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► **To cite this version:**

W. Dekker, Laurent Beaulaton. Climbing back up what slippery slope? Dynamics of the European eel stock and its management in historical perspective. ICES Journal of Marine Science, 2016, 73, pp.5-13. 10.1093/icesjms/fsv132 . hal-02631240

HAL Id: hal-02631240

<https://hal.inrae.fr/hal-02631240v1>

Submitted on 5 Dec 2023

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ICES Journal of Marine Science.

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proof-corrections or pagination.

Citation for the published paper:

Dekker, Willem & Beaulaton, Laurent. (2015) Climbing back up what
slippery slope? Dynamics of the European eel stock and its management in
a historical perspective. ICES Journal of Marine Science. Volume: 73,
Issue: 1, pp 5-13.

<http://dx.doi.org/10.1093/icesjms/fsv132>.

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Standard set statement from the publisher:

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ICES Journal of Marine Science] following peer review. The version of record is available
online at: <http://dx.doi.org/10.1093/icesjms/fsv132>.

Epsilon Open Archive <http://epsilon.slu.se>

1 Dekker, W. and Beaulaton, L. (2016). Climbing back up what slippery slope? Dynamics of the European
2 eel stock and its management in historical perspective. *ICES Journal of Marine Science*, 73(1): 5-
3 13, doi: 10.1093/icesjms/fsv132.

4 Climbing back up what slippery slope?

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

6
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14 **Abstract**

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

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

29

30

31 **Introduction**

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

34 The European eel is exploited in nearly all countries in Europe, and in the Mediterranean parts
35 of Africa and Asia (Dekker 2003a). It occurs in rivers, lakes, lagoons and estuaries, as well as
36 coastal areas. It is a main target of the inland fisheries in Europe. According to FAO (2014), eel
37 constituted 7.5% of the total landings from inland waters in 1950, diminishing to 1.5% in 2010.
38 Since eel is generally 3 to 5 times higher valued than other freshwater fish (FAO 2014; export
39 prices), this corresponds to approximately 5-30% of the landings value. For earlier periods, no
40 quantitative information is available; most likely, the eel was even more important (Radcliffe
41 1921).

42 The population of the eel is considered critically endangered (Jacoby and Gollock, 2014). In
43 recent decades, the yield from eel fisheries has gradually declined to approximately 10 % of
44 the quantity caught just half a century ago (Dekker 2003b; ICES 2013; Figure 1). Since 1980,
45 recruitment of young eel from the ocean has fallen to 1-10 % of former levels (Moriarty 1990;
46 Dekker 2000; ICES 2014; Figure 2). Additionally, current anthropogenic mortality is at an
47 unsustainably high (or unknown) level in most of the distribution area (ICES 2013). Neither the
48 causes of the historical low abundance, nor minimal protection levels are currently beyond
49 discussion (ICES 2014). In 1999, ICES (2000) advised “that a recovery plan should be
50 implemented for the eel stock and that the fishing mortality be reduced to the lowest possible
51 level until such a plan is agreed upon and implemented”. After lengthy discussions (Dekker
52 2008), the European Union adopted a stock recovery plan (Anonymous 2007), which was
53 implemented from 2009 onwards.

54 In this article, we investigate the stock dynamics in historical times. Noting that the dynamics
55 of the stock are not well known, and certainly not understood – in the current time frame, and

56 the more so in the historical periods that we will discuss – we do not aspire to compile a
57 quantified assessment of the past status and trends, since that is simply unachievable. Instead,
58 we aim at a critical review of what has been published in the past centuries, how one has
59 looked upon the status of the stock, and what management actions were pursued. Analysing
60 the slippery slope the eel stock has come down from, and how that has been perceived, may
61 improve our understanding of stock dynamics, of how the current depleted state eventually
62 arose and what pitfalls can be identified that were troubling past management of the stock
63 and fisheries.

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

71

72 **Historical information sources**

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

80 The eel population constitutes the most widespread, exploited fish stock in Europe. The wide
81 distribution area, however, is fragmented among thousands of river catchments, with little or
82 no natural interaction between them (Dekker 2000). Until 2007, management of eel fisheries

83 and their ecosystems has traditionally operated only on a localised scale (Dekker 2008).
84 Furthermore, the small scale of most eel fishing in rural areas has complicated the collection of
85 essential stock-wide data, such as total fishing yield (Dekker 2003b). Although the sum of all
86 local fisheries justifies adequate data collection, each separate local situation has long been
87 considered negligibly small (Dekker 2008), and essential data were (and still are; ICES 2014)
88 incomplete or absent. It is only from approximately 1950 onwards, that a quantified
89 reconstruction of stock dynamics is available (Dekker 2004a). In this article, our aim is to
90 discuss a much longer time span – two centuries or more – for which there is definitely no
91 information allowing a quantitative reconstruction of any kind. Consequently, we will build our
92 reconstruction on historical sources discussing abundance and anecdotal information, and
93 elaborate on quantitative aspects where possible.

94 **Historical stock abundance and trends**

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

101 In 1085, William the Conqueror, the first Norman king of England, ordered a survey of all
102 landholders, which was completed in 1086 (Anonymous 1086) and is now known under the
103 name of ‘Domesday Book’. His main aim was to have an inventory of all property that allowed
104 taxation. We processed the text of the English translation (known as the Phillimore-edition,
105 see Anonymous 1086) and checked the facsimile Latin originals (available at www.archive.org)
106 for a few exceptional records (e.g.: Figure 4). The text lists properties and taxes, including over
107 600 fisheries (piscaria, piscina; Figure 3). For 225 of these, the specified tax comprises - next to
108 a tax in cash - a number of eels (anguillae), ranging from zero to 75,000 eels per site per year

109 (Figure 4). In total, a tax of over 400,000 eels is listed. In addition to these, there are a small
110 number of cases mentioning lamprey, salmon and herring, and a few weir fisheries. For the
111 eastern (Norfolk, Suffolk and Essex) and the south-western shires (Cornwall, Devon, Somerset,
112 Dorset and Wiltshire), separate books were compiled first (the Little Domesday Book resp.
113 Exeter Domesday Book), and the main records in Domesday Book appear to be only a
114 condensed summary of these – mentioning fisheries to be taxed, but hardly specifying any eel.
115 In 150 of the records, the eel catch is directly linked to the presence of a mill (molinus), that is:
116 a water mill. The larger eel fisheries for which no mill is mentioned appear to be concentrated
117 along a line parallel to the north-eastern coast (Figure 3), often at the border between alluvial
118 plains and higher grounds (Darby 1977). The spatial association between fisheries with and
119 without a tax in eel, in particular the absence of both in the north-west where much less
120 watermills occurred (Darby 1977), suggests that most of the fisheries for which no mill is listed
121 probably were nevertheless located at watermills, and likely were targeting eel - but paid their
122 tax in cash rather than in kind. If so, the number of eel fishing sites would have been more
123 than double the number of explicit eel-records.

