, 2005; Christiansen et al., 2006) and will not be dealt with in detail in this paper.

In an era when modern fisheries science was not yet invented, historical reconstruction of catches and effort is dependent on the availability of documents from various archives, which were originally produced by the central Danish authorities as well as the local authorities in the Limfjord area for other purposes, such as taxation. For the economically important herring and eel fisheries, it has been possible to derive catch data from custom records of fish exports. This material forms the basic data for this paper.

We have estimated fishing effort based on the fact that the Limfjord was the most regulated fishing region in early modern Denmark. The earliest information on regulations of mesh size in the herring fisheries are from 1515, and mesh sizes remained the same throughout the period of investigation in the study (Rasmussen, 1968). This investigation has mainly profited from source material produced in the aftermath of the royal decrees of 1750, by which fisheries with beach seines, seines, pound nets and various traps were to be taxed according to the number of each type of gear being used annually. This included the three main fisheries for herring, eel and common whitefish. With money at stake for the authorities as well as the fishers, the annual registration of fishing licences for various types of gear was an important procedure. This ensured that the documents produced had a reliable and uniform character year after year. Undoubtedly, some fish were caught illegally, and some fishers engaged in a black market economy, which was not recorded on paper. Proxy-data should be treated with caution, but since the administrative situation was stable throughout the period analyzed, there is no reason to believe that the level of tax evasion was considerably larger or smaller in some years than in others. Moreover, and contrary to the use of many modern day commercial catch statistics, the fishers themselves had no incentives to misreport catches, since the taxes were levied on the type and number of fishing gear rather than on the catch, and there was no limit as to how much one fisher was allowed to catch.

The royal decree of 1750 regulated fisheries in the Limfjord until 1857, when the first modern Danish fishing laws were instated, and the registration of catch and effort was altered. However, the Limfjord itself and the fisheries changed substantially after the North Sea breach in 1825 (see Section 3 below). Fisheries for plaice began soon after this major incident, but since this fishery had not been established around the time of the implementation of the 1750 regulations, it is not possible to quantify the development of the plaice fisheries before 1857.

Another historical side effect of the changes after the 1825 breach is that dramatic changes in the fisheries provoked the interest of natural historians of the time, as well as local administrators writing about the changes facing the fishers in their local area. This material is also included in our interpretations.

2.4. Reconstructing herring fisheries

2.4.1. Estimated herring catch

With regard to the catches, we have established a time series of more than 300 years from 1667 onwards using custom records and account books as proxy-data for the first ca. 200 years. These data have been supplemented by modern day statistics (Fig. 2). The derivation of catch data from the custom records and account books is described below.

For most years between 1667 and 1835 custom records from the Limfjord town of Aalborg are available, and they form an excellent set of catch data for herring. All salted herring exported from the fjord was processed administratively by the Aalborg customhouse. This was the only point of access to the open sea when coming from the west: furthermore, the town jurisdiction and custom rights spanned the entire area to the mouth of the Limfjord (Degn, 1995, p. 95). Since the custom records were

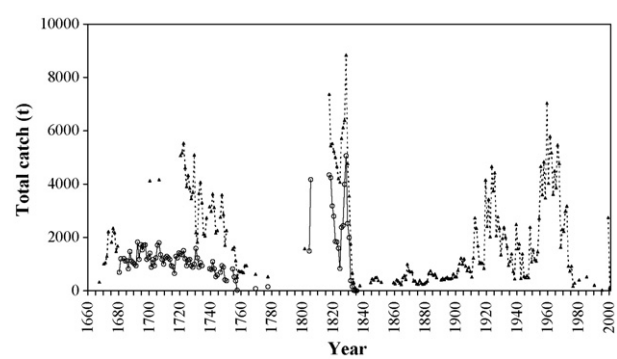

Fig. 2. Estimated total catch of herring in the Limfjorden from 1667 to 1999. Catches are reconstructed using custom records and account books as proxy-data, these being supplemented by modern day statistics. Triangles represent total estimated landings based on exports from Limfjord to foreign, Danish and Norwegian markets; circles represent landings based on exports only to foreign markets. Blank spaces mean that no data source was available (Christensen, 1977, pp. 61–62, 126; Poulsen and Christensen, 1990, pp. 74–75; Olrik, 1773, p. 237; LA.Bo.D.382; Begtrup, 1810, pp. 291 and 369; KB. Beck. Add. 314–319; KB. Collin. Krøyer, 28; RA.Rtk.2426.211–213 and 215; LA.B298.505; LA.B298.672; Anonymous, 1838–1839, 1840, 1841–1842, 1843, 1845; RA.IL.DS, 1848–1850 and 1851–1865, Johansen, 1929, pp. 19–37; Anonymous, 1930–1977, 1980, 1985, 1990, 1995, 1999).

financially important, the figures can be regarded as having a high degree of reliability.

Custom records need to be converted from barrels to metric tonnes. In this period, one standard Danish barrel with salted herring contained 108.21 Liters, which contained gutted and cured herring that was approximately the equivalent of 100 kg of round fish (Thestrup, 1991, p. 29). However, the total output of processed herring was not only salted, but also dry-salted, smoked and dried, as well as untreated catches of fresh herring. Herring of inferior quality were boiled and made into train oil.

For dried herring, the conversion from *ol* (80 fish) to barrels depends on the season. In springtime, the herring was lean and it took 16.6 *ol* to fill a barrel, while the larger herring caught in autumn could fill a barrel with only 13.3 *ol* of fish (Begtrup, 1810, p. 382).

It is possible to calculate the total output based on the proportion of production of salted herring relative to the reported total catches for a period of 8 years (1825–1832). We then assume that the ratio of production of salted herring to total herring catches (includes salted herring which was exported, as well as herring which was exported as smoked herring, and salted, fresh and smoked herring which was consumed locally) is representative for the rest of the period 1667–1835, so that the total output can be extrapolated from the custom records of production of salted herring. For each year during the period 1825–1835 total export figures of salted herring are available for Nibe (KB. Collin, Krøyer. 45). During 1812–1832, Nibe merchant fisher, Peder Kold, compiled an estimate of the annual catches in *ol* pr. *kåg*, the local type of fishing boat, listing both the spring and autumn herring fisheries in the area (KB. Beck. Add. 314a–b. fol.). These catches represent all types of herring product (i.e., fresh, salted, dried, smoked) destined for both export and local markets. After conversion of both time series into metric tonnes of fish, it is possible to compare catch rates in spring with those in autumn and to estimate the relationship between total production and the exports. During the time period 1812–1832 the average catch rate in spring was 83% (standard error = 0.02) of a whole year's catch, and catch rates in fall were strongly correlated with those in spring (fall CPUE = 0.23 × spring CPUE + 120; $R^2 = 0.53$, $P = 0.0003$ with one outlier in 1828 removed).

From a petition to the king in 1830, we know that 59 *kåg* fishing boats operated from Nibe (RA.Rtk.2426.215). So, assuming that all exported herring was salted, and that on average 59 boats operated in all years between 1825 and 1832, the total annual catch can be estimated from the product of the number of boats and the catch per boat in spring and autumn, using season-specific numbers of herring per barrel (see above). The ratio of salted exports to the total catch in Nibe can then be calculated as follows:

(i) Annual catch in Nibe for year i = ((catch_i in ol per boat in spring × 16.6 ol/barrel in spring) + (catch_i in ol per boat in autumn × 13.3 ol/barrel in autumn)) × 59 boats in Nibe × 0.1 tonnes/barrel, where the subscript i is years between 1825 and 1832.

(ii) Annual exported salted herring for year i from Nibe = no. barrels × 0.1 tonnes/barrel.

(iii) Mean ratio of total catch/exports of salted herring = 1.18 (standard error = 0.21).

