

Long-term reduction of late-stage European eel larval abundance at the continental slope reflects glass eel recruitment decline

Lasse Marohn ^{*}, Klaus Wysujack , Marko Freese , Jan-Dag Pohlmann, Tina Blancke, Reinhold Hanel

Thünen Institute of Fisheries Ecology, Herwigstr. 31, 27572 Bremerhaven, Germany

*Corresponding author. E-mail: lasse.marohn@thuenen.de

Abstract

Between 1971 and 1991, a series of ichthyoplankton surveys were conducted along the European continental slope to assess the abundance of late-stage European eel larvae (*Anguilla anguilla*). The information from these surveys provides a valuable baseline for assessing the situation prior and during the recruitment collapse as well as for comparisons with the present-day status. The resulting information can supplement existing eel recruitment data, particularly in regions that are currently not sufficiently covered by glass eel recruitment time series (e.g. eastern and southern Mediterranean Sea). In addition, comparing trends in late-stage larval eel abundance with trends at other life stages may facilitate the identification of life phases and areas with increased mortality, helping to understand the importance of oceanic mortalities for the recruitment decline. In November 2022, a survey was conducted from the northern Bay of Biscay to the Strait of Gibraltar to investigate the current abundance of eel larvae along the continental slope and to test whether current data support the hypothesis of correlated changes between late-stage larval eel abundance and glass eel recruitment. Although this study represents a snapshot of the current situation, the results demonstrate that larval eel densities around the Iberian Peninsula have continued to decrease since the 1980s and that this is in line with the trend observed in glass eel recruitment. The consistency of glass eel and late-stage larval data further indicates that no disproportionately increased mortalities occur during the final larval phase.

Keywords: *Anguilla anguilla*; leptocephalus larvae; fish larval survey; stock management

Introduction

This study investigated the occurrence of European eel larvae (*Anguilla anguilla*), so-called leptocephali, along the European continental slope. By comparing their current abundance with historical catch data from the same area, changes of larval eel abundance since the early 1970s were analyzed with a focus on the potential value of late-stage larval eel assessments for stock management.

When arriving at the continental slope, European eel larvae are close to complete their trans-Atlantic migration that has started in the eel's spawning area in the Sargasso Sea months or years before (Bonhommeau et al. 2010). At this point, the larvae measure between 55 and 85 mm (Tesch 1980) and are about to metamorphose into glass eels before they arrive at continental waters (Cresci 2020), where they colonize a wide range of habitats in fresh, brackish, and marine waters. The European eel is considered a pan-mictic species (Als et al. 2011, Righton et al. 2021), forming a single stock across its entire distribution range, which extends from northern Africa and the Mediterranean in the south to the Barents Sea and the Baltic Sea in the north. As so-called yellow eels, they feed and grow for several years in continental waters until they metamorphose into silver eels, their migratory stage, and migrate back to the Sargasso Sea, where they spawn and die. [For further details of the European eel life cycle, see Hanel et al. 2019 and Cresci 2020].

In the early 1980s, the recruitment of young eels (i.e. glass eels) into European estuaries and coastal waters collapsed and continued to decline until 2011 to values between 1% and 10% compared to the geometric mean of the reference period 1960–79 (ICES 2024a). Since 2011, glass eel recruitment has remained low, and despite the implementation of various measures, there are yet no signs of recovery of the stock (ICES 2024a). Reasons for the recruitment decline are considered to be manifold (e.g. Miller et al. 2016, Righton et al. 2021). While river engineering, river fragmentation, and contaminant loads severely reduced the availability and quality of suitable eel habitats, mortalities caused by hydropower turbines and other water management structures, fisheries, introduced parasites, pathogens, and natural predators have additional negative impacts on the stock. Furthermore, changing oceanic conditions are regarded as potentially relevant (e.g. changes of water temperatures or currents), while their impact on larval survival is still unknown (e.g. Knights 2003, Bonhommeau et al. 2008, Righton et al. 2021).

