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Climbing back up what slippery slope?

Dynamics of the European eel stock and its management in historical perspective.

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Abstract

Few fish stocks are as influenced by (intentional and inadvertent) human impacts as the European eel, all across the continent. The dynamics of this stock, however, are poorly understood - neither the causes of the historically low abundance, nor minimal protection levels are beyond discussion. Rather than analysing contemporary processes, this paper turns back in time - two centuries or more - unravelling historical abundances and distribution patterns; reviewing historical actions and objectives; and discussing technical developments and scientific advice - picturing the slippery slope the eel stock has come down from.

The first claim, that the continental stock was in decline, dates from the early 1800s; stock-enhancement actions were initiated shortly after. Diffuse objectives, technical innovations, eternal optimism and - above all - no quantification impede the exact evaluation of historical reports. After 1950, when quantification improved, a slow but consistent decline was observed, but it is only two decades after the crash in glass eel recruitment (in 1980), that protection plans addressed the bad status of the stock. A slippery slope, full of pitfalls - and yet, we now observe several years of increasing recruitment.

Introduction

The population of the European eel *Anguilla anguilla* (L.) is in a deplorable state. In this article, we investigate the dynamics of the stock and its management in historical perspective.

The European eel is exploited in nearly all countries in Europe, and in the Mediterranean parts of Africa and Asia (Dekker 2003a). It occurs in rivers, lakes, lagoons and estuaries, as well as coastal areas. It is a main target of the inland fisheries in Europe. According to FAO (2014), eel constituted 7.5% of the total landings from inland waters in 1950, diminishing to 1.5% in 2010. Since eel is generally 3 to 5 times higher valued than other freshwater fish (FAO 2014; export prices), this corresponds to approximately 5-30% of the landings value. For earlier periods, no quantitative information is available; most likely, the eel was even more important (Radcliffe 1921).

The population of the eel is considered critically endangered (Jacoby and Gollock, 2014). In recent decades, the yield from eel fisheries has gradually declined to approximately 10 % of the quantity caught just half a century ago (Dekker 2003b; ICES 2013; Figure 1). Since 1980, recruitment of young eel from the ocean has fallen to 1-10 % of former levels (Moriarty 1990; Dekker 2000; ICES 2014; Figure 2). Additionally, current anthropogenic mortality is at an unsustainably high (or unknown) level in most of the distribution area (ICES 2013). Neither the causes of the historical low abundance, nor minimal protection levels are currently beyond discussion (ICES 2014). In 1999, ICES (2000) advised “that a recovery plan should be implemented for the eel stock and that the fishing mortality be reduced to the lowest possible level until such a plan is agreed upon and implemented”. After lengthy discussions (Dekker 2008), the European Union adopted a stock recovery plan (Anonymous 2007), which was implemented from 2009 onwards.

In this article, we investigate the stock dynamics in historical times. Noting that the dynamics of the stock are not well known, and certainly not understood – in the current time frame, and the more so in the historical periods that we will discuss – we do not aspire to compile a quantified assessment of the past status and trends, since that is simply unachievable. Instead, we aim at a critical review of what has been published in the past centuries, how one has looked upon the status of the stock, and what management actions were pursued. Analysing the slippery slope the eel stock has come down from, and how that has been perceived, may improve our understanding of stock dynamics, of how the current depleted state eventually arose and what pitfalls can be identified that were troubling past management of the stock and fisheries.

We structure our discussion into four themes: the status of the stock through times and contemporary views on that; the discussions on the reproduction of the eel; the contrast between a wild stock and a cultured crop; and the scientific advice on management. Dekker & Beaulaton (in press) discussed the history of restocking of young eels in habitats/areas of low abundance; those results will be included here as a fifth theme where relevant. For each theme, we will also explore how it manifests itself in modern time, but that is in no way meant to be a thorough review of current literature.