Thus, the conversion factor to raise export figures of salted herring to total catches was 1.18 in 1825–1832. This conversion factor was used to estimate the total catch of herring for the period 1667–1835 (Fig. 2).

After the collapse of 1830, salted herring never regained its position as an important export commodity. Therefore, estimations for the following period come from other sources. In 1832 questionnaires were sent to the district bailiffs in all districts around the fjord. The total catch in spring that year was estimated at 46,725 ol herring. For several years until 1851, the bailiff, Westenholz, at the village of Løgstør, submitted reports on the spring herring fishery at Løgstør. In 1832, Westenholz wrote that 27,354 ol were caught in spring (RA.Rtk.2426.215). Assuming that 1832 is representative for the poor years until 1837–1851 a conversion factor from the catch in spring at Løgstør to the total catch in metric tonnes in the Limfjord can be calculated as follows:

(iv) Ratio of total catch caught in Løgstør 1832 = Limfjord spring catches/Løgstør spring catches = 46,725/27,354 = 1.71.

The total annual catches are then derived by scaling for the proportion of annual catches which are made in spring, assuming that fisherman Peter Kold's seasonal distribution of catches (mean = 83%; S.E. = 0.02) are representative for the entire Limfjord. Annual catches for the years 1837–1851 can then be estimated as:

(v) catch i = 1.71 × (catch in ol in spring/16.6 ol per barrel in spring) × 1.2 × 0.1 tonnes/barrel.

where i = year, 1.71 is the scaling factor to raise Løgstør catches to the entire Limfjord, and 1.2 (0.83^{-1}) is the multiplier for raising spring catches to annual catches.

There are some years in which no data sources exist, and in these cases no annual estimate was made. In the final time series there are no observations for the years 1778–1800, which leaves room to speculate about the size of the fishery in that period. Several contemporary testimonies agree that this was a period of very low catches as well as very low export figures for the salted herring (Hoffmann, 1769, p. 14; RA.Rtk.235.18; KB. Collin. Krøyer. 41–42; Lybecker, 1772, 1792; Just, 1802). The time series show an abundance of herring from the very beginning of the 19th century, and other reports from local fishers support the notion that a new era of great catches started just after 1800 (Feddersen, 1878, pp. 224–271). This suggests that the last quarter of the 1700s was marked by poor catches, but the impact of competition from the neighbouring Swedish herring fishery in eastern Kattegat at the county of Bohuslän should not be overlooked. The Bohuslän herring fishery is known for having dramatic fluctuations due to migration of the resident herring stock (Alheit and Hagen, 1997; Corten, 2001). In the good periods the Bohuslän herring fishery was the largest fishery in

Europe dominating the whole Baltic market (Dalén, 1941). One of these great periods started in 1756 and lasted until 1808, where annual catches were three times bigger than at any period of time in the Limfjord (Nilsson, 1963). It seems plausible that the low export figures from the Limfjord at that time were affected by Swedish competition.

Furthermore, the times series 1667–1835 is based on different aggregate figures. For many years the data covers the sum of all shipments from Aalborg ($n = 46$), either as one figure or divided between exports to other parts of Denmark, to Norway (Denmark and Norway was ruled jointly by the same king from 1380 to 1814) and to foreign countries. However, for 40 years (1680–1705, 1707–1719 and 1804–1805) there are no recorded exports to Norway, which itself was a major herring exporting country (Nedkvitne, 1988; Fossem, 1979), although herring was exported to foreign countries. Thus, the Limfjord exports in these 40 years are likely an underestimate of the total landings. During the 31 years from 1720 to 1750 data are available concerning the foreign exports ($n = 26$) and Norwegian exports ($n = 27$), but no data exist for the shipments directed towards the rest of Denmark. The export figures for Norway and foreign countries arising from the data at hand are very large in these years, so the shipments to the rest of Denmark have been conservatively estimated at 500 tonnes/year in the period 1720–1750.

In 1857, the first modern fishing law concerning the fisheries in the Limfjord was passed in the Danish parliament. The implementation of the law resulted in a more systematic and uniform collection of catch data. The raw data of this collection is, unfortunately, not preserved, but figures of the total output are mentioned in late 19th century fisheries journals: however only the value of the catch is recorded and not the size of the catch (Andersen, 1866, 1870, 1882). More modern-day practices in the compilation of catch records are available from 1889 and onwards (Bager et al., 2007; Eero et al., 2007).

The early 19th century marine biologist, A.C. Johansen, solved the problems of conversion from value to catch size. Johansen estimated the price for herring to be 1.00 Danish Kroner for the period 1859–1888, and 1.20 Danish Kroner for the years 1890–1895 (Johansen, 1929, pp. 11–12). In this way, Johansen arrived at a number of catch estimates in metric tonnes, which are all implemented in the catch reconstruction.

2.4.2. Herring catch per unit effort

Catch per unit effort is a well-established method to establish an index of abundance of fish species through the use of commercial catch data. In 18th and 19th century Limfjord, two datasets of individual fishers' reports of their fisheries were retrieved from archives (KB. Beck. Add. 316IIIb).

During the years 1757–1781, farmer-fisher Anders Pallesen from the village of Valsted near Nibe fished for herring with a number of pound nets each spring. He had leased the right to fish from a nearby estate and kept an annual account of his activities. From Pallesen's account book we can see that during his entire career he used the same type of pound nets in exactly the same sites on the same ground in the Nibe area (KB. Beck. Add. 316IIIb). These data therefore form a reliable basis for a CPUE time series as number of fish caught per pound net per season. Since the unit of effort is very stable, the falling catch rates indicate a falling abundance of fish in this time period.

The next dataset of commercial catch data was compiled by the merchant and fisher, Peder Kold in town of Nibe, who created a list of the annual number of fish caught per pound net in the Nibe area (1812–1832) (KB. Beck. Add. 314a–b. fol.). Similar to Pallesen there is no reason to doubt the validity of the data compiled by Peder Kold. Neither fisherman had any incentive to present deliberately false information, and they were both financially dependent on the accuracy of the available information on their fisheries.

2.4.3. Reconstructing effort of herring fisheries

The herring fishery was mainly conducted with pound nets, which is a passive fishing gear consisting of an arrangement of nets strung between stakes and guiding the fish into an enclosure. The pound net fishery in the Limfjord was the most regulated fishery that demanded a high level of capital investment. Following an extensive regulation of the fisheries in the Limfjord in 1750 the town bailiff in Nibe was given the task of submitting annual reports on the fishery leases in the pound net fisheries in the most important fishing grounds of the fjord, Nørlå and Sebberlå. For most of the period between 1752 and 1860 it is possible to count the number of pound nets in use in the spring fishery. Due to the regulations, the pound nets were always the same size and were set in the same sites, thereby providing a precise account of fishing effort. The fishers owning the locations, or leasing the fishing right from the owner, all had to pay a fixed tax to the king. Therefore, the local administrators carried out thorough on-site investigations as the basis of their annual reports. Moreover, both these two sites were fully developed as early as the mid-17th century (Rasmussen, 1968, pp. 394–440). This evidence increases the reliability of the long time series (Fig. 6).

One of the leading fishers in Nibe, Christian Westergaard, made an account of the total number of locations where pound nets could be set up in the year 1829 at four major grounds. Nørlå fishing ground had 750 of these sites, Øland had 433, Østerland had 110 and Sebberlå had 226, which gives a total of 1519 sites (KB. Add. 314a–b. fol.). The report of 1820 indicates that 831 nets were in use in the grounds of Nørlå and Sebberlå (LA.B3.1565). Thus, with 976 available sites at Nørlå and Sebberlå, the frequency of sites in use was $831/976 = 0.85$ pound nets per available site during 1820. On average, one boat fished using 13 pound nets (Rasmussen, 1962, p. 60). Several reports testify that in the early 19th century it took three men to operate one fishing boat (Begtrup, 1810, p. 383; Feddersen, 1878, pp. 348–361).