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

130 All in all, the Domesday Book provides evidence for a tax in kind of over 400 000 eels in 225
131 fisheries and another 375 fisheries potentially catching eel too. Noting that quantities of eel
132 were specified in numbers, we consider it most likely that large, female silver eel was implied,
133 of approximately 500 gr each – not males of less than 100 gr each. If so, the 225 fisheries and
134 400 000 eels would represent a tax in kind of 200 tonnes. The tax in cash from the remaining
135 375 fisheries - if making the same average catch per mill - would have represented another

136 333 tonnes. That suggests a total catch in the order of hundreds of tonnes, far above today's
137 fisheries of 33 t yellow eel and 6 t silver eel (ICES 2013).

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

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

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

163 the whole of Czech Republic amount less than 20 tonnes per year, of which far less than 1 t is
164 exported.

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

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

184 In the mid-1800s, interest in inland fisheries and fish culture increased considerably, especially
185 in relation to the artificial reproduction of fish – which we will discuss below. This gave rise to a
186 vast body of literature on eel, and some publications do discuss stock abundance. However,
187 there is a remarkable duality in the views expressed. On the one hand, there are some
188 publications that explicitly discuss the abundance (Anonymous 1865; Anonymous 1867;
189 Adickes 1888), and most of these either indicate a decline or discuss the low abundance. On

190 the other hand, there are the publications discussing mitigation measures, predominantly
191 restocking (Dekker and Beaulaton, in press; all the references therein) and fish ladders
192 (Benecke 1884; Anonymous 1888). Especially the publications on mitigation measures are
193 extremely optimistic, ignoring negative side-effects and the finitude of their resources. Coste
194 (1849), for instance, considers that the abundance of glass eel in France allows stocking of all
195 waters of the world ("*peupler toutes les eaux de la terre*"). Fishermen in the source areas
196 worrying about the limits to their resources are not paid any attention (Millet 1828; Le Clerc
197 1935), while for example Elsner (1899), Schmidt (1906) and Dąbrowski (1952) consider their
198 resources to be infinite. In times of technical development and growing economies, a golden
199 future is more easily sold than a realistic view on the finiteness of the resources. Even after the
200 deteriorating state of the stock had been first noted (EIFAC 1968), one first focused on further
201 development; on improving fishing gear (EIFAC 1971) and restocking. This focus on the sunny
202 side has often led to biased views or a total denial of the facts. For example, ICES (1980)
203 concluded that "there was no evidence of a reduction in the breeding stock of eels" on the
204 argument that "in recent times catches remained high", while the opposite was demonstrably
205 true (Figure 1); the additional argument that "glass-eels remained plentiful" was correct, but
206 turned false immediately after (Figure 2). Even in recent discussions, biased views still exist.
207 For example, most studies of the potential effect of ocean and atmospheric conditions on eel
208 recruitment (reviewed in Miller et al. 2009) - though often acknowledging that low spawner
209 abundance might be involved in the decline - do not include an index of spawner abundance in
210 their analysis, while estimates of the continental production of silver eel have been used as a
211 proxy for that before (Dekker 2003b; ICES 2005, 2014). Moreover, many authors (e. g., Bilotta
212 et al. 2011; Armitage et al. 2013; Capoccioni et al. 2014; Colombier et al. 2015) describe the
213 relatively recent downward trend in recruitment (since 1980) as the start of the stock decline,
214 ignoring the information on the preceding decline of the continental stock (Svärdson 1976;
215 Dekker 2003b, 2004a,b; ICES 2014). That is: the finiteness and long-lasting decline of the

216 continental stock remained out of sight, or the observed trends were described as local
217 phenomena (Svårdson 1976), while the continent-wide declining yield indicated otherwise.

218 **The eel problem – la question de l’anguille – die Aalfrage**

219 Over the centuries, the growing human population and accumulating human pressures on
220 fresh water habitats eventually led to a need to restore and increase fish production. In
221 medieval times, millponds and dedicated fishponds enabled the culture of carp and other
222 cyprinids in stagnant water (Hoffman 1995), but to our knowledge, that did not particularly
223 involve eel. As successful as pond culture has been, its production was limited and fresh fish
224 was predominantly reserved for the nobility and clergy. Towards the mid-1800s, however, a
225 major breakthrough in fish culture was achieved, enabled by the development of artificial
226 reproduction of fish (Kinsey 2006) and the contemporary development of railway networks
227 across Europe. In 1852, a ‘fish factory’ was set up in Huningue, just north of Basel along the
228 river Rhine, where millions of fish have been produced, that have been stocked into outdoor
229 waters (Kinsey 2006). Initially, many different fish species were tried, such as perch and tench,
230 and it was generally expected that artificial reproduction could also be applied to ‘salmon and
231 eel, et cetera’ (Anonymous 1852). In the years following, millions of salmonids have been
232 produced in Huningue indeed (Coumes 1862), but the artificial production of eel remained
233 unsuccessful. Though the reproductive organs (e.g. Syrski 1874; Freud 1877) and the silver eel
234 migration (Millet 1870; Benecke 1884) were intensely studied, it remained unclear where and
235 how the eel reproduced. Frustrated by this lack of progress on this important species, the issue
236 became to be denoted by a standard phrase: “the eel problem” (Brown Goode 1881; Tucker
237 1959; D’Ancona 1959; Sinha and Jones 1967; Righton et al. 2012); “die Aalfrage” (Kaumann
238 1878; Jacoby 1880; Hermes 1881; Lübbert 1907); “la question de l’anguille” (Schaeck 1894).
239 Though a pragmatic approach was adopted in advocating mitigation measures (e.g., restocking
240 – de Rivière 1841; eel ladders - von Benecke 1884), the hope to reproduce the eel artificially

241 remained and progress on the Eel Problem was extensively and frequently discussed by many
242 authors.