Historical information sources

Noël (1815), Yarrell (1836), Radcliffe (1921) and Koch (1925) earlier discussed historical views on eel biology, mythical aspects, religious importance, preservation, culinary qualities, and the technical and legal developments of eel fisheries across Europe – but remarkably little information is given by these authors on (trends in) abundance and fishing yields; management of the stock and fisheries is not discussed at all. We will complement those studies, focusing on stock dynamics and the impact of (intentional and inadvertent) human actions.

The eel population constitutes the most widespread, exploited fish stock in Europe. The wide distribution area, however, is fragmented among thousands of river catchments, with little or no natural interaction between them (Dekker 2000). Until 2007, management of eel fisheries and their ecosystems has traditionally operated only on a localised scale (Dekker 2008). Furthermore, the small scale of most eel fishing in rural areas has complicated the collection of essential stock-wide data, such as total fishing yield (Dekker 2003b). Although the sum of all local fisheries justifies adequate data collection, each separate local situation has long been considered negligibly small (Dekker 2008), and essential data were (and still are; ICES 2014) incomplete or absent. It is only from approximately 1950 onwards, that a quantified reconstruction of stock dynamics is available (Dekker 2004a). In this article, our aim is to discuss a much longer time span – two centuries or more – for which there is definitely no information allowing a quantitative reconstruction of any kind. Consequently, we will build our reconstruction on historical sources discussing abundance and anecdotal information, and elaborate on quantitative aspects where possible.

Historical stock abundance and trends

The earliest references to stock abundance and trends we have found are Anonymous (1865) and Anonymous (1867), reporting that 'the eels, that feed us, have almost disappeared from our small waters', respectively 'Since 40 years, factories have raised their weirs to such an extent that small eels can no longer overcome these obstacles and migrate upriver'. Earlier references do not allow any quantification. However, there is one very early, major exception: the Domesday Book.

In 1085, William the Conqueror, the first Norman king of England, ordered a survey of all landholders, which was completed in 1086 (Anonymous 1086) and is now known under the name of 'Domesday Book'. His main aim was to have an inventory of all property that allowed taxation. We processed the text of the English translation (known as the Phillimore-edition, see Anonymous 1086) and checked the facsimile Latin originals (available at www.archive.org) for a few exceptional records (e.g.: Figure 4). The text lists properties and taxes, including over 600 fisheries (piscaria, piscina; Figure 3). For 225 of these, the specified tax comprises - next to a tax in cash - a number of eels (anguillae), ranging from zero to 75,000 eels per site per year

(Figure 4). In total, a tax of over 400,000 eels is listed. In addition to these, there are a small number of cases mentioning lamprey, salmon and herring, and a few weir fisheries. For the eastern (Norfolk, Suffolk and Essex) and the south-western shires (Cornwall, Devon, Somerset, Dorset and Wiltshire), separate books were compiled first (the Little Domesday Book resp. Exeter Domesday Book), and the main records in Domesday Book appear to be only a condensed summary of these – mentioning fisheries to be taxed, but hardly specifying any eel.

In 150 of the records, the eel catch is directly linked to the presence of a mill (molinus), that is: a water mill. The larger eel fisheries for which no mill is mentioned appear to be concentrated along a line parallel to the north-eastern coast (Figure 3), often at the border between alluvial plains and higher grounds (Darby 1977). The spatial association between fisheries with and without a tax in eel, in particular the absence of both in the north-west where much less watermills occurred (Darby 1977), suggests that most of the fisheries for which no mill is listed probably were nevertheless located at watermills, and likely were targeting eel - but paid their tax in cash rather than in kind. If so, the number of eel fishing sites would have been more than double the number of explicit eel-records.

It is not known what percentage of the catch was taxed (Darby 1977), and it is unclear what size of eel was targeted. Eel bucks at weirs and mill dams, often constructed from braided willow twigs, would predominantly select the silver eels migrating down the river. Fisheries on yellow eel, using eel spears or other movable gears, were probably hard to attest, not allowing taxation. Though spear and other fisheries undoubtedly occurred, we have no means to quantify their occurrence.