Moving onto the shore-based seine fishery, the fishing intensity can be measured using registers of fishing licences, which were auctioned for periods of 3, 5 or 10 years to teams operating in the seine fishery. The number of licences in the Limfjord was laid down in the regulation of 1750. This means that, when all available licenses were auctioned, the only variation is the size of the individual seines, which was not presented in the reports submitted to the regional authorities. However, since the licenses issued were confined to fishing within a specifically defined area

Table 1
Data sources per species, time period and geographical area

Time period	Species	Type of information	Geographical area	Fishing method	Raw data	Illustration in text	References to published and archival material
1667–2000	*Clupea harengus*	Estimate of total catch	Entire fjord	Various	Extrapolation from custom rolls, catch records of sections of Limfjord, statistical accounts of export from Aalborg and modern fisheries statistics	Fig. 2, Fig. 6	Christensen, 1977, pp. 61–62, 126; Poulsen and Christensen, 1990, pp. 74–75; Olrik, 1773, p. 237; LA.Bo.D.382; Begtrup, 1810, pp. 291 and 369; KB. Beck. Add. 314–319; KB. Collin. Krøyer. 28; RA.Rtk.2426.211–213 and 215; LA.B298.505; LA.B298.672; Anonymous, 1838–1843, 1845; RA.IL.DS, 1848–1850 and 1851–1865, Johansen, 1929, pp. 19–37; Anonymous, 1930–1977, 1980, 1985, 1990, 1995, 1999
1812–1832	*C. harengus*	CPUE data, no. fish per pound net	Nørlå and Sebberlå grounds	Pound nets	Contemporary account by merchant and fisher, Peder Kold	Fig. 3	KB. Add. 314a–b. fol.
1757–1781	*C. harengus*	CPUE data, no. fish per pound net	Sebberlå ground	Pound nets	Annual accounts from farmer-fisher, Anders Pallesen	Fig. 4, Fig. 5	KB. Add. 316IIb
1752–1862	*C. harengus*	Effort data, pound nets in use during spring fishery	Nørlå and Sebberlå grounds	Pound nets	Annual reports by town bailiff	Fig. 8	LA.Bo.D.351; LA.Bo.D.352; RA.Rtk.2426.211–213; RA.Rtk.2425.310; LA.B3.1565; RA.IL.DS, 1848–1850 and 1851–1865; Andersen, 1870, pp. 330–336
1779–1852	*C. harengus*	Effort data, licenses in use	Kjær district	Beach seines	Annual reports by district bailiff	Fig. 9	LA. B31E. 268
1783–1848	*C. harengus*	Effort data, licenses in use	Gjøl island	Beach seines	Annual reports by district bailiff	Fig. 10	RA.Rtk.2426.211–215; RA.Rtk.2425.310; RA.IL.DS, 1848–1850
1801–1851	*C. harengus*	Effort data, licenses in use	Near Løgstør town	Beach seines	Annual reports by district bailiff, account from naturalist, Krøyer	Fig. 11	Begtrup, 1810, pp. 287 and 379; KB. Collin. Krøyer. 55–56; RA.IL.DS, 1848–1850 and 1851–1865; RA.Rtk.252.276; RA.Rtk.2426.215
1741–1841	*C. harengus*	Effort data, no. boats	Kjær district	Gill nets	Annual reports by district bailiff	Fig. 12	LA.B31E.268; Rasmussen, 1968
1801–1845	*Anguilla anguilla*	Export figures	Entire fjord	Various	Custom rolls and statistical accounts of export from Aalborg	Fig. 13	Begtrup, 1810, p. 294; Christensen, 1832, p. 143; Anonymous, 1838–1839, 1840, 1841–1842, 1843, 1845
1794–1853	*A. anguilla*	Effort data, no. of seines	Hillerslev and Hundborg districts	Pulse seining	Annual reports by district bailiff	Fig. 14	RA.Rtk.2426.212–215; LA.B2.396; LA.B33.336
1794–1835	*A. anguilla*	Effort data, no. of seines	Hassing and Refs districts	Pulse seining	Annual reports by district bailiff	None	RA.Rtk.2426.212–215; RA.IL.DS, 1848–1850
1798–1845	*A. anguilla*	Effort data, no. of seines	Vester Han district	Pulse seining	Annual reports by district bailiff	None	LA.B2.396; RA.Rtk.2426.213–215; RA.IL.DS, 1848–1850
1818–1845	*A. anguilla*	Effort data, no. of seines	Hjerm and Ginding districts	Pulse seining	Annual reports by district bailiff	None	LA.B78A.502; RA.IL.DS, 1848–1850
1823	*A. anguilla*	Effort data, no. of seines	Fjends and Nørlyng districts	Pulse seining	Annual reports by district bailiff	None	RA.Rtk.2426.213
1797–1841	*A. anguilla*	Effort data, no. of seines	Sallingland district	Pulse seining	Annual reports by district bailiff	None	RA.Rtk.2426.213; LA.B43.302
1794–1839	*A. anguilla*	Effort data, no. of seines	Mors island	Pulse seining	Annual reports by district bailiff	None	LA.B2.396; RA.Rtk.2426.213–215; RA.IL.DS, 1848–1850
1812–1832	*Coregonus lavaretus*	CPUE data, no. of fish per pound net	Østerild, Tømmerby Fjord, Mellem Fjord and Hovsør Port	Pound nets	Annual reports by prefect of Thisted county	Fig. 15	RA.Rtk.2426.211–114

of the beach, and the seines were only allowed to reach into the middle of the fjord, this would limit the size of the gear (Table 1).

One interesting exception is the seine fishery at the town of Løgstør, where the seine fishery consisted of only one to three seines in the 18th century (Rasmussen, 1968, p. 143; Hoffmann, 1769, pp. 15–20; Lindhard, 1985, p. 17). In the first two decades of the 19th century five to seven licenses for seine fishery were issued. The 1820s though, marked the arrival of a decade in which fishing intensity more than doubled, reaching 18 licenses for seine fishery in 1829. The local district bailiff, Major Westenholz, was highly engaged in the welfare of the local fishery and several times in the 1820s he successfully petitioned the king for making exceptions from the regulation of 1750, and allowing new locations for seine fisheries to be set up (Table 1). Based on 18th century brass cylinders used for measuring mesh sizes, we know that the diameter of one mesh in the beach seines used at the time was 4.55 cm and 4.08 cm in the central part of the seine where the catch was collected (Rasmussen, 1968).

The third important type of gear in the Limfjord herring fishery was the gill net. The gill net fishery was less regulated and was regarded as an extra source of income for the poor people in autumn (Rasmussen, 1968). However, the district bailiffs still included the gill net fisheries in their annual reports, and for Kjær district, the archival data allow for the construction of a time series from 1741 to 1841 (Fig. 10).

2.5. Reconstructing eel fisheries

The second most important fishery of the Limfjord was the eel fishery, mainly located in the western half of the fjord. With its high content of fat, eel was a highly valued export commodity was sold as dried, smoked or salted product. Unfortunately, archival material has not been preserved in great quantities. However, from a number of different sources the export figures from the town of Aalborg can be reconstructed for 14 years during the period 1801–1845 (Table 1). Eel from the Limfjord was sold throughout Denmark, but the bulk of the products will have left the Limfjord region aboard vessels from Aalborg. Exports from here therefore are a reliable approximation of what the total catch of eel will have been during the period covered by these data.