As a consequence of the severe recruitment decline, the species is considered *critically endangered* (Pike et al. 2023), an international framework for eel management is effective (EU 2007), the international trade of *A. anguilla* products is restricted (CITES Annex II), and an immediate stop of fisheries at all life stages as well as a further reduction of anthropogenic eel mortalities is scientifically advised (ICES 2024b). In accordance with the central goal of the European Eel

Regulation [Council Regulation (EC) No. 1100/2007], many of the proposed management measures aimed at increasing silver eel escapement from coastal and freshwater habitats in order to increase the number of potential spawners. These measures included, among others, restrictions of commercial and recreational fisheries, the improvement of river connectivity, the regulation of predators as well as restocking of juvenile eels and they vary in their implementation in different EU member states. The increase of silver eel escapement as a management target implies that a critically low effective spawning biomass is considered the major driver for stock decline (Dekker 2003). However, alternative hypotheses on climate impact or consequences resulting from impaired spawner quality or larval survival exist (Bonhommeau et al. 2008, Belpaire et al. 2019, Freese et al. 2019). Against this background, the only possibility to disentangle the variety of impacts that affect different life stages of the European eel over time is to add time-series information also to different oceanic life stages of the species, wherever data from before the stock decline exist.

Currently, the development of the European eel stock is assessed by the analysis of glass and yellow eel recruitment time series, indicating relative changes in year-class strengths on an annual basis (ICES 2024a). For these time series, recruiting glass eels are collected among large parts of the distribution area. In some areas, however, recruitment time series are scarce or missing (e.g. eastern and southern Mediterranean Sea, marine habitats) (ICES 2024a). To improve our understanding of stock development and mortalities during different life phases, additional time series in under-monitored distribution areas are helpful. Local yellow and silver eel abundances are usually estimated by modeling approaches (Höhne et al. 2024) and the existing empirical yellow and silver eel time series are often affected by stocking activities, reducing their informative value for an assessment of the total stock.

In this context, a better understanding of the abundance and distribution of eel larvae in the Atlantic Ocean could provide additional information on the development of the stock (Hanel et al. 2014, Westerberg et al. 2018). As shown for other species, standardized surveys on early life stages provide reliable estimates of relative changes in spawning stock biomass and recruitment success [e.g. the international herring larval surveys (ICES 2024c) and the mackerel and horse mackerel eggs survey (MEGS, ICES 2024d)]. The investigation of oceanic larval occurrence and distribution has a long history for the European eel as well (Miller et al. 2015) and efforts have again been increased recently to further investigate and assess temporal and spatial changes of larval abundance in the Sargasso Sea (Hanel et al. 2014, Westerberg et al. 2017, 2018, Miller et al. 2019). But in contrast to early-stage eel larvae in the spawning area and despite the promising results from former surveys, late-stage larval abundance in the eastern Atlantic has not received much attention after a long-term series of ichthyoplankton surveys ended in 1991. This series started >50 years ago and consisted of repeated larval eel surveys that were conducted in the northeastern Atlantic and along the European continental slope to assess the abundance and distribution of late-stage European eel larvae (Tesch 1980, Tesch et al. 1983, 1986, Antunes and Tesch 1997). The surveys were carried out from 1971 to 1977 and from 1982 to 1991 and covered different areas from the British Isles in the north to the Strait of Gibraltar in the south (Tesch 1980, Tesch

et al. 1983, 1986, Antunes and Tesch 1997). The documented catch data indicated that the steep decline in eel recruitment during the early 1980s was also reflected by lower eel larval densities along the continental slope (Tesch et al. 1985). This hypothesis was supported by the observation that strong annual fluctuations in late-stage larval abundance in the Bay of Biscay were directly reflected by changes in glass eel recruitment in the German Ems River (Tesch 1980).

These historical data on late-stage larval eel abundance provide a valuable baseline from which to compare the present-day status with the situation prior and during the recruitment collapse. The dataset facilitates the assessment of changes in eel larval abundance along the continental slope over a long time period. While the development of recruitment is well documented and monitored by glass eel indices in continental waters and while an early-stage larval time series is being developed in the Sargasso Sea (Hanel et al. 2014), indicators for stock development obtained by late-stage larval abundance time series could help assessing changes in year-class strengths at an additional developmental stage and at the same time complement the data obtained from glass eel time series. In addition, insights into larval abundances at the end of the transoceanic migration can also provide important information on mortalities at different time points during the larval phase. In this context, studies on late-stage larval abundance in the Bay of Biscay and along the Iberian coast are of particular importance as these areas account for the major part of the overall European glass eel recruitment (Bornarel et al. 2018). Last but not least, the monitoring of larval abundances at geographical key points has the potential to assess information on recruitment into large parts of the species' distribution area, as described in Freese et al. (2025) for the Mediterranean Sea.