All in all, the Domesday Book provides evidence for a tax in kind of over 400 000 eels in 225 fisheries and another 375 fisheries potentially catching eel too. Noting that quantities of eel were specified in numbers, we consider it most likely that large, female silver eel was implied, of approximately 500 gr each – not males of less than 100 gr each. If so, the 225 fisheries and 400 000 eels would represent a tax in kind of 200 tonnes. The tax in cash from the remaining 375 fisheries - if making the same average catch per mill - would have represented another

333 tonnes. That suggests a total catch in the order of hundreds of tonnes, far above today's fisheries of 33 t yellow eel and 6 t silver eel (ICES 2013).

The watermill fisheries described in the Domesday Book were not unique in Europe. Comparable cases have been described in France (as in the Seine and Marne rivers. Lecomte-Schmitt, 2009) and for some, the volume of the catch is documented (e.g.: 426 pound of eel at Beygnac mill in the Dordogne River, France, in 1761-1762; Yéni, 2004). However, none of these studies can rival the Domesday Book in geographical coverage and consistency of the quantification.

In later centuries, there is little information allowing quantification of stock abundance and fishing yield. Reading the literature from 1086 until the 1800s and later, however, there was one recurrent issue that caught the eye: the presence of eel much further upstream than currently observed. Naismith and Knights (1993) analysed the distribution reported in the Domesday Book for the River Thames and compared that to contemporary information. Here, we document two remarkable but less quantifiable cases in central Europe: the area Danube/Elbe and the upper reaches of the River Rhine.

The natural occurrence of eel in the Danube has been a point of discussion since the 1200s. Albertus Magnus (±1200) reported that eels do not occur in the Danube, adding 'it is said, if put in, they die'. For ages, the words of Albertus Magnus have been taken as indisputable truth, but in the 1700s, Marsilius (1726) finally noted that live eels are actually observed at several places along the Danube. Windrington (1842), however, observed that live eels imported from other drainage areas to the market in Vienna sometimes escaped into the river. Kerschner (1956) even reported that, for centuries, live transport by horse carts to the market in Linz (Austria) occurred regularly. Remarkably, he mentions the River Moldau (Czech: *Vltava)*, a tributary of the Elbe (North Sea drainage, over 1000 km from the river mouth) as the source. Apparently, the eel stock in the River Moldau, in the swamps between Schwarzbach and Friedberg (now hydropower reservoir Lipno) was abundant enough to allow a considerable fishery and export, continuing for centuries. Today's landings statistics (FAO 2014) for eel for the whole of Czech Republic amount less than 20 tonnes per year, of which far less than 1 t is exported.

In the upper reaches of the River Rhine in Germany, a comparable case occurs: masses of migrating eel had been observed at the waterfall in Schaffhausen (47.678°N 8.616°E), which were considered as a source for restocking into the Danube (Anonymous 1884). The abundance of eel in Baden (just north of Basel) was that high that local people were aware of the weather conditions triggering eel migration ("*Mit den ersten Gewittern kommen die Aale*"; Anonymous 1887). Though neither of these two anecdotes allows quantification, they give the impression of very high abundance. Today's catch for the whole region Baden-Württemberg amounts 9 t (ICES 2013). Nowadays, it seems rather unlikely that anyone in Baden can learn about eel migration from local observations, and the River Rhine eel stock is supplemented with, rather than being a source of young eels.

Though this type of anecdotal information is hard to quantify, more direct evidence from archaeological remains - though not really quantifying abundance either - does corroborate the far-upriver distribution (Kettle et al. 2008). Later publications on upriver migration, discussing eel-ladders (Benecke 1884) or assisted migration (Adickes 1888), often focus on migration obstacles in the lower stretches of the rivers. Apparently, one had already given up on the upper regions (Walter 1910). How was the eel stock affected by the loss of upstream habitats, where females could have typically dominated (Syrski 1874; Lasne et al. 2008)? Did the accumulation in more downstream habitats favour a shift towards the production of more males, or enable the fisheries?