Much of the eel fishery was conducted with small traps, spears and hooks, which did not fall under government control and therefore have not left traces in the source material. One important exception was the pulse seine fishery and the intensity of this fishery can be measured by counting the number of licenses issued for each fishing season.

Each party of pulse seine fishers consisted of two boats with two fishers in each. The seine was held out between the boats, and with a large concave stick the fishers would hit the surface causing shock waves in the water thereby disturbing the fish (Rasmussen, 1968). The fishing season lasted from the 24 June to 24 August; during the season the district bailiffs around the Limfjord were regulating the fishery, for instance overseeing that the gear had been approved with a metal badge before the season started (Rasmussen, 1968). Due to these regulatory measures, the pulse seine fishery is a consistent and reliable type of proxy-data for fishing effort.

For all districts in the western half of the fjord, except for the districts of Skodborg and Vandfuld, records have been kept (Table 1). The most complete records come from the pulse seine fishery in Hillerslev and Hundborg districts in the northwestern parts of the fjord, where a time series from 1794 to 1853 can be established (Fig. 12).

2.6. Reconstructing whitefish fisheries

The third important fishery in the Limfjord was the fishery for common whitefish, *Coregonus lavaretus*. Whitefish belongs to the Salmonidae family, and prefers freshwater and waters of low salinity. Hence, it is very common in the Baltic (Muus and Nielsen, 1998). In the brackish period of the Limfjord a stock of whitefish had adjusted to the conditions in the western part of the fjord from Løgstør Grunde to Agger Tange. When all the Limfjord fisheries were examined and registered in the 1740s, whitefish were caught around the entire western half of the fjord (Rasmussen, 1968, p. 48). By a royal decree which was enforced in 1811, the use of special pound nets became regulated, and records of the catch and effort began to be recorded by the county's prefect. In the northwestern part of the Limfjord at Østerild, Tømmerby Fjord, Mellem Fjord and Hovsør Port, the prefect's reports from the pound net fishery were found for 15 seasons in the period 1812–1829. The pound net used for whitefish was distinct from the herring pound nets used in the fjord, because the position of each net in the water was less precise, while the meshes were larger matching the larger fish; however it still took two men per net to manage the gear. The season started in late September and ended around Christmas, or as long as the fjord was free of ice. This relatively short period of time did not leave room for the development of a particular group of full-time whitefish fishers. Rather the whitefish fishery was carried out by local farmers in order to supplement their income from agriculture, when there was not much else to do after the autumn ploughing (Rasmussen, 1968, p. 237). This information allows for a reconstruction of the CPUE as number of whitefish caught per pound net per season.

The whitefish fishery was also conducted with beach seines. The beach seines used for whitefish were less regulated, and the sources are therefore less informative. However, the commission of 1741 once again throws light on the intensity of this particular year, when 130 beach seines were in use. The size of each seine varied with the specific conditions on each beach; but the nature of the fishery required at least three fishers. One stayed ashore holding one end of the seine while two others rowed out the rest of the nets and then ashore further down the beach (Rasmussen, 1968, pp. 249–254).

Some qualitative data though, were also available. On the 29 October 1827 an article emerged in local newspaper, *Thisted Avis*, where whitefish along with other brackish or fresh water species were reported to swim into the smaller bays and almost ashore trying to escape the saline intrusion (KB. Beck. Add. 314c. fol.). Another important source of information concerning the state of the whitefish fisheries is a questionnaire, which

the prefect Faye circulated in 1832. Several answers came back which reported that very few fish had been caught and by some there was suspicion by the local fishers that the whitefish had become extinct (RA.Rtk.2426.215). These reports are the last testimonies of any whitefish fishery in the Limfjord.

3. Results

3.1. Herring

On the basis of available historical evidence the analyses have resulted in the reconstruction of historical data series for herring, eel and whitefish. In economic terms the herring fisheries were the most important, and this has enabled the reconstruction of a data series for the total removal of herring covering 203 years during the period 1667–1999. Sixty-eight of these years fall within the years 1667–1835 (Fig. 2). This means that the time series leaves a number of gaps of several years, for which no data is available. During the years from 1679 to 1720 only 2 years (1700 and 1706) of data are available. Judging from the available data for the 1670s and 1700s though, it seems fair to assume that the period in between was marked by good catches. A similar gap occurs between 1777 and 1817, where only data for 1801 have been preserved. However, as mentioned in Section 2, anecdotal evidence supports the notion that the herring fisheries were poor during the last decades of the 18th century, while herring occurred in great numbers in the Limfjord from 1800 onwards.

This means that until 1830, we can observe two phases of very large catches of herring. Moreover, during the 1810s and 1820s, the total removal was larger than at any time since. In 1830, the fishery of this stock, known as the *Aalborgsild*, collapsed and herring was caught at a level of less than 1000 tonnes until the second decade of the 20th century. The 20th century saw periods of larger herring catches peaking at 4000 and 6000 tonnes in the 1920s and 1960s, respectively. The 20th century herring catches are likely to be taken from populations which immigrated after the North Sea breach of 1825, whereas it is not known if the old Aalborgsild was still present in the 20th century catch statistics.

Archival research uncovered two data series of CPUE for herring caught with pound net in the Limfjord covering the years 1757–1781 (Fig. 3) and 1812–1832 (Fig. 4). We applied linear regression and scatterplot visualizations to these catch and effort data and investigated whether variations in catches were due to differences in fishing effort. We also evaluated whether the catch data from these individual fishermen co-varied with those for the entire Limfjord. During 1757–1781, A. Pallesen's catches were significantly higher in years when he deployed more nets ($R^2 = 0.29$; $P = 0.0033$; Fig. 5); catches also tended to be higher when the fishing season was longer ($R^2 = 0.07$; $P = 0.11$). However, the annual catch rates by A. Pallesen, expressed as CPUE (nos. of herring caught/nos. of nets), did not co-vary with the total landings in Limfjord ($P > 0.05$). This may be due to the small number of years when total landings data were available during this period ($N = 9$) or factors affecting landings by other fishermen in the Limfjord.

The second period when CPUE indices were available overlaps the period when the herring fishery collapsed. The collapse is seen in both time series, and there is a significant correlation between the CPUE and total landings series ($R^2 = 0.50$; $P = 0.0013$; Fig. 6). Especially the coinciding collapse of CPUE and total removals from 1829 to 1830 is striking, and the falling total catches in these years are reflected in rising prices for herring exported from Aalborg (Fig. 7). The coincident declines in Peder Kold's CPUE and the total landings in the Lim-

Fig. 3. Catch of herring per pound net by farmer-fisher Anders Pallesen each spring during 1757–1781.

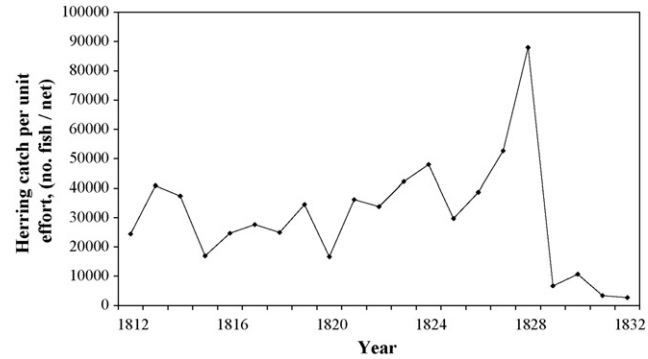

Fig. 4. Catch of herring per pound net by the merchant and fisher, Peder Kold in the Nibe area (1812–1832) during spring (KB. Beck. Add. 314a–b. fol.).