To assess whether the decline of the European eel stock over the last decades is also reflected by a reduced abundance of late-stage eel larvae along the European continental slope, an ichthyoplankton survey was conducted in November 2022 from the northern Bay of Biscay, around the Iberian Peninsula, and into the western Mediterranean Sea (Fig. 1). Survey region, fishing locations, time of year, and sampling methods were chosen in accordance with previous surveys used for direct comparison. This study aimed to test whether late-stage larval abundance along the continental slope provides additional information on relative changes in recruitment over time. In addition, the size distribution of eel larvae among the study area was assessed and data on leptocephalus larvae of other Elopomorph species were collected.

Materials and methods

Study area and sampling procedure

An ichthyoplankton survey was conducted on board *R/V Meteor* (M185) in November 2022 across the Bay of Biscay, around the Iberian Peninsula, and into the Alboran Sea (Fig. 1). An Isaacs-Kidd midwater trawl (IKMT-S, Hydro-Bios GmbH, Altenholz, Germany) with a net opening of ~7 m² and a mesh size of 1550 µm was used to catch leptocephalus larvae at 48 stations (60 hauls). The IKMT-S was deployed at a speed of ~2.5 kn through water for a duration 37–201 min. Filtered water volumes were assessed with flowmeters (2030R, General Oceanics, Miami, USA) and varied between 13 545 and 75 733 m³ per haul. During darkness, stations were usually

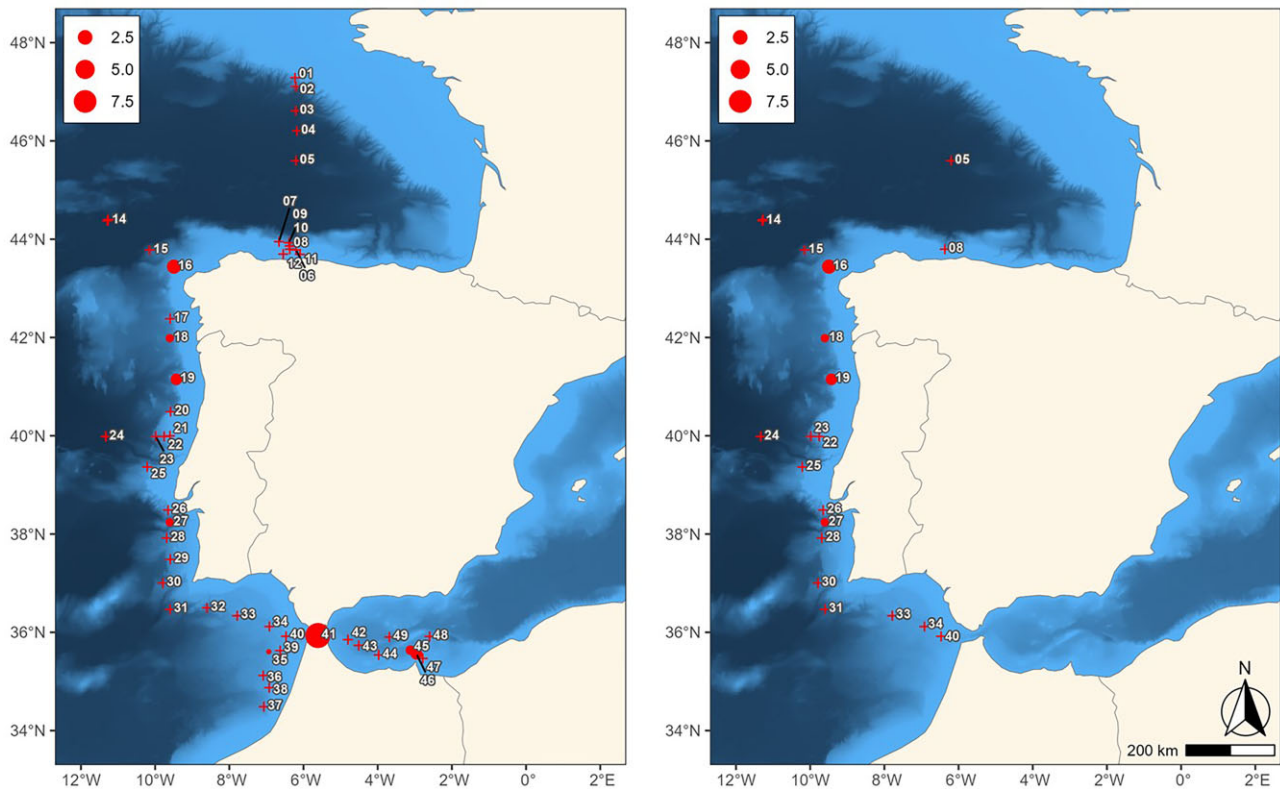


Figure 1. Issacs–Kidd midwater trawl (IKMT) sampling stations and *A. anguilla* larval abundance. The size of the circles indicates larval densities (number of larvae per hour of trawling) and crosses represent stations where no *A. anguilla* larvae were caught. Left panel: all stations; right panel: stations used for comparison with historical catches. For detailed information on leptocephalus catches at stations, see [Table S2](#).