In the mid-1800s, interest in inland fisheries and fish culture increased considerably, especially in relation to the artificial reproduction of fish – which we will discuss below. This gave rise to a vast body of literature on eel, and some publications do discuss stock abundance. However, there is a remarkable duality in the views expressed. On the one hand, there are some publications that explicitly discuss the abundance (Anonymous 1865; Anonymous 1867; Adickes 1888), and most of these either indicate a decline or discuss the low abundance. On the other hand, there are the publications discussing mitigation measures, predominantly restocking (Dekker and Beaulaton, in press; all the references therein) and fish ladders (Benecke 1884; Anonymous 1888). Especially the publications on mitigation measures are extremely optimistic, ignoring negative side-effects and the finitude of their resources. Coste (1849), for instance, considers that the abundance of glass eel in France allows stocking of all waters of the world ("*peupler toutes les eaux de la terre*"). Fishermen in the source areas worrying about the limits to their resources are not paid any attention (Millet 1828; Le Clerc 1935), while for example Elsner (1899), Schmidt (1906) and Dąbrowski (1952) consider their resources to be infinite. In times of technical development and growing economies, a golden future is more easily sold than a realistic view on the finiteness of the resources. Even after the deteriorating state of the stock had been first noted (EIFAC 1968), one first focused on further development; on improving fishing gear (EIFAC 1971) and restocking. This focus on the sunny side has often led to biased views or a total denial of the facts. For example, ICES (1980) concluded that "there was no evidence of a reduction in the breeding stock of eels" on the argument that "in recent times catches remained high", while the opposite was demonstrably true (Figure 1); the additional argument that "glass-eels remained plentiful" was correct, but turned false immediately after (Figure 2). Even in recent discussions, biased views still exist. For example, most studies of the potential effect of ocean and atmospheric conditions on eel recruitment (reviewed in Miller et al. 2009) - though often acknowledging that low spawner abundance might be involved in the decline - do not include an index of spawner abundance in their analysis, while estimates of the continental production of silver eel have been used as a proxy for that before (Dekker 2003b; ICES 2005, 2014). Moreover, many authors (e. g., Bilotta et al. 2011; Armitage et al. 2013; Capoccioni et al. 2014; Colombier et al. 2015) describe the relatively recent downward trend in recruitment (since 1980) as the start of the stock decline, ignoring the information on the preceding decline of the continental stock (Svärdson 1976; Dekker 2003b, 2004a,b; ICES 2014). That is: the finiteness and long-lasting decline of the continental stock remained out of sight, or the observed trends were described as local phenomena (Svärdson 1976), while the continent-wide declining yield indicated otherwise.

The eel problem – la question de l'anguille – die Aalfrage

Over the centuries, the growing human population and accumulating human pressures on fresh water habitats eventually led to a need to restore and increase fish production. In medieval times, millponds and dedicated fishponds enabled the culture of carp and other cyprinids in stagnant water (Hoffman 1995), but to our knowledge, that did not particularly involve eel. As successful as pond culture has been, its production was limited and fresh fish was predominantly reserved for the nobility and clergy. Towards the mid-1800s, however, a major breakthrough in fish culture was achieved, enabled by the development of artificial reproduction of fish (Kinsey 2006) and the contemporary development of railway networks across Europe. In 1852, a 'fish factory' was set up in Huningue, just north of Basel along the river Rhine, where millions of fish have been produced, that have been stocked into outdoor waters (Kinsey 2006). Initially, many different fish species were tried, such as perch and tench, and it was generally expected that artificial reproduction could also be applied to 'salmon and eel, et cetera' (Anonymous 1852). In the years following, millions of salmonids have been produced in Huningue indeed (Coumes 1862), but the artificial production of eel remained unsuccessful. Though the reproductive organs (e.g. Syrski 1874; Freud 1877) and the silver eel migration (Millet 1870; Benecke 1884) were intensely studied, it remained unclear where and how the eel reproduced. Frustrated by this lack of progress on this important species, the issue became to be denoted by a standard phrase: "the eel problem" (Brown Goode 1881; Tucker 1959; D'Ancona 1959; Sinha and Jones 1967; Righton et al. 2012); "die Aalfrage" (Kaumann 1878; Jacoby 1880; Hermes 1881; Lübbert 1907); "la question de l'anguille" (Schaeck 1894). Though a pragmatic approach was adopted in advocating mitigation measures (e.g., restocking – de Rivière 1841; eel ladders - von Benecke 1884), the hope to reproduce the eel artificially remained and progress on the Eel Problem was extensively and frequently discussed by many authors.