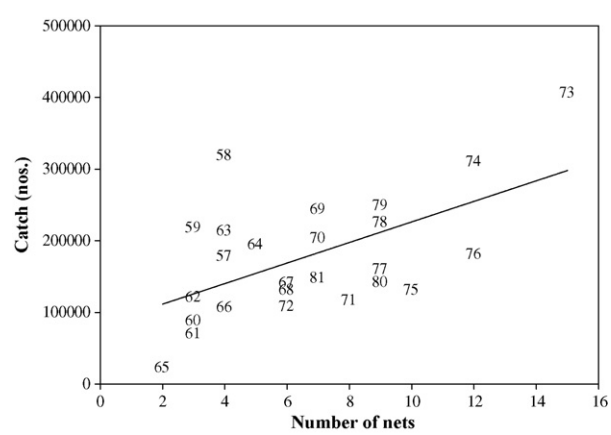

Fig. 5. Interannual variation in the numbers of herring caught by fisher Anders Pallesen and the number of nets which he deployed in the years 1757–1781 ($y = 14350x + 82823$; $R^2 = 0.29$; $P = 0.0033$; $N = 25$). Symbols on the figure represent years in the 1700s.

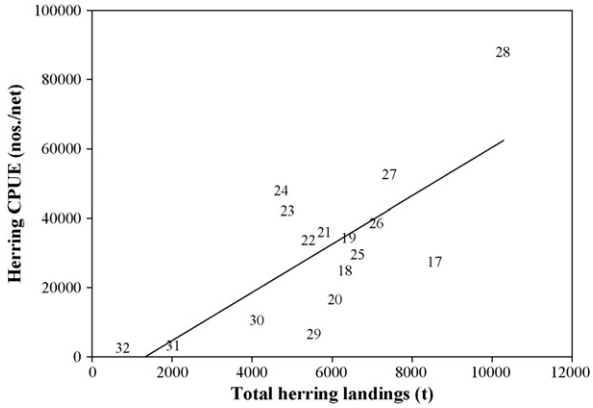

Fig. 6. The relationship between the interannual variation in herring catch rate in Nibe area as estimated by merchant and fisher Peder Kold (CPUE; numbers of herring caught per net) and the total landings of herring in Limfjord by all fishermen during 1817–1832 ($y = 6.96x - 9214$; $R^2 = 0.50$; $P = 0.0013$; $N = 21$). Symbols in the figure represent years in the 1800s.

fjord indicates that the collapse in the fishery was due to a sharp drop in herring abundance, rather than a drop in fishing effort.

Even for the large quantities caught prior to 1830 the total fishing effort was dependent on a limited number of technologies such as pound nets, beach seines and gill nets. Since these techniques all remained unchanged from the 17th century until the 1850s no technological innovation took place over this very long time span.

For the pound net fisheries in Nibe during 1752–1862, the number of nets in use ranged from 400 to 700 during the 18th century (Fig. 8). In the 1820s more than 800 nets were used, while from the 1830s onwards the fishing intensity was drastically reduced to less than 300. We observed a similar tendency for the beach seine fishery at Løgstør (Fig. 9) and the gill net fishery at Kjær district from 1812 to 1830 (Fig. 10). This pattern coincides with the record high total production, but the scarcity of matching years, have not allowed for statistical testing of this relationship. With regards to the beach seine fisheries at Kjær (Fig. 11) and Gjøl (Fig. 12) no increase in effort was found in the first decades of the 19th century, possibly because the number of licences was already fully exploited.

In the years 1828–1832 all records show that the fishing effort dropped significantly, and in the case of both the gill net and

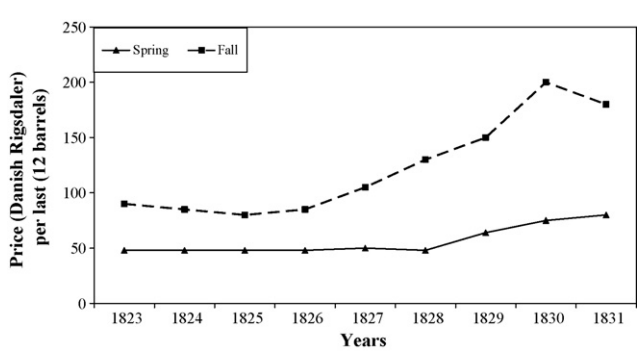

Fig. 7. The mean seasonal market price in Aalborg for Limfjord herring from 1823 to 1831 (Christensen, 1832, p. 144).

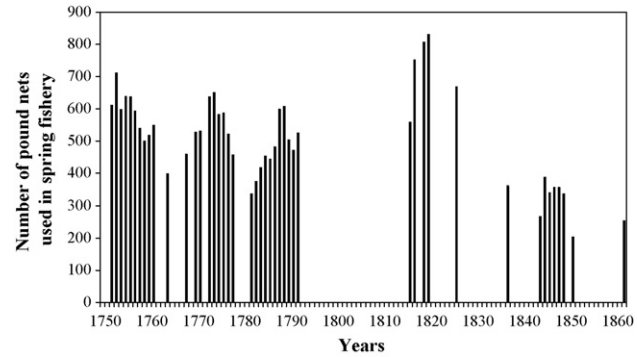

Fig. 8. The number of pound nets used in spring fishery based on existing annual reports by the town bailiff (1752–1862). For years when no data source existed, the space was left blank in the figure. Data exist only for the Nørlå ground for 1816 and 1826; for the year 1862 the data covers the entire Limfjorden (LA.Bo.D.351; LA.Bo.D.352; RA.Rtk.2426.211–213; RA.Rtk.2425.310; LA.B3.1565; RA.IL.DS, 1848–1850 and 1851–1865; Andersen, 1870, pp. 330–336).

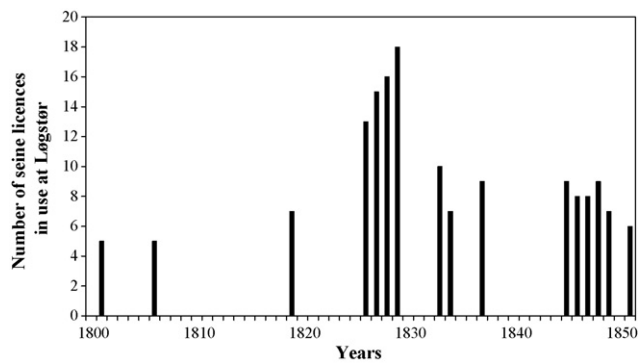

Fig. 9. The development in fishing intensity in the beach seine fishery for herring near the town of Løgstør (Begtrup, 1810, pp. 287 and 379; KB. Collin. Krøyer. 55–56; RA.IL.DS, 1848–1850 and 1851–1865; RA.Rtk.252.276; RA.Rtk.2426.215). Note: For years when no data source existed, the space was left blank in the figure.

beach seine fishery at Kjær the fishery came to a complete stop in the late 1830s (Figs. 10 and 11).

Overall, the reconstruction of the herring fishery has documented the collapse of the herring fishery in the Limfjord in the late 1820s. We observed a marked increase in total catch and

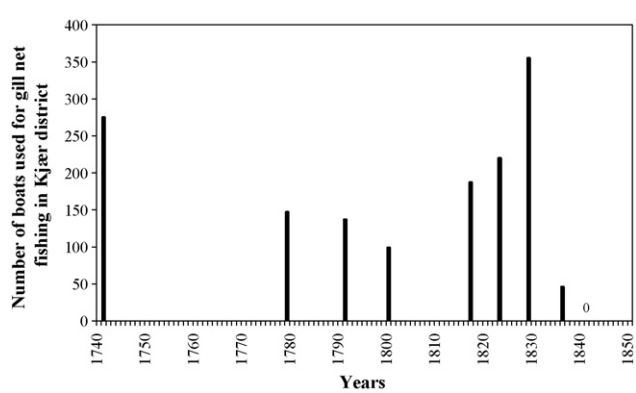

Fig. 10. The number of boats as indicative of the intensity of the gill net fishery from the Kjær district (1741–1841) (Rasmussen, 1968; LA.B31E.268).