fished in double oblique hauls to maximum depths of 100 or 200 m ($N = 37$; 39–121 min; 15 244–43 964 m^3), while day-time catches ($N = 23$; 37–201 min; 13 545–75 733 m^3) were mostly conducted in single oblique hauls to maximum depths between 400 and 600 m to account for the diel vertical migrations of late-stage eel larvae as described by Tesch (1980). Detailed information on stations is summarized in [Table S1](#).

In addition, a larger mesh size (4 mm) IKMT (IKMT-L, Hydro-Bios GmbH, Altenholz, Germany) with a net opening of 14.6 m^2 (3.10 m x 4.70 m) was deployed at 12 stations (13 hauls) with a speed of ~ 3 kn through water for a duration of 66–309 min (55 557–342 057 m^3) and maximum depths between 220 and 1500 m ([Table S1](#)).

All leptocephalus larvae (including non-*Anguilla* species) were sorted from the catches immediately after the samples were on board, morphologically identified, and measured to the lowest millimeter. Tissue samples were taken from all leptocephalus larvae and preserved in ethanol (96% abs.) for a subsequent genetic verification of the morphological species identification.

Genetic species identification of leptocephalus larvae

DNA was extracted from tissue samples of leptocephalus larvae using Chelex 100 (Walsh et al. 1991). Anguillid species were analyzed by a real-time polymerase chain reaction (PCR) based assay for the detection of *A. anguilla* and *A. rostrata*, and all other species were assessed by Nucleotide BLAST of the mitochondrial DNA cytochrome c oxidase I (COI)

(Altschul et al. 1990). In addition, all *Anguilla* leptocephali were tested for the occurrences of *A. anguilla*/*A. rostrata* hybrids with a restriction fragment length polymorphism (RFLP) test based on a nuclear 18S rRNA gene marker (Frankowski et al. 2010), modified by replacing the original restriction enzymes with their isoschizomers BssSI-v2 and BssHIII (New England Biolabs, Frankfurt am Main, Germany).

Reanalysis of historical data and comparison with current catches

For the analysis of historical catch data, all available information from scientific publications and reports was used. For comparison, historical surveys had to meet the following criteria: (i) The survey took place between October and December, (ii) stations were located within the study area of the M185 survey, (iii) an IKMT (or comparable gear) was used, (iv) catches were made during night time within the upper 200 m, and (v) *A. anguilla* larval abundance was assessed as number of larvae per hour of trawling. Based on these criteria, 14 surveys were selected for the reanalysis of *A. anguilla* catch data ([Table 1](#)). The level of detail in available data varied considerably between studies, and from most surveys, only mean values for larval catches per region were reported and raw data and confidence intervals were usually missing. Information on zero-catch stations was also lacking in most sources. Therefore, the analysis of historical data was limited to mean values per region. Larval surveys in the 1970s only took place in the Bay of Biscay and north of it, while the expeditions in the 1980s also covered the continental slope off the Iberian Peninsula.

Table 1. List of surveys used for the comparison of *A. anguilla* larval abundance