243 From this point onwards, three different lines of thinking developed. First, we find studies
244 focused on the natural reproduction in the field, including studies of the morphology and
245 physiology of the eel (e.g. Freud 1877), the location of the natural spawning location (Millet
246 1870; Schmidt 1906, 1922; Grassi and Calandruccio 1894; Righton et al. 2012). Secondly, there
247 is a pragmatic line: accepting that artificial reproduction will not be easily achieved, one
248 focuses on the redistribution of natural-born recruits to enhance the production, i.e.
249 restocking (de Rivière 1841; Millet 1854; Dekker and Beaulaton, in press). Finally, the artificial
250 reproduction itself has remained a still unsolved challenge (Fontaine 1936; Boëtius et al. 1962;
251 Fontaine et al. 1964; Okamura et al. 2014).

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

258 **Wild versus cultured**

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

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

276 From the mid-1800s onwards, fisheries development programmes started all over Europe, first
277 in France, then in Germany and later in the rest of northern Europe. New habitats were
278 created (Pouchet 1856), food competitors and predators were suppressed (von dem Borne
279 1889), and eel recruits were transported to areas of low abundance (de Rivière 1840; Dekker
280 and Beaulaton, in press) or even outside the natural distribution (Haack 1877; Kokhenko 1969;
281 Egusa 1970). From around 1970, the culture of eels in natural or artificial outdoor ponds was
282 gradually replaced by/upgraded to indoor systems using heated, recirculated water (Kamstra
283 2003), though the Italian lagoons continue their traditional extensive system at the same time.
284 Between the indoor culture and the outdoor stock, there is a frequent and diverse interaction.
285 Nowadays, wild-caught glass eel is taken in by aquaculture facilities to seed their culture; in
286 the 1980s, wild-caught half-grown yellow eel has been used for that purpose too. Additionally,
287 glass eel are quarantined in indoor facilities before being restocked in outdoor waters, or
288 grown to medium sized yellow eels before being released into the wild (Baer et al. 2011;
289 Dekker & Beaulaton, in press). Finally, the intensive aquaculture industry contributes
290 (financially) to management measures to protect and recover the stock (SEG 2014). Production
291 statistics from outdoor fisheries and aquaculture are often undifferentiated or mixed up
292 (Dekker 2003b; ICES 2005; FAO 2014). All in all, almost all variants in-between outdoor fishery
293 on the wild stock in natural habitats, and indoor culture in recirculating systems using artificial

294 food, exists. Since 1995, the production in indoor aquaculture effectively exceeds the fisheries
295 production, but - 'The Eel Problem' remaining a mystery - all production still depends on the
296 wild stock. The presence of such a wide variety of exploitation forms complicates the
297 management of the wild stock. Moreover, restocking, extensive and intensive culture of eel
298 have often been advocated as a complement or even as a replacement for the wild fisheries –
299 and in that way have effectively distracted attention from the increasingly worrying status of
300 the stock.

301 **Science and management**

302 Conventionally, the European eel has been considered a freshwater fish (freshwater eel, river
303 eel, Flussaal – often set in contrast to the conger: anguille de mer, Meeraal, zeepaling). Though
304 the unsolved 'Eel Problem' eventually has put the eel in a rather exceptional position, research
305 and management have traditionally been embedded in the general developments of the inland
306 fisheries. International cooperation in research and technical innovation in support of fisheries
307 occurred as for any other freshwater fish: focused on the development of the national stocks
308 and fisheries, often based on international exchange of scientific knowledge and expertise. For
309 example, the concept of restocking - developed in France in the mid-1800s - spread across the
310 continent within a decade (Dekker and Beaulaton, in press); old and new gear designs were
311 copied from country to country (Le Clerc 1930; Schlieker 1957 in Tesch 2003; et cetera), as
312 were processing techniques (Anonymous 1865; Forrest 1976) and transport systems (e.g., eel
313 barges – a long-distance transport technique already used in the mid-1400s by the Dutch, that
314 spread around when regional market supplies declined; Ypma 1962; Åklundh 1992; Nilsson
315 1996; Devall 1998). A notable exception to the international collaboration has been the hostile
316 relationships between the French and Germans after the Franco-Prussian War in 1871, which
317 blocked the French export of glass eel for restocking in central Europe until 1948 and
318 hampered the exchange of expertise (Dekker and Beaulaton, in press).

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

332 **What slippery slope to climb back?**

333 The population of the European eel is critically endangered. Historical publications indicate,
334 that the decline in stock abundance and/or fishing yield might have started as early as in the
335 1800s, and might have been related to inadvertent side-effects of anthropogenic actions
336 (water management). The downward trend in yield has been acknowledged internationally
337 since the late 1960s, but up to today, it is unclear what processes were causing the decline,
338 which occurred even in times of high recruitment up to 1980. Our historical review indicates a
339 time-scale, indicates what solutions did not work before, but does not give a final answer.
340 Meanwhile, efforts to protect and restore the stock, as now aimed for by the European Eel
341 Regulation, will have to overcome the decline, will have to outdo the factors causing the
342 decline – which won't be easy for unidentified factors. Ground-truthing will be needed, to
343 proof the net achievements of protective measures.