From this point onwards, three different lines of thinking developed. First, we find studies focused on the natural reproduction in the field, including studies of the morphology and physiology of the eel (e.g. Freud 1877), the location of the natural spawning location (Millet 1870; Schmidt 1906, 1922; Grassi and Calandruccio 1894; Righton et al. 2012). Secondly, there is a pragmatic line: accepting that artificial reproduction will not be easily achieved, one focuses on the redistribution of natural-born recruits to enhance the production, i.e. restocking (de Rivière 1841; Millet 1854; Dekker and Beaulaton, in press). Finally, the artificial reproduction itself has remained a still unsolved challenge (Fontaine 1936; Boëtius et al. 1962; Fontaine et al. 1964; Okamura et al. 2014).

Though these three lines focus on different aspects (academic interest - pragmatic mitigation measures - developing alternatives), even at different places (ocean – continent - indoor), the discussions are often confused and many authors expressed vague objectives. Modern studies on the oceanic phases and on artificial reproduction frequently mention the depleted state of the stock, but fail to work out the relation to their study (e.g.; van Ginneken and Maes 2005; Dirks et al. 2014; Mordenti et al. 2014; Tomkiewicz et al. 2012).

Wild versus cultured

The fisheries described above mostly targeted the wild stock in its natural habitat. Fisheries at weirs and in mill-ponds exploited new opportunities, created as an inadvertent side-effect of other anthropogenic actions (mill constructions, water management). Loss of access to up-river habitats in the larger rivers (e.g. the Rivers Elbe and Rhine discussed above) may have concentrated the stock in the lower reaches, thus potentially facilitating the fisheries downstream. In all these cases, the fisheries exploited rather than actively managed the stock. In northern Italy, however, in the lagoons near Venice, a much more active system of eel management had developed (Coste 1855), tracing back to Roman times (Ardizzone et al. 1988;

see also Aalto et al. 2015). What probably had started as a fishery on the wild stock in open lagoons, developed into a system of eel culture in heavily managed, regulated lagoons ('valli'), in which the immigration of recruits and the water quality and quantity were intricately manipulated, maximising the production of the silver eels that were exploited. When natural recruitment declined, stocks were supplemented from nearby glass eel resources on the coast, or – in more recent decades - by imports of glass eel and young yellow eel from elsewhere in Italy or from abroad. In the mid-1800s, the eel culture in the lagoons of Comacchio was considered a glorious example of how eel fisheries in Western Europe could be developed (Coste 1855).