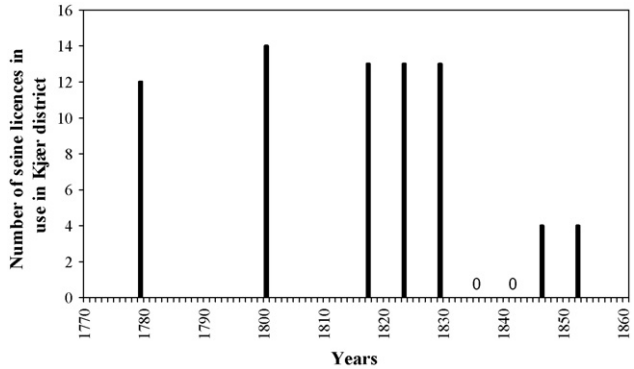

Fig. 11. The number of beach seine licences issued for fishing herring in Kjær district (1779–1852). In the 1830s no teams fished with seines in Kjær district, and in the 1840s, just four seines were in use (LA.B31E.268). Note: For years when no data source existed, the space was left blank in the figure.

CPUE in the years prior to 1828 followed by a drastic decline in 1829 and falling total catches in the following years. In 1834, the export of salted herring to foreign countries ceased while the domestic trade had disappeared in 1838.

The fishing effort measured as pound nets in active use was decimated by 50% in 1837, the beach seine fishery diminished to one-tenth of the previous level by 1840, while the gill net fishery came to a complete halt in 1841.

3.2. Eel

For the Limfjord eel fishery the archival material is less abundant than in the case of the herring fishery. Therefore, it was not possible to reconstruct the total catch of eel prior to the advent of 20th century statistics. For the years 1801–1845, data for the total export from Aalborg was reconstructed (Fig. 13). According to this time series, the export of eel decreased by more than 50% in the years after 1825, and only by 1841 was the level of 1825 reached again (Fig. 14).

The fishing effort was reconstructed for the pulse seine fishery (Fig. 13). In spite of interannual variations the effort increased during 1794–1826 followed by a drastic decline in 1827. The intensity of the pre-1826 years was not reached again until 1841.

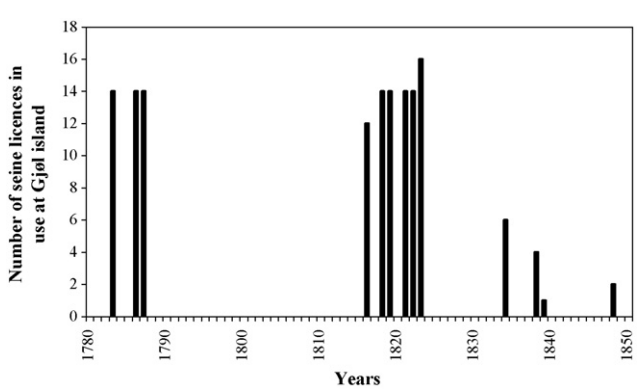

Fig. 12. The number of beach seine licences issued for fishing herring from the island Gjøl (1783–1848) (RA.Rtk.2426.211–215; RA.Rtk.2425.310; RA.IL.DS, 1848–1850). Note: For years when no data source existed, the space was left blank in the figure.

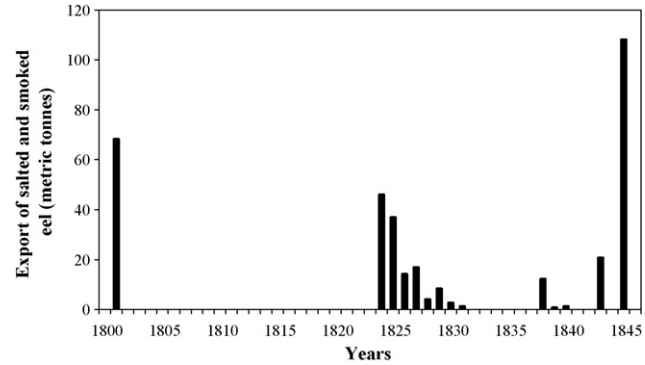

Fig. 13. Exports of salted and smoked eel from the Limfjord area through Aalborg (Begtrup, 1810; Christensen, 1832; *Statistisk Tabelværk*, 1838–1843 and 1845).

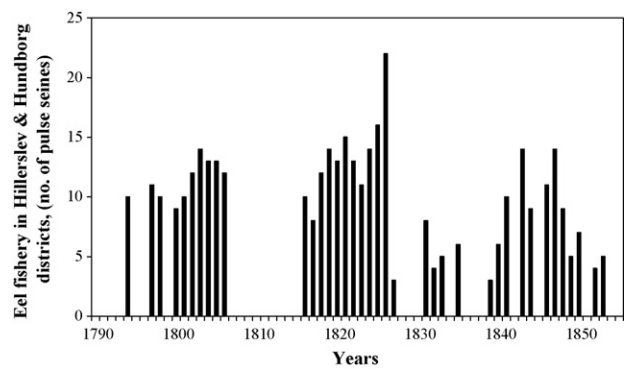

Fig. 14. The number of pulse seines being used for eel fishing in Hillerslev and Hundborg districts in the northwestern parts of the Limfjorden (1794–1853) (RA.Rtk.2426.212–15; LA.B2.396; LA.B33.336).

The number of data points was not sufficient for testing for correlation between landings and effort.

3.3. Whitefish

The archival material enabled a reconstruction of the pound net fishery for whitefish, the third major fishery in the Limfjord during this period. The total catch of whitefish in the fjord cannot be estimated, but the CPUE (catch in numbers of fish per pound net) was reconstructed for the years 1812–1929 (Fig. 15). Until 1824 there was a rising intensity, which dropped again by 1826. Following a very low fishing intensity in 1829 the pound net fishery for whitefish disappeared altogether. The catch rates varied interannually, but the year of 1829 was an absolute minimum before the fish seems to have gone locally extinct. Contemporary testimonies in local newspapers describe how whitefish and other fish accustomed to brackish water fled the salt water intrusion in these years.

4. Discussion

From the point of view of historical ecology the Limfjord fisheries form an interesting case study. For centuries, central authorities have shown a strong interest in the Limfjord fisheries. The results of this study show that in relation to the available fish-

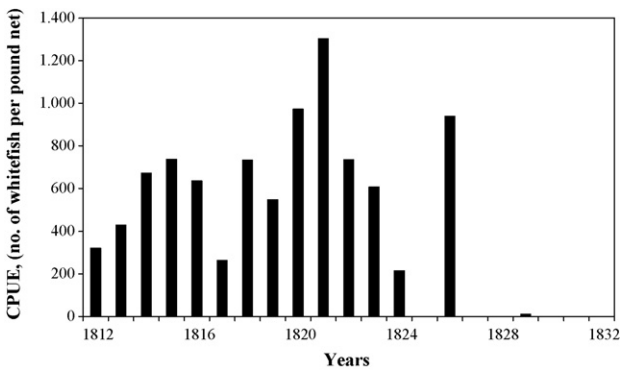

Fig. 15. The number of whitefish caught per pound net in the sites at Østerild, Tømmerby Fjord, Mellem Fjord and Hovsør Port. No data sources exist for 1825, 1826–1827, whereas from 1830 to 1832 the pound net fishery for whitefish were recorded to have been unsuccessful altogether (RA.Rtk.2426.211 and 214).

ing technology the Limfjord was fully commercially exploited at least from the end of the 17th century. This is evident from the tax register of the entire Limfjord fisheries drawn up in the 1690s, as well as from the considerable foreign export of salted herring. In this low technology period, when nets were made of hemp and no motorization of trawling or propulsion had been introduced, the herring catches in the Limfjord were larger than the 20th century herring catches in the area.