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

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

358

359 **References**

- 360 Aalto, E., Capoccioni, F., Mas, J. T., Schiavina, M., Leone, C., De Leo, G., & Ciccotti, E. 2015.
361 Quantifying 60 years of declining European eel (*Anguilla anguilla* L., 1758) fishery yields in
362 Mediterranean coastal lagoons. ICES Journal of Marine Science, available at [http:](http://icesjms.oxfordjournals.org/content/early/2015/05/07/icesjms.fsv084.full.pdf)
363 [//icesjms.oxfordjournals.org/content/early/2015/05/07/icesjms.fsv084.full.pdf](http://icesjms.oxfordjournals.org/content/early/2015/05/07/icesjms.fsv084.full.pdf)
- 364 Adickes, W. 1888. Oral presentation cited by an anonymous in: Zweiter Deutscher Fischereitag in
365 Freiburg i. B.; Plenarversammlungen des Deutschen Fischereitag. *Allgemeine Fischerei-Zeitung*
366 13(20): 241–242.
- 367 Åklundh, P. 1992. Ålkvassar. Småskrifter utgivna av Santa Annas Gille i Åhus, Vol. 20. Winjetryckeriet,
368 Tollarp. 8 pp.
- 369 Anonymous 1086. The Domesday Book (English translation 1977, Morris J., ed.), Phillimore, London.
370 Available at <https://hydra.hull.ac.uk/resources/hull:461>, accessed 01-Nov-2014.
- 371 Albertus Magnus ±1200. Opera Omnia, volumen 6, de Animalibus, ed. Jammy. Lugduni (Lyon), 1651.
372 335 pp.
- 373 Anonymous 1852. Rapport de M. le Préfet sur le Pisciculture. Procès-Verbal des Délibérations du Conseil
374 Général du Département de l'Isère. F. Allier, Grenoble. pp. 349-353.
- 375 Anonymous 1865. Pêche fluviale. Rapport du Préfet et Procès-Verbaux des Séances et des Délibérations
376 du Conseil General. Vignancour, Pau. pp. 70-72.
- 377 Anonymous 1867. Dépeuplement de la Seine. Rapport du Préfet et Procès-Verbal des Délibérations.
378 Bertrand-Hu, Troyes. pp. 99-100.
- 379 Anonymous 1884. (no title). Circulare des Deutschen Fischerei-Vereins im Jahre 1884. W. Moeser,
380 Berlin. p. 75.
- 381 Anonymous 1887. Aufsteigen des Aals in Badischen Gewässern. Circulaire des Deutschen Fischerei-
382 Verein im Jahre 1887. W. Moeser, Berlin. pp. 52–53.
- 383 Anonymous 1888. Aalbrut. *Circulare des Deutschen Fischerei-Verein im Jahre 1888*. W. Moeser, Berlin.
384 pp. 27–28.
- 385 Anonymous 2007. Council Regulation (EC) No 1100/2007 of 18 September 2007 establishing measures
386 for the recovery of the stock of European eel. Official Journal of the European Union L 248/17.
- 387 Anonymous 2014. Report from the Commission to the Council and the European Parliament on the
388 outcome of the implementation of the Eel Management Plans. [http:](http://data.consilium.europa.eu/doc/document/ST-14619-2014-init/EN/pdf)
389 [//data.consilium.europa.eu/doc/document/ST-14619-2014-init/EN/pdf](http://data.consilium.europa.eu/doc/document/ST-14619-2014-init/EN/pdf), accessed 1-Dec-2014
- 390 Ardizzone G.D., Cataudella S. & Rossi R. 1988. Management of coastal lagoon fisheries and aquaculture
391 in Italy. FAO Fisheries Technical Paper 293: 103 pp.
- 392 Armitage, J., Hewlett, N. R., Twigg, M., Lewin, N. C., Reading, A. J., Williams, C. F., Aprahamian M.,
393 Way, K., Feist, S.W. & Peeler, E. J. 2014. Detection of *Herpesvirus anguillae* during two
394 mortality investigations of wild European eel in England: implications for fishery management.
395 *Fisheries Management and Ecology*, 21(1): 1-12.
- 396 Baer, J., Brämick, U., Diekmann, M., Karl, H., Ubl, C. and Wysujack, K. 2011. Fischereiliche
397 Bewirtschaftung des Aals in Deutschland. Rahmenbedingungen, Status und Wege zur
398 Nachhaltigkeit. Schriftenreihe des Verbandes Deutscher Fischereiverwaltungsbeamter und
399 Fischereiwissenschaftler e. V., Heft 16: 140 pp.
- 400 Benecke, B. 1884. Die Wanderung der Aalbrut und die Einrichtung von Aalbrutleitern. Königsberg:
401 Leupold, 8 pp.
- 402 Bilotta, G. S., Sibley, P., Hateley, J., & Don, A. 2011. The decline of the European eel *Anguilla anguilla*:
403 quantifying and managing escapement to support conservation. *Journal of fish biology*, 78(1): 23-
404 38.
- 405 Boëtius, J., Boëtius, I., Hemmingsen, A.M., Bruun, A.F. & Møller-Christensen, E. 1962. Studies of
406 ovarian growth induced by hormone injections in the European and American eel (*Anguilla*