From the mid-1800s onwards, fisheries development programmes started all over Europe, first in France, then in Germany and later in the rest of northern Europe. New habitats were created (Pouchet 1856), food competitors and predators were suppressed (von dem Borne 1889), and eel recruits were transported to areas of low abundance (de Rivière 1840; Dekker and Beaulaton, in press) or even outside the natural distribution (Haack 1877; Kokhenko 1969; Egusa 1970). From around 1970, the culture of eels in natural or artificial outdoor ponds was gradually replaced by/upgraded to indoor systems using heated, recirculated water (Kamstra 2003), though the Italian lagoons continue their traditional extensive system at the same time. Between the indoor culture and the outdoor stock, there is a frequent and diverse interaction. Nowadays, wild-caught glass eel is taken in by aquaculture facilities to seed their culture; in the 1980s, wild-caught half-grown yellow eel has been used for that purpose too. Additionally, glass eel are quarantined in indoor facilities before being restocked in outdoor waters, or grown to medium sized yellow eels before being released into the wild (Baer et al. 2011; Dekker & Beaulaton, in press). Finally, the intensive aquaculture industry contributes (financially) to management measures to protect and recover the stock (SEG 2014). Production statistics from outdoor fisheries and aquaculture are often undifferentiated or mixed up (Dekker 2003b; ICES 2005; FAO 2014). All in all, almost all variants in-between outdoor fishery on the wild stock in natural habitats, and indoor culture in recirculating systems using artificial food, exists. Since 1995, the production in indoor aquaculture effectively exceeds the fisheries production, but - 'The Eel Problem' remaining a mystery - all production still depends on the wild stock. The presence of such a wide variety of exploitation forms complicates the management of the wild stock. Moreover, restocking, extensive and intensive culture of eel have often been advocated as a complement or even as a replacement for the wild fisheries – and in that way have effectively distracted attention from the increasingly worrying status of the stock.

Science and management

Conventionally, the European eel has been considered a freshwater fish (freshwater eel, river eel, Flussaal – often set in contrast to the conger: anguille de mer, Meeraal, zeepaling). Though the unsolved 'Eel Problem' eventually has put the eel in a rather exceptional position, research and management have traditionally been embedded in the general developments of the inland fisheries. International cooperation in research and technical innovation in support of fisheries occurred as for any other freshwater fish: focused on the development of the national stocks and fisheries, often based on international exchange of scientific knowledge and expertise. For example, the concept of restocking - developed in France in the mid-1800s - spread across the continent within a decade (Dekker and Beaulaton, in press); old and new gear designs were copied from country to country (Le Clerc 1930; Schlieker 1957 in Tesch 2003; et cetera), as were processing techniques (Anonymous 1865; Forrest 1976) and transport systems (e.g., eel barges – a long-distance transport technique already used in the mid-1400s by the Dutch, that spread around when regional market supplies declined; Ypma 1962; Åklundh 1992; Nilsson 1996; Devall 1998). A notable exception to the international collaboration has been the hostile relationships between the French and Germans after the Franco-Prussian War in 1871, which blocked the French export of glass eel for restocking in central Europe until 1948 and hampered the exchange of expertise (Dekker and Beaulaton, in press).

While the population of the European eel constitutes a single panmictic stock occurring over a very large distribution area (Europe, parts of Africa and Asia), exploitation and management have traditionally been executed on a very local scale only (Dekker 2000), and consequently, it has taken a long time before the stock-wide declines in abundance and fishing yield were noticed (Dekker 2008). In recent times, scientists jointly alarmed about the critical state of the stock (EIFAC 1968; Dekker 2003c; Dekker et al. 2003; Dekker & Casselman 2014). Monitoring and management, however, remained uncoordinated until the implementation of the European protection and recovery plan (Anonymous 2007; Dekker 2008). This protection plan hinges on decentralised but coordinated management at river basin level. Though a shared toolbox for eel stock assessment had been initiated (Dekker et al. 2006, Walker et al., 2013), no standardised or coordinated assessments have been achieved across the EU Member States (Dekker 2010; ICES 2013; Anonymous 2014). That is: the typical structure of fresh water fisheries research and management persists, despite its failure for eel in the past.

What slippery slope to climb back?