This study documents the effect on fish of the ecological regime shift from a brackish to a salt water environment following the North Sea breach of Agger Tange in 1825. Within very few years of the salt water intrusion, the species composition in the Limfjord changed dramatically. With regard to the whitefish fishery, we have documented a clear connection between the regime shift and the disappearance of the whitefish. We have also observed a sharp decline in the catch and effort in the eel fishery between 1825 and 1840, which is a likely consequence of the increase in salinity in the Limfjord waters.

In the decades after the North Sea breach of 1825 a number of other species became commercially important. Thus, in the first fisheries statistics of the 1860s plaice feature prominently, while cod, oyster and lobster became a frequent catch as well (Andersen, 1866). Hence the hydrographic event of 1825 was detrimental to some species either permanently (whitefish) or temporarily (eel), and beneficial to others (plaice, cod, oyster and lobster).

4.1. Herring

The largest fishery in the brackish period of the Limfjord though, was the herring fishery. We have documented the collapse from 1829 of a fishery, which for most of the 1820s had witnessed a larger total output than ever before or since. We also found evidence that the herring fishery was of comparable large scale in the first half of the 18th century followed by a period in the latter half of the 18th century, when catch rates, total output as well as fishing intensity all suggest that many fewer herring were present in the Limfjord from ca. 1760 to 1800. However, since the technology applied in the 18th and 19th centuries was radically different from modern fishing technology, it is difficult to see to what extent the historical abundance of herring in the Limfjord is reflected in total catch levels. With regards to the Newfoundland cod fisheries, similar historical records have been used in a reconstruction of the stock abundance of cod stretching back to the 16th century (Rose, 2004). Such an analysis however requires knowledge of present day levels of stock abundance for the Limfjord, which do not exist.

The timing of the North Sea breach of Agger Tange (1825) and the disappearance of the herring (after 1829) suggests that the two incidents might be interconnected. Salinity did increase after the North Sea breach (Penney, 1992; Christensen et al., 2004), and in much historical literature on the Limfjord herring fisheries, this event has been perceived as the likely reason behind the disappearance of the herring (Matthiessen, 1960; Christensen, 1977; Wohlfahrt, 1994; Rasmussen, 1997; Holm, 1999). However, since herring tolerate a wide range of salinities, it seems unlikely that this species would have been directly (i.e., physiologically) stressed by an *increase* in salinity. Furthermore, there is a historical precedent to the 1825 breach event: a large intrusion of North Sea salt water occurred in 1624. This breach occurred during a period of rather poor herring fishing, which did not further deteriorate in the aftermath of 1624 (Christensen, 1977).

There was also speculation after the 1825 breach that benthic conditions in the Limfjord changed and that this led to the herring collapse. In the decades following the breach, several local fishermen as well as natural historians investigated the fjord. Some reports claimed that the spawning conditions for herring were altered, causing reproductive problems. The Nibe merchant and fisher, Peder Kold, published an article in the regional newspaper, *Aalborg Stiftstidende og Adresse-Avis*, where he argued that a change in salinity led to a change in benthic ecology. This ecological change included increases in the amount of benthic plants suited to the new saline conditions and a decrease in the amount of brackish plants (KB. Beck. Add. 314c. fol.). Other commentators such as Nibe fisher Christian Westergaard were more skeptical claiming that the benthic fauna was the same in 1829 as it had been for decades, in the sense that the benthic ecology was in an ongoing process of growth, decay and death, but rarely at the same time on all spawning grounds, and only causing problems in very short intervals of time (Feddersen, 1878). Given the limited ecological information available for the time period it is difficult to assess the importance of these changes on herring ecology.

The reason for the collapse itself does not appear therefore in an obvious way related to the 1825 salt water intrusion. We therefore examine the potential role of fishing on the herring decline.

Fishing pressure was mentioned by contemporaries as a likely cause of the decimation of the herring stocks. Around 1830 for instance the Nibe fisher, Christian Westergaard suggested that, 'The number of seines have increased, without any regulation or restraints regarding their length, whereby at Løgstør they have a length, so they could reach from one shore to the other and thereby meeting and stopping everything trying to get past' (Feddersen, 1878). As observed in the sections on fishing effort, the years 1800–1830 did witness an overall rise in fishing effort,

also for the Løgstør seine fishery. The new seines were used in places never before exploited in this way, and judging from the immediate success of this strategy, it appeared that something of a 'silver mine' had opened up: in the late 1820s, 3800 tonnes, or more than a third of the total output of the Limfjord, came from Løgstør (RA.Rtk.252.276).

Around 1840 natural historian, Henrick Beck, who had conducted several investigations of the fjord, developed a theory of the collapse in line with Westergaard's thoughts. Beck wrote to the town bailiff in Nibe: 'I believe to have proven that the cause for this, since 1824, steady diminishment of the herring fry, bears no link to the Limfjord's connection with the North Sea through the Agger channel from this time on, but is a direct consequence of the destruction of the herring fry' (LA.B3.1579). Henrick Beck explains how the seines were filled with larvae: '. . .Not seldom have I seen entire barrels filled with larvae, each containing millions of herring youngsters, after a single pull thrown out useless on the beach.' According to Beck, the seine fisheries from Løgstør really took off from 1822. Huge seines were dragged along the bottom in the shallow waters, which, according to several accounts, was right on top of the spawning beds of the herring. As the diamond shaped seines were dragged through the water, the meshes in the net tightened to such an extent that the original shape became constricted, thereby transforming the heavy seine into a tightly knit curtain, capturing everything in its way (LA.B3.1579). These reports indicate that fishing intensity and mortality was increasing not only on adults, but also on juveniles, larvae and eggs. Moreover, fishing was now being conducted in previously unexploited parts of the Limfjord and the fishing practices were damaging reproductive output, thus eroding the potential production of new herring. Hence the Limfjord herring was being impacted by fishing activity at both ends of its life history. The cumulative effects of these impacts were apparently unsustainable and probably a major factor leading to the collapse.

An alternative hypothesis for the collapse of the Limfjord herring could be due to changes in the distribution and migration of herring in the North Sea-Skagerrak-Kattegat area, including a complete failure to migrate into the Limfjord. The influence of climate variability and change on the distribution and abundance of pelagic fish stocks has received a growing amount of attention in recent years, and studies have shown that European herring, anchovy and sardine fisheries to some extent co-fluctuate at multi-decadal scales over several centuries (Alheit and Hagen, 1997). Perhaps, most famously of these, the Bohuslän herring fisheries exhibit clear phases of very large fisheries during the last thousand years, the so-called Bohuslän herring periods (Ljungman, 1879).

However, the fluctuations observed in the Limfjord herring fisheries do not correspond directly to the fluctuations observed on a European or regional Bohuslän level. Although there is evidence that fishing activity increased along the neighbouring Kattegat coast of Jutland in the 1830s, it is not known whether this development represented a change in herring migration patterns, an increase in herring abundance in the Kattegat (e.g., due to a series of strong year classes) or a change in fishing patterns (e.g., redistribution of fishing effort from other areas, or deployment of new effort in a new area). However, an investigation in 1840 into the new Kattegat herring fisheries along the Jutland coast suggested that the Limfjord fishers were pushed towards the open sea as a consequence of the herring collapse rather than being pulled there by new opportunities (KB. Collin. Krøyer. vol. III). This evidence suggests that the eastern Kattegat herring fishery in the 1830s developed due to a redistribution of existing fishing effort, which had become superfluous after the collapse of the Limfjord herring populations.