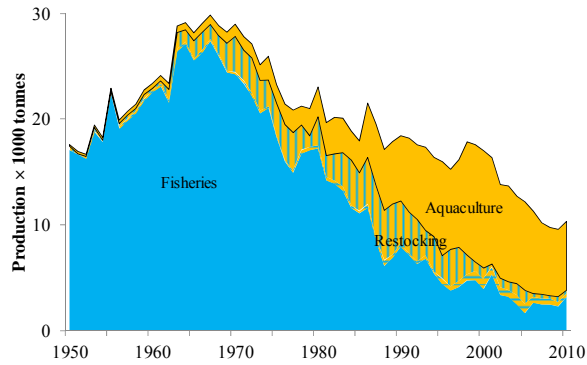
- 407 *anguilla* L., and *Anguilla rostrata* LeSueur). Meddelelser fra Danmarks Fiskeri-Og
408 Havundersogelser 3: 183–198.
- 409 Borne, M. von dem 1889. Tod den Fischfeinden. Deutsche Fischerei-Verein, Berlin. 18 pp.
- 410 Brown Goode, G. 1881. The eel question. Transactions of the American Fisheries Society 10(1): 81-124.
- 411 Capoccioni, F., Costa, C., Canali, E., Aguzzi, J., Antonucci, F., Ragonese, S., & Bianchini, M. L. 2014.
412 The potential reproductive contribution of Mediterranean migrating eels to the *Anguilla anguilla*
413 stock. Scientific reports, 4.
- 414 Colombier, S. B. du, Jacobs, L., Gesset, C., Elie, P., & Lambert, P. 2015. Ultrasonography as a non-
415 invasive tool for sex determination and maturation monitoring in silver eels. Fisheries Research,
416 164: 50-58.
- 417 Coste, V. 1849. Recherches sur la domestication des poissons et sur l'organisation des piscines. *Comptes*
418 *rendus de l'Académie des Sciences* 29: 797– 801.
- 419 Coste, V. 1855. Voyage d'exploration sur le littoral de la France et de l'Italie: Rapport à M. le ministre de
420 l'agriculture, du commerce et des travaux publics, sur les industries de Comacchio, du lac Fusaro,
421 de Marennes, et de l'Anse de l'Aiguillon. Imprimerie impériale, Paris. 184 pp.
- 422 Coumes, J. 1862. Notice historique sur l'établissement de pisciculture de Huningue. Veuve Berger-
423 Levrault, Strasbourg. 143 pp.
- 424 Dąbrowski, B. 1952. O zarybianiu węgorzem [The restocking of eel]. *Gospodarra Rybna* 4: 5–6.
- 425 D'Ancona, U. 1959. Old and new solutions to the eel problem. *Nature* 183: 1405.
- 426 Darby, H.C. 1977. Domesday England. Cambridge University Press, London. 416 pp.
- 427 Dekker, W. 2000. The fractal geometry of the European eel stock. *ICES Journal of Marine Science* 57:
428 109–121.
- 429 Dekker, W. 2003a. On the distribution of the European eel and its fisheries. *Canadian Journal of Fisheries*
430 *and Aquatic Sciences* 60, 787-799.
- 431 Dekker, W. 2003b. Did lack of spawners cause the collapse of the European eel, *Anguilla anguilla*?
432 *Fisheries Management and Ecology* 10: 365–376.
- 433 Dekker, W. 2003c. Eels in crisis. *ICES Newsletter* 40: 10–11.
- 434 Dekker, W. 2004a. Slipping through our hands – population dynamics of the European eel. Amsterdam:
435 University of Amsterdam, PhD thesis, 186 pp. [http:](http://www.diadfish.org/doc/these_2004/dekker_thesis_eel.pdf)
436 [//www.diadfish.org/doc/these_2004/dekker_thesis_eel.pdf](http://www.diadfish.org/doc/these_2004/dekker_thesis_eel.pdf)
- 437 Dekker, W. 2004b. What caused the decline of Lake IJsselmeer eel stock since 1960? *ICES Journal of*
438 *Marine Science* 61: 394–404.
- 439 Dekker, W. 2008. Coming to Grips with the Eel Stock Slip-Sliding Away. *In International Governance of*
440 *Fisheries Eco-systems: Learning from the Past, Finding Solutions for the Future*, pp. 335-355. Ed.
441 by M.G. Schlechter, N.J. Leonard, and W.W. Taylor. American Fisheries Society, Symposium 58,
442 Bethesda, Maryland.
- 443 Dekker, W. 2010. Every five years delay so far has roughly halved the remaining eel stock. [http://efp-](http://efp-reformwatch.eu/2010/12/%E2%80%9Cevery-five-years-delay-so-far-has-roughly-halved-the-remaining-eel-stock%E2%80%9D/)
444 [reformwatch.eu/2010/12/%E2%80%9Cevery-five-years-delay-so-far-has-roughly-halved-the-](http://efp-reformwatch.eu/2010/12/%E2%80%9Cevery-five-years-delay-so-far-has-roughly-halved-the-remaining-eel-stock%E2%80%9D/)
445 [remaining-eel-stock%E2%80%9D/](http://efp-reformwatch.eu/2010/12/%E2%80%9Cevery-five-years-delay-so-far-has-roughly-halved-the-remaining-eel-stock%E2%80%9D/)
- 446 Dekker W., Casselman J.M., Cairns D.K., Tsukamoto K., Jellyman D., Lickers H. 2003. Worldwide
447 decline of eel resources necessitates immediate action. *Québec Declaration of Concern. Fisheries*
448 28(12): 28–30.
- 449 Dekker W., Pawson M., Walker A., Rosell R., Evans D., Briand C., Castelnaud G., Lambert P., Beaulaton
450 L., Åström M., Wickström H., Poole R., McCarthy T.K., Blaszkowski M., de Leo G. and
451 Bevacqua D. 2006 Report of FP6-project FP6-022488, Restoration of the European eel population:
452 pilot studies for a scientific framework in support of sustainable management: SLIME. 19 pp. +
453 CD, <http://www.diadfish.org/english/SLIME.htm>
- 454 Dekker, W., and J. M. Casselman (eds.). 2014. The 2003 Québec Eel Declaration: Are Eels Climbing
455 Back up the Slippery Slope? The 2003 Québec Declaration of Concern about eel declines – 11
456 years later. *Fisheries* 39(12): 613-614.
- 457 Dekker, W. & Beaulaton, L. (in press) Faire mieux que la nature - the history of eel restocking in Europe.
458 Environment and History, accepted 2015-Feb-19. Publication expected spring 2016.
- 459 Devall CA. 1998. Heybridge Basin Eel Industry 1928-1968. Maldon and the tidal Blackwater Volume 1.
460 Devall, Chelmsford. 83 pp.