The population of the European eel is critically endangered. Historical publications indicate, that the decline in stock abundance and/or fishing yield might have started as early as in the 1800s, and might have been related to inadvertent side-effects of anthropogenic actions (water management). The downward trend in yield has been acknowledged internationally since the late 1960s, but up to today, it is unclear what processes were causing the decline, which occurred even in times of high recruitment up to 1980. Our historical review indicates a time-scale, indicates what solutions did not work before, but does not give a final answer. Meanwhile, efforts to protect and restore the stock, as now aimed for by the European Eel Regulation, will have to overcome the decline, will have to outdo the factors causing the decline – which won't be easy for unidentified factors. Ground-truthing will be needed, to proof the net achievements of protective measures.

In the mid-1800s, many publications discussed the low abundance of eel and the declining yield. Against this background, research on mitigation and compensation measures was initiated, notably on aquaculture, artificial reproduction and restocking. As successful as that research has been, application of those measures has not been able to halt the decline. Noting the lasting reluctance of the scientific community to see the multi-decadal stock decline for what it was, we consider that eternally optimistic mitigation/compensation measures have distracted the attention, more than they have contributed to the fisheries or management of the declining stock.

A multi-decadal, possibly a centennial decline; unidentified causes; a misplaced focus on mitigation and compensation – has the eel stock come down a slope that is too slippery and steep to climb back? In most recent years, the multi-decadal downward trend in recruitment appears to have been broken: for three years in a row now, recruitment has increased across the continent (Figure 2). Clearly, it is too early to conclude whether this increase is related to recent protective actions – but it gives hope that the eel can still climb back.

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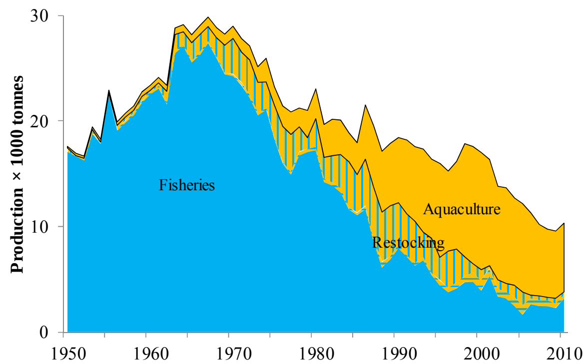

Figure 1. Time trend in eel production, combining the fishing yield taken from the wild stock with aquaculture (using wild glass eel). Data from ICES (2013); fishing yield for non-reporting countries has been reconstructed using the model of Dekker (2003b); the data after 2010 are still too incomplete to allow a reconstruction. For the fishing yield, the hatched part is what Dekker & Beaulaton (in press) attribute to restocking.

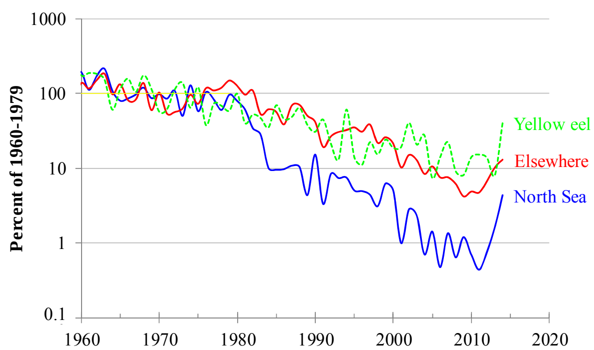

Figure 2. Time trend in eel recruitment, estimated by ICES (2014). For the glass eel, two series a shown: one for the North Sea area and one for data from elsewhere. For yellow eel, only one series is given. This plot shows the common trends in 16 (glass eel in the North Sea), 24 (glass eel, elsewhere), resp. 12 (yellow eel) site-specific data series across Europe (. Note the logarithmic scale on the vertical axis.