Date	Ship	Gear (net opening, mesh size)	Number of hauls	Area	xSource
Oct/Nov 1973	<i>RV Friedrich Heincke</i>	IKMT (2 m ² , 850 µm)			Tesch (1980)
Oct/Nov 1974	<i>RV Friedrich Heincke</i>	IKMT (2 m ² , 850 µm)		West Ireland to	Tesch (1980)
Oct/Nov 1975	<i>RV Friedrich Heincke</i>	IKMT (2 m ² , 850 µm)	135	southern Bay of	Tesch (1980)
Oct/Nov 1976	<i>RV Friedrich Heincke</i>	IKMT (2 m ² , 850 µm)		Biscay	Tesch (1980)
Oct/Nov 1977	<i>RV Friedrich Heincke</i>	IKMT (2 m ² , 850 µm)			Tesch (1980)
28.10.1982–21.11.1982	<i>RV Friedrich Heincke</i>	IKMT (6 m ² , 1800 µm)	44	Biscay to west of	Tesch et al. (1983,
				Gibraltar	1986)
01.11.1982–03.11.1982	<i>RV Tridens</i>	Modified trawl (7 m ² , 850 µm)	4 stations	Biscay to west of	Tesch et al. (1983)
				Portugal	
10.11.1983–11.12.1983	<i>RV Friedrich Heincke</i>	IKMT (6 m ² , 1800 µm)	74	Biscay to west	Tesch et al. (1986)
				Mediterranean	
15.11.1984–13.12.1984	<i>RV Friedrich Heincke</i>	IKMT (6 m ² , 1800 µm)	29	Biscay to west of	Tesch et al. (1986)
				Gibraltar	
11.11.1985–14.11.1985	<i>RV Friedrich Heincke</i>	IKMT (6 m ² , 1800 µm)	22	Bay of Biscay	Tesch et al. (1986)
31.10.1986–08.11.1986	<i>RV Friedrich Heincke</i>	IKMT (6 m ² , 1800 µm)	Between		Tesch and Niermann
		(occasionally 2 m ² , 850 µm)	20 and 43		(1992)
06.11.1987–15.11.1987	<i>RV Friedrich Heincke</i>	IKMT (6 m ² , 1800 µm)	Between	Biscay to west of	Tesch and Niermann
		(occasionally 2 m ² , 850 µm)	20 and 43	Portugal	(1992)
12.11.1988–20.11.1988	<i>RV Friedrich Heincke</i>	IKMT (6 m ² , 1800 µm)	Between		Tesch and Niermann
		(occasionally 2 m ² , 850 µm)	20 and 43		(1992)
23.10.1991–28.10.1991	<i>RV Heincke</i>	IKMT (6 m ² , 850 or 1800 µm)	31	Biscay to west of	Antunes and Tesch
				Portugal	(1997)
04.11.2022–24.11.2022	<i>RV Meteor</i>	IKMT-S (7m ² , 1550 µm)	60	Biscay to west	This study
				Mediterranean	

To account for differences in IKMT net openings between studies, the abundance of eel leptocephali was adjusted to a theoretical net opening of 7 m², as used in this study, by extrapolating the number of caught larvae accordingly. Different mesh sizes between studies were regarded irrelevant, since they were all considered to effectively catch *A. anguilla* larvae in the investigated regions.

In this study, the number of stations in the Bay of Biscay was limited by weather conditions, which prevented a reliable assessment of leptocephalus abundance in this region. Only five hauls from four stations met the requirements for a comparative analysis (Table S1). Therefore, in this region, only a comparison among historical surveys was possible, as already done by Tesch et al. (1986). Along the western and southwestern Iberian Peninsula, however, 16 stations from 2022 fulfilled the criteria for the comparative analysis (Table S1).

Results

Total catch of *A. anguilla* larvae

A total of 31 *A. anguilla* leptocephalus larvae were caught in 60 hauls (Table S2), of which 28 were caught during darkness with the IKMT-S in the upper 100 m ($N = 15$) or 200 m ($N = 13$). Only one European eel leptocephalus larva was captured during daytime (IKMT-S, deployed to 600 m depth) and two individuals were caught with the IKMT-L (stations 31-3 and 40-3 at darkness during net deployments to 1000 and 400 m depth, respectively). Except from stations around Gibraltar and in the Alboran Sea, *A. anguilla* larvae were only caught at sites with a water depth of >800 m off the continental shelf.

Along the western Iberian Peninsula (stations 16-3 to 30-3), seven eel larvae were caught in four out of 18 IKMT-S hauls, and off the Moroccan Atlantic coast, one eel leptocephalus

larva was caught in four hauls (stations 35-3 to 39-2). The highest number of eel larvae was sampled in the central part of the Strait of Gibraltar (stations 41-1 to 41-14) with 17 larvae in eight IKMT-S hauls. The vast majority of these leptocephali was caught in one haul ($N = 13$) under special hydrographic conditions found in the Strait of Gibraltar (for details, see Freese et al. 2025). In the Mediterranean Sea (stations 42-2 to 49-2), four eel larvae were captured in eight hauls. No eel larva was caught with the IKMT-S in the Bay of Biscay (17 hauls, stations 1-2 to 15-3) and along the southern Iberian Peninsula (five hauls, stations 31-2 to 34-3 and 40-2).