- 461 Dirks, R.P., Burgerhout, E., Brittijn, S.A., Wijze, D.L. de, Ozupek, H., Tuinhof-Koelma, N., Minegishi,
462 Y., Jong-Raadsen, S.A., Spaink, H.P., Thillart, G.E.E.J.M. van den, 2014. Identification of
463 molecular markers in pectoral fin to predict artificial maturation of female European eels (*Anguilla*
464 *anguilla*), *General and Comparative Endocrinology*, 204: 267-276.
- 465 Egusa, S. 1970. Notes on sex and growth of European eels in freshwater eel-rearing ponds. *Bulletin of the*
466 *Japanese Society of Scientific Fisheries* 36(2): 1224 – 1225.
- 467 EIFAC. 1968. Report of the Fifth Session of the European Inland Fisheries Advisory Commission. Rome
468 20-24 May 1968. 73 pp.
- 469 EIFAC. 1971. EIFAC Consultation on eel fishing gear and techniques. EIFAC Technical paper No 14,
470 edited by C.J. McGrath. 187 pp.
- 471 Elsner, B. 1899. Ueber die Besetzung der Binnengewässer mit Aalen. *Allgemeine Fischerei-Zeitung*
472 24(7): 107–111.
- 473 FAO, 2014. FishStatJ, a tool for fishery statistics analysis, Release 2.11.4. Datasets: Capture Production
474 1950-2012 & Fisheries Commodities Production and Trade 1976-2011. <http://www.fao.org/fishery/statistics/software/fishstatj/en>, accessed 01-Oct-2014.
475
- 476 Fontaine, M. 1936. Sur la maturation complète des organes génitaux de l'anguille male et l'émission
477 spontanée. *Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences* 202: 1312–
478 1314.
- 479 Fontaine, M., Bertrand, E., Lopez, E. & Callamand, O. 1964. Sur la maturation des organes génitaux de
480 l'Anguille femelle (*Anguilla anguilla* L.) et l'émission spontanée des œufs en aquarium. *Comptes*
481 *Rendus Hebdomadaires des Séances de l'Académie des Sciences* 259: 2907–2910.
- 482 Forrest, D.M., 1976. Eel capture, culture and processing. Fishing News Books, Farnham. 205 pp.
- 483 Freud, S. 1877. Beobachtungen über Gestaltung und feineren Bau der als Hoden beschriebenen
484 Lappenorgane des Aals. *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaft, Wien*. 75:
485 419-431.
- 486 Ginneken, V.J.T. van and Maes, G.E. 2005. The European eel (*Anguilla anguilla*, Linnaeus), its lifecycle,
487 evolution and reproduction: a literature review. *Reviews in Fish Biology and Fisheries* 15: 367–
488 398.
- 489 Grassi, B., and Calandrucchio, S., 1894, Soluzione di un enigma antichissimo ossia Scoperta della
490 metamorfosi dell' *Anguilla*. *Neptunia: Rivista Italiana di Oceanografia Pesca ed Acquacultura*, 15-
491 30 sett. 1894: 195: 201.
- 492 Haack, H. 1877. Die Einführung von Aalen in das Donaugebiet. *Mittheilungen über Fischereiwesen* 2(5):
493 33–35.
- 494 Hermes, O. 1881. Zur Aufzucht junger Aale. *Circulare des Deutschen Fischerei-Vereins im Jahre 1881*.
495 W. Moeser, Berlin. pp. 20-21.
- 496 Hoffmann, R.C. 1995. Environmental change and the culture of common carp in medieval Europe.
497 *Guelph Ichthyology Reviews* 3: 57–85.
- 498 ICES. 1976. First report of the working group on stocks of the European eel, Charlottenlund, 27–31
499 October 1975. *ICES CM 1976/M: 2*. 34 pp.
- 500 ICES. 1980. Report of the joint ICES/EIFAC working group on eels, Hamburg 24-26 June 1980. *ICES*
501 *C.M. 1980/M: 30*. 24 pp.
- 502 ICES. 2000. International Council for the Exploration of the Sea. ICES cooperative research report N°
503 236. Report of the ICES Advisory Committee on Fisheries Management, 1999: 237 - 241.
- 504 ICES. 2005. International Council for the Exploration of the Sea. Report of the ICES/EIFAC Working
505 Group on Eels. *ICES C.M. 2005/ I: 01*.
- 506 ICES. 2013. Report of the Joint EIFAAC/ICES Working Group on Eels (WGEEL), 18–22 March 2013 in
507 Sukarietta, Spain, 4–10 September 2013 in Copenhagen, Denmark. *International Council for the*
508 *Exploration of the Sea, ICES CM 2013/ACOM: 18*. 851 pp.
- 509 ICES. 2014. Report of the Joint EIFAAC/ICES/GFCM Working Group on Eels (WGEEL), 3-7
510 November in Rome, Italy. *International Council for the Exploration of the Sea, ICES CM*
511 *2014/ACOM: 18*. 203+704 pp.
- 512 Jacoby, L. 1880. Der Fischfang in der Lagune von Comacchio nebst einer Darstellung der Aalfrage. A.
513 Hirschwald, Berlin. 93 pp.
- 514 Jacoby, D. and Gollock, M. 2014. The IUCN Red List of Threatened Species. Version 2014.3.
515 www.iucnredlist.org

- 516 Kamstra A. 2003. Eel culture. *In* The Eel, 3rd edition, pp. 295-305. Ed. By F.W. Tesch, Parey Blackwell
517 Science, Oxford, 408 pp.
- 518 Kaumann, E. 1878. Zur Aalfrage. *Circulars des Deutschen Fischerei-Zeitung*. 1: 214-215.
- 519 Kerschner, T. 1956 Der Linzer Markt für Süßwasserfische insbesondere in seiner letzten Blüte vor dem
520 ersten Weltkrieg. *Naturkundliches Jahrbuch der Stadt Linz* 2: 119–155.
- 521 Kettle, A. J., Heinrich, D., Barrett, J. H., Benecke, N., & Locker, A. 2008. Past distributions of the
522 European freshwater eel from archaeological and palaeontological evidence. *Quaternary Science*
523 *Reviews*. 27(13): 1309-1334.
- 524 Kinsey, D. 2006. Seeding the water as the earth: The epicenter and peripheries of a western aquaculture
525 revolution. *Environmental History* 11: 527–566.
- 526 Koch, W. 1925 Die Geschichte der Binnenfischerei von Mitteleuropa. *Handbuch der Binnenfischerei*
527 *Mitteleuropas, Band IV*. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart. 52+11 pp.
- 528 Kokhenko, V. 1969. *Европейский Угорь [Evropeiskii ugor, European eel]*. Moscow: Пищевая
529 промышленность [Pishchevaya promyshlennost, Food Industry], 108 pp.
- 530 Lasne, E., Acou, A., Vila-Gispert, A., & Laffaille, P. 2008. European eel distribution and body condition
531 in a river floodplain: effect of longitudinal and lateral connectivity. *Ecology of Freshwater Fish*,
532 17(4): 567-576.
- 533 Le Clerc, J. 1930. 'L'anguille dans le bassin de la Loire'. *Bulletin Français de Pisciculture* 2(19): 145–
534 152 & 177–182.
- 535 Le Clerc, J. 1935. Le repeuplement de la Loire en anguilles. *Bulletin Français de Pisciculture*, 87: 49–57.
- 536 Lecomte-Schmitt, B. 2009. Pêche en milieu fluvial. Deux sites sur la Seine et la Marne utilisés du
537 Néolithique au Moyen Âge. *Archéopages*: 28–33.
- 538 Lübbert, H. 1907. Neue Forschungsergebnisse über das Leben des Aals und deren Einfluß auf die
539 Aalfischerei. *Verhandlungen des Naturwissenschaftlichen Vereins in Hamburg, dritte Folge XV*.
540 Hamburg: L. Friederichsen & Co, pp. XLIX-LII.
- 541 Marsilius, A. F. 1726. *Danubius pannonico-mysicus, observationibus geographicis, astronomicis,*
542 *hydrographicis, historicis, physicis perlustratus et in sex Tomos digestus. Tomus IV. De piscibus*
543 *in aquis Danubii viventibus. Hagae et Amstelodami: P. Gosse, R. Chr. Alberts, P. de Hondt, Herm.*
544 *Uytwerf & Franç. Changuion, 92 pp.*
- 545 Miller, M. J., Kimura, S., Friedland, K. D., Knights, B., Kim, H., Jellyman, D. J., & Tsukamoto, K. 2009.
546 Review of ocean-atmospheric factors in the Atlantic and Pacific oceans influencing spawning and
547 recruitment of anguillid eels. *In* Challenges for diadromous fishes in a dynamic global
548 environment. Edited by A.J. Haro *et al.* American Fisheries Society Symposium Vol. 69, Bethesda
549 Maryland, p 231–249.
- 550 Millet, P.-A. 1828. Faune de Maine et Loire ou description méthodique des animaux qu'on rencontre dans
551 toute l'étendue du département de Maine et Loire, tant sédentaires que de passage; avec des
552 observations sur leurs moeurs, leurs habitudes, etc., etc. Rosier, Paris. 773 pp.
- 553 Millet, C. 1854. Observation sur la Communication Verbale de M. Coste. *Bulletin de la Societe*
554 *Zoologique d'Acclimatation*. Goin, Paris. pp. 14-20.
- 555 Millet, C. 1870. *La culture de l'eau*. Alfred Mame et Fil, Tours. 364 pp.
- 556 Moriarty, C. 1990. European Catches of Elver of 1928–1988. *Internationale Revue des gesamten*
557 *Hydrobiology*, 75: 701–706.
- 558 Mordenti, O., Casalini, A., Mandelli, M., & Di Biase, A. (2014). A closed recirculating aquaculture
559 system for artificial seed production of the European eel (*Anguilla anguilla*): Technology
560 development for spontaneous spawning and eggs incubation. *Aquacultural Engineering*. 58: 88-94.
- 561 Naismith, I.A. & B. Knights. 1993. The distribution, density and growth of the European eel, *Anguilla*
562 *anguilla*, in the freshwater catchment of the River Thames. *J. Fish Biol.* 42: 217–226
- 563 Nilsson, S.-W. 1996. A-B Ålexporten Åhus. *Skrifter utgivna av Santa Annas Gille i Åhus, Vol. 16.*
564 *Åhustryckeriet, Åhus. 30 pp.*
- 565 Noël, S.B.J. 1815. *Histoire Générale des Pêches Anciennes et Modernes*. L'imprimerie Royale, Paris. 428
566 pp.
- 567 Okamura, A., Horie, N., Mikawa, N., Yamada, Y. and Tsukamoto, K. 2014. Recent advances in artificial
568 production of glass eels for conservation of anguillid eel populations. *Ecology of Freshwater Fish*
569 23: 95–110.

- 570 Pouchet, F-A. 1856. Lettre sur les bancs d'anguilles de la Seine et sur l'industrie de Commachio. A.
571 Péron, Rouen. 11 pp.
- 572 Radcliffe, W. 1921. Fishing from the earliest times. John Murray, London. 478 pp.
- 573 Righton, D., Aarestrup, K., Jellyman, D., Sébert, P., Van den Thillart, G., & Tsukamoto, K. 2012. The
574 *Anguilla* spp. migration problem: 40 million years of evolution and two millennia of speculation.
575 *Journal of fish biology*, 81(2), 365-386.
- 576 Rivière, L.R. baron de 1841. Considérations sur les poissons, et particulièrement sur les Anguilles.
577 *Mémoires d'Agriculture, d'Economie Rurale et Domestique* (Paris: Société Royale et Centrale
578 d'Agriculture), 1840: 171–199d.
- 579 Schaeck, (H.E.?) de 1894. La question de l'anguille. *Revue des Sciences Naturelles Appliquées*. 41: 61-
580 66.
- 581 Schlieker, E. 1957. Probleme des Baues und der Anwendung von Großreusen. *Zeitschrift für den*
582 *Fischerei* 6: 531–558.
- 583 Schmidt, J. 1906. Contributions to the life-history of the eel (*Anguilla vulgaris*, Flem.). *Rapports et*
584 *procès-verbaux des réunions du Conseil permanent international pour l'exploration de la mer* 5:
585 137–264.
- 586 Schmidt, J. 1922. The Breeding Places of the Eel. *Philosophical Transactions Royal Society, series B*.
587 211: 178–208.
- 588 SEG. 2014. Sustainable Eel Group, <http://www.sustainableeelgroup.com/>, accessed 01-Dec-2014.
- 589 Sinha, V.R.P. and Jones, J.W. 1967. The Atlantic Eel Problem. *Proceedings of the Third British Coarse*
590 *Fish Conference*: 70-73.
- 591 Svårdson G. 1976. The decline of the Baltic eel population. *Reports of the Institute Freshwater Research*
592 *Drottningholm* 143: 136-143.
- 593 Syrski, S. 1874 Über die Reproductions-Organen der Aale. *Sitzungsberichte der Kaiserlichen Akademie*
594 *der Wissenschaft, Wien*. 69: 315-326.
- 595 Tesch, F.-W. 2003. *The Eel*. Blackwell Science, Oxford. 408 pp.
- 596 Tomkiewicz, J., Tybjerg, L., Støttrup, J., McEvoy, F., Ravn, P., Sørensen, S.R., Lauesen, P., Graver, C.,
597 Munk, P., Holst, L.K., Vestbø, B., Svalastoga, E., Jacobsen, C., Holst, B., Steinfeldt, S.J.,
598 Buelund, L., Hornum, T., Kofoed, T., 2012. Reproduction of European Eel in Aquaculture
599 (REEL). DTU Aqua Report Series, 249-2012, 47 pp.
- 600 Tucker, D.W. 1959. A new solution to the Atlantic eel problem. *Nature* 183: 495–501.
- 601 Walker, A. M., E. Andonegi, P. Apostolaki, M. Aprahamian, L. Beaulaton, D. Bevacqua, C. Bri-and, A.
602 Cannas, E. De Eyto, W. Dekker, G. A. De Leo, E. Diaz, P. Doering-Arjes, E. Fladung, C. Jouanin,
603 P. Lambert, R. Poole, R. Oeberst and M. Schiavina. 2013. Lot 2: Pilot project to estimate potential
604 and actual escapement of silver eel. Final project report, Service contract S12.539598, Studies and
605 Pilot Projects for Carrying out the Common Fisheries Policy. Brussels, European Commission,
606 Directorate - General for Maritime Affairs and Fisheries (DG Mare): 358 pp.
- 607 Walter, E. 1910. *Der Flusssaal, eine biologische und fischereiwirtschaftliche Monographie*. Neumann,
608 Neudamm. 346 pp.
- 609 Widdrington, S.E. 1842. On the Eel, and on the Freshwater Fish of Austria. *The Annals and Magazine of*
610 *Natural History* Vol. 8: 207- 210.
- 611 Yarrell, W. 1836. *A history of British Fishes*. John van Voorst, London. Vol. 2, 472 pp.
- 612 Yény É. 2004. – La pêche des Milandes. *Actes des premières rencontres internationales de Liessies:*
613 *pêches et pisciculture en eau douce, la rivière et l'étang au Moyen Age*, 27, 28 et 29 avril 1998,
614 publication sur CD-ROM, Lille, Conseil Général du Nord.
- 615 Ypma Y.N. 1962. *Geschiedenis van de Zuiderzeevisserij*. Publicaties van de Stichting voor het
616 *Bevolkingsonderzoek in de Drooggelegde Zuiderzeepolders No 27*, Amsterdam, 224 pp.
- 617