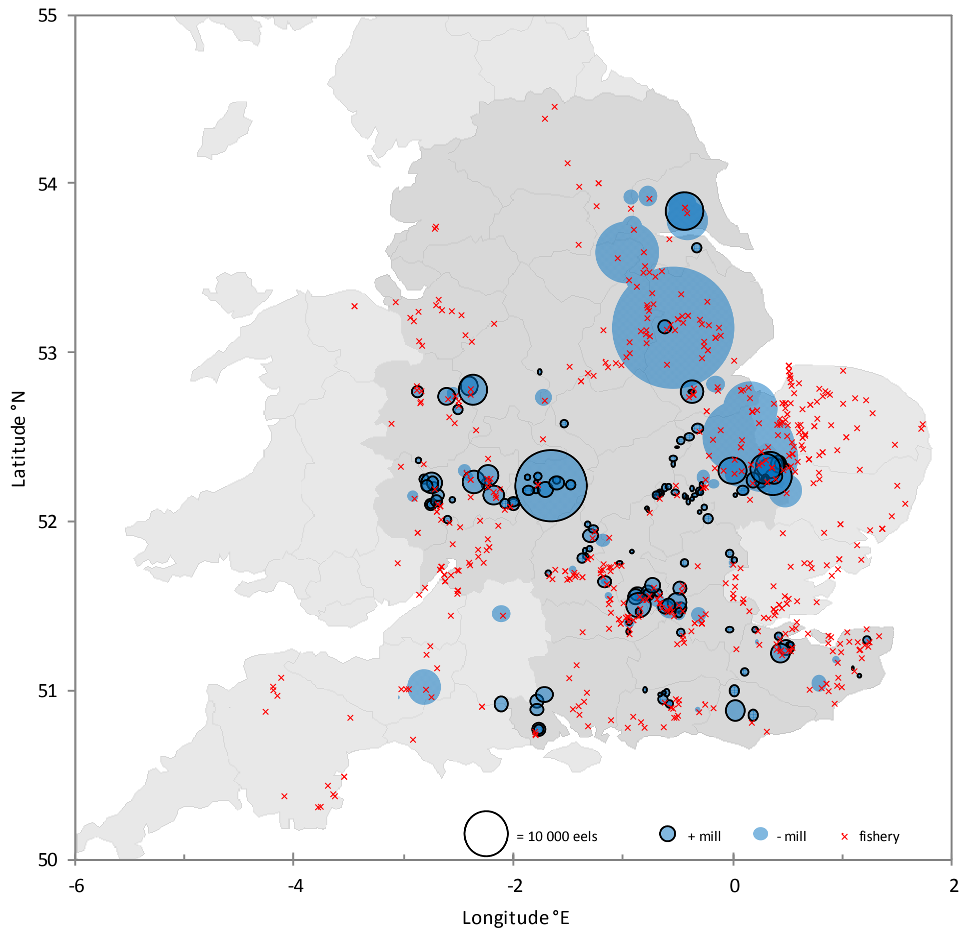

Figure 3. Records of fisheries and eels in the Domesday Book (1086). For the eel fisheries, the number of eels being taxed (size of the circles) and the presence/absence of a mill (symbols with/without a border) are indicated. All fisheries, for which no detail on species or tax is known, are indicated by their location only (crosses). For the eastern and western shires (lighter background), the Domesday Book provides only second-hand information with little detail.

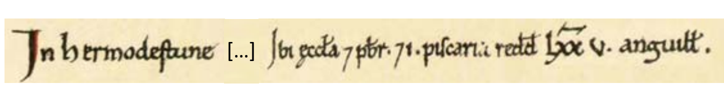

Figure 4. The highest record of eels in Domesday Book, for Harmston (53.15°N 0.55°W), reads: 'In Hermodestune [...] Here is a church and a priest and 1 fishery yields L$\overline{xx}$v eels.' The number L$\overline{xx}$v is constructed from L=50, x=10, v=5 and the overbar (macron); the overbar indicates a multiplication by thousand; "L$\overline{xx}$v anguillae" thus equals 75,000 eels. This quantity reflects the tax yield, not the catch.