Comparison of larval abundances with historical catches

During the first series of ichthyoplankton surveys (1973–77), the abundance of European eel larvae in the Bay of Biscay fluctuated strongly between years, with high catches in 1973, 1975, and 1977 (52.5, 50.0, and 24.7 $N h^{-1}$) and lower catches in the years 1974 and 1976 (6.7 and 5.7 $N h^{-1}$) (Fig. 2, Table S3). During the second sampling period (1982–91), catches in the Bay of Biscay were one order of magnitude lower compared to the strong year classes in the 1970s, ranging from 1.1 to 5.4 eel larvae per hour of trawling (Fig. 2, Table S3). In 2022, no eel larva was caught in the Bay of Biscay, but sampling effort was low due to bad weather conditions.

Further south, along the western and southern coast of the Iberian Peninsula, data from the 1970s were not available because the region was not sampled at that time. Between 1982 and 1991, abundances in this region ranged from 2.2 to 9.5 larvae per hour. In 2022, seven *A. anguilla* larvae were caught in this area (Table S2), corresponding to an abundance of 0.4 eel larvae per hour of trawling and a density of 1.46 eel larvae per 100 000 m³ water volume. One specimen caught at station 19-2 already commenced the metamorphosis into a glass eel,

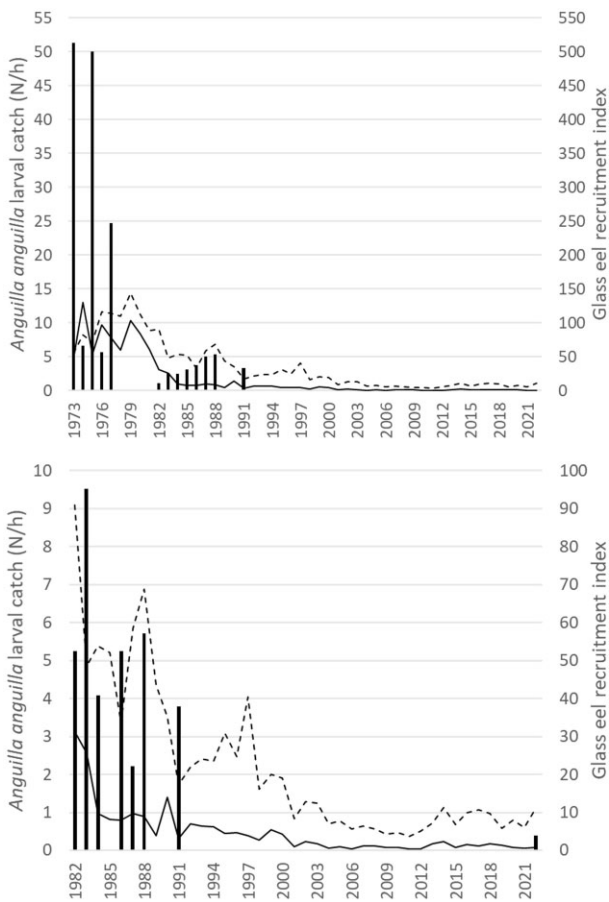


Figure 2. Abundance of *A. anguilla* larvae in the Bay of Biscay from 1973 until today (upper panel) and off the western and southern Iberian Peninsula from 1982 until today (lower panel). Columns represent the number of eel larvae caught per hour of trawling. ICES glass eel recruitment indices (ICES 2023) are indicated by a solid (“North Sea Index”) and a dashed line (“Elsewhere Europe Index”).

showing clear changes in shape and transparency (Fig. S1). In 12 hauls, no *A. anguilla* larva was caught, corresponding to a 75% share of zero-catch stations.

Length distribution of *A. anguilla* larvae

The body length of European eel larvae caught in this study ranged from 54 to 76 mm (Fig. 3, Table 2). Along the Iberian west coast, only one specimen measured <70 mm. This individual had a length of 65 mm and was already metamorphosing into a glass eel. Its comparably low body length could therefore be the result of size reduction during metamorphosis. Larvae caught at the entrance to the Mediterranean Sea measured between 54 and 66 mm and individuals caught in the Alboran Sea were between 59 and 69 mm.

Catches of leptocephalus larvae from other Elopomorpha

In addition to European eel larvae, 55 leptocephalus larvae of seven other Elopomorph species from five families were caught. These were *Conger conger* ($N = 30$), *Gnathophis* sp. ($N = 5$), and *Pseudopichthys splendens* ($N = 1$) (all Congridae), *Synphobranchius kaupii* (Synphobranchidae, $N = 8$), *Cyema atrum* (Cyematidae, $N = 5$), *Eurypharynx*