618

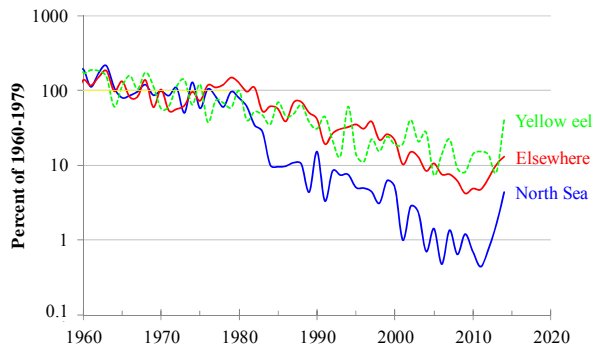


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620 **Figure 1.** Time trend in eel production, combining the fishing yield taken from the wild stock with aquaculture (using
 621 wild glass eel). Data from ICES (2013); fishing yield for non-reporting countries has been reconstructed using the
 622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

624

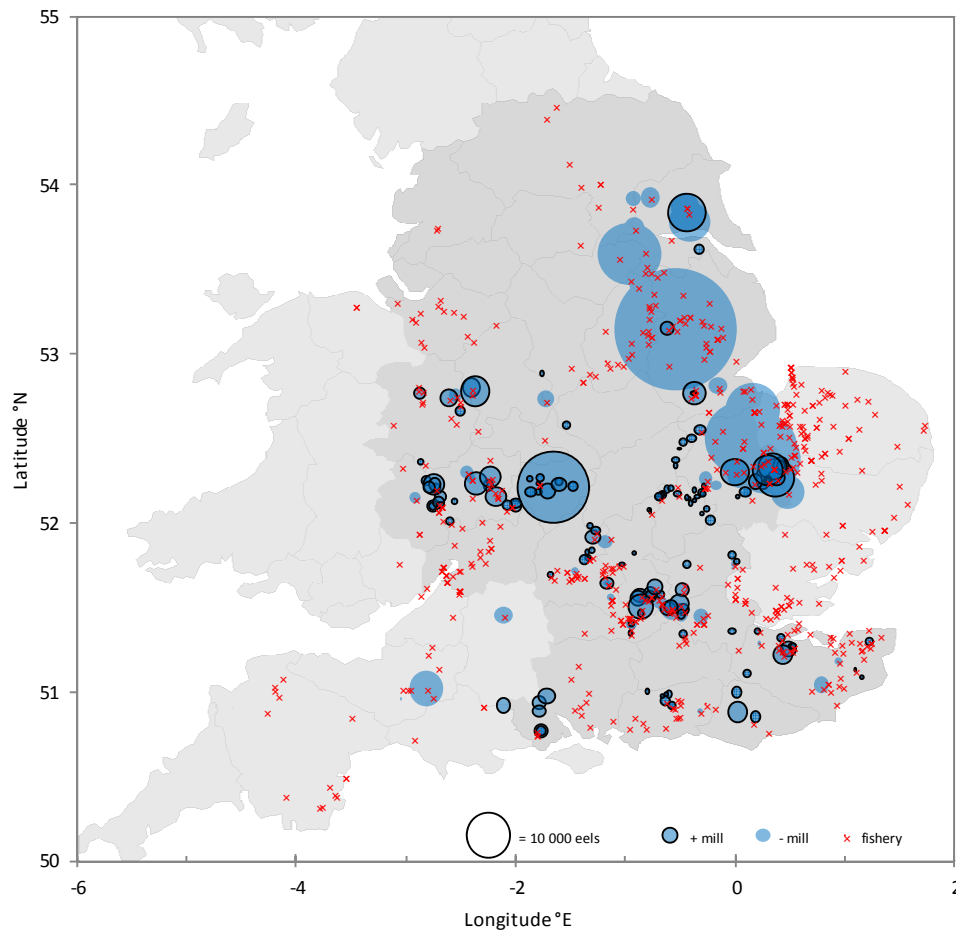
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627 **Figure 2.** Time trend in eel recruitment, estimated by ICES (2014). For the glass eel, two series are shown: one for the
 628 North Sea area and one for data from elsewhere. For yellow eel, only one series is given. This plot shows the
 629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

631



632

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

638

639

640 *In hermodestune [...] Ibi gada 7 pbr. 71. piscaria redit Lxx̄ v. anguill.*

641 **Figure 4.** The highest record of eels in Domesday Book, for Harmston (53.15°N 0.55°W), reads: 'In Hermodestune
 642 [...] Here is a church and a priest and 1 fishery yields Lxx̄ eels.' The number Lxx̄ is constructed from L=50, x=10,
 643 v=5 and the overbar (macron); the overbar indicates a multiplication by thousand; "Lxx̄ anguillae" thus equals
 644 75,000 eels. This quantity reflects the tax yield, not the catch.