4.2. Eel

The fishing intensity as well as the export figures both display a drastic decline in the period from 1826 to 1840. No CPUE data were available to check whether this was caused by a declining abundance of eel. Notably, those eel fishermen who remained active and tried to continue to catch eel following the salt water intrusion observed many jellyfish (precise taxonomic name not known), in the Limfjord in 1827 and several subsequent years. The species of jellyfish present at the time is not known; however, *Aurelia aurata* is the dominant gelatinous predator in the Limfjord and in other waters near Denmark in summer in recent years (Hansson et al., 2005; Lynam et al., 2005) and may also have been the dominant species in the 1820s. In the report of 1827, the district bailiff of Hillerslev and Hundborg districts mentioned that invading jellyfish, obstructed that year's fishery (LA.B2.396). The jellyfish took up so much space that the seines could not be drawn through the water, because the jellyfish would weigh down and destroy the gear. Therefore, the fishers coming from the western end of the fjord near Agger Tange, left the grounds at Hillerslev and Hundborg again after only a few days of fishing. Around 1840 it was mentioned as a common feature of the eel fishery that jellyfish obstructed the fishery, so this was very likely a lasting side effect of the new opening to the North Sea at the western end of the Limfjord caused by the breaching of the isthmus at Agger in 1825 (Diørup, 1842, pp. 481–482).

The eel fishery seems to have overcome the crisis during the 1850s because landings eventually partly recovered; eel supported commercial fishing in the Limfjord until the early 1980s. The reasons for the reappearance of the eel during the 1850s and the recovery of the fishery are unclear. One reason could have been a major technological innovation, namely the *snurrevodsteknik*, which in English became known as the *Danish seine*. The Danish seine was invented in the Limfjord in 1848 by farmer-fisher, Jens Væver. His objective was to increase catches of the population of plaice, which was booming in the decades after the breach of 1825. He discovered that if he replaced one of the two boats used in the pulse seine fishery with an anchor, he would have a firm grip of where he was fishing. After throwing the anchor he would row in a circle laying out the seine and after returning to the anchor he could drag the nets. When using the traditional pulse seine technique pulling the seines often meant that the boat would be pulled towards the seine rather than dragging the seine through the water. With the new technique the boat was anchored, so that pulling the seine really meant dragging the seine through the water towards the boat. Another benefit was that the Danish seine could be operated by only one boat and two

fishers instead of two boats and four fishers (Hjorth Rasmussen, 1991).

While invented for catching plaice, the technique immediately spread to the eel fishery. In 1857, the first fishery law for the Limfjord was implemented creating simple statistics and in 1859, 462 people were fishing mainly for eel and plaice with purse seines while 118 fishers fished with Danish seines (Andersen, 1870). However, over the next 20 years the Danish seine fishery for eel in the Limfjord expanded rapidly and in 1880 no less than 308 Danish seines were in use, while virtually no one used the older type of seine (Andersen, 1882, p. 91). The use of the Danish seine in the eel fishery subsequently spread to the rest of Denmark, and by the end of the 19th century the technique was employed in the deep sea plaice fisheries throughout the North Sea and Skagerrak. One could say that the challenges posed by the Limfjord breach presents a structural background for the invention of this new technique, which in the 21st century is still used in flatfish fisheries around the world.

5. Conclusion

We have presented a reconstruction of the scale of the commercially important fisheries in the Limfjord from ca. 1667 to 1860. The Limfjord estuary was commercially exploited intensively since at least the late 17th century. Especially for the herring fisheries the archival data allowed for a reconstruction and standardization into metric tonnes of the total removal of herring from the Limfjord supplemented by time series of effort and CPUE for individual fishers. The result revealed two periods, the first half of the 18th century and the 1810s and 1820s, when the size of the herring fishery was comparable to the size of any modern 20th century catch of herring in the Limfjord. Moreover, the fluctuations in fishing effort and catches in these periods seem to reflect changes in stock size. Especially the collapse of the herring fishery from 1829 onwards was spectacular and well documented. A major factor contributing to this collapse is the impact of fishing on adults, juveniles, larvae and eggs. The North Sea breach of Agger Tange in 1825 had profound impacts on other Limfjord fisheries. These include, the disappearance of the whitefish, and a 15-year long crisis for the eel fisheries. The study of the Limfjord fisheries provides an example of how historical ecology may help 'shift the baseline' by revealing the previous existence of a marine ecosystem very different from that which is known from contemporary ecological research.

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Appendix A. Archival material

Regional State Archive, Landsarkivet, Viborg, Denmark (LA)

LA.Bo.D.351	Aalborghus m. fl. Amters arkiv. Inkvisitionsforretninger over Limfjordsfiskeriet (1751–1760)
LA.Bo.D.352	Aalborghus m. fl. Amters arkiv. Inkvisitionsforretninger over Limfjordsfiskeriet (1761–1793)
LA.Bo.D.382	Aalborghus m. fl. Amters arkiv. Blandede Sager
LA.B2.396	Thisted amtsarkiv. Journalsager 'K'. Fiskerisager, 1805–1840
LA.B3.1565	Aalborg amtsarkiv. Synsforretninger over Limfjordsfiskeriet i henhold til Forordning, af 15/12-1750, §26 (1820–1824)
LA.B3.1579	Aalborg amtsarkiv, Varia
LA.B298.505	Aalborg toldarkiv. Koncepter til generalekstrakter år 1825–1838
LA.B298.672	Aalborg toldarkiv, konsumtionsekstrakter. 1831–1838
LA.B31E.268	Kær og Hvetbo Herreders arkiv. Synsforretninger over Fiskeredskaber 1779–1800-10-54, og sognefogedforretninger om sildefiskeriet, 1832–1841
LA.B33.336	Thisted Byfogedarkiv. Indberetning om ålefiskeri, The Limfjord, 1839–1853
LA.B43.302	Sallingland herreders arkiv 1688. Synsforretninger over puls og sildevåder
LA.B78A.502	Hjerm og Ginding Herreders arkiv 1690. Synsforretninger over Pulsvåder i The Limfjord, 1751–1781, 1818–1831

The Manuscript Collection of the Royal Library, Copenhagen, Denmark (KB)

KB. Beck. Add. 314–319	H. Becks Samlinger til The Limfjords topografi og Historie
KB. Collinske Samlinger (KB. Collin. Krøyer) 294.4	bd.I–III, H.N. Krøyer: De Danske Fiskeriers Historie

Public records office, Rigsarkivet, Copenhagen, Denmark (RA)

RA.Rentekammeret (Rtk).2426.211	Diverse dokumenter vedr. Limfjordsfiskeriet
RA.Rtk.2426.212	Indkomne breve vedr. limfjordsfiskeriet, 1815–1818
RA.Rtk.2426.213	Indkomne breve vedr. limfjordsfiskeriet, 1819–1823
RA.Rtk.2426.214	Indkomne breve vedr. limfjordsfiskeriet, 1824–1830
RA.Rtk.2426.215	Indkomne breve vedrørende limfjordsfiskeriet, 1831–1840
RA.Rtk.235.18	Indberetninger til Finansraad Oeder, 1771
RA.Rtk.2425.310	Journalsager ang. Limfjordsfiskeriet (1786–1811)
RA.Rtk.252.276	Sagen angående sildefiskeriet ved Løgstør, 1825–1841

RA.IL.DS (Rigsarkivet, Ministry of interior, agricultural office) Indenrigsministeriet, Landvæsenkontoret, domænesager), 1848–1850.

RA.IL.DS (Rigsarkivet, Ministry of interior, agricultural office) Indenrigsministeriet, Landvæsenkontoret, domænesager), 1851–1865.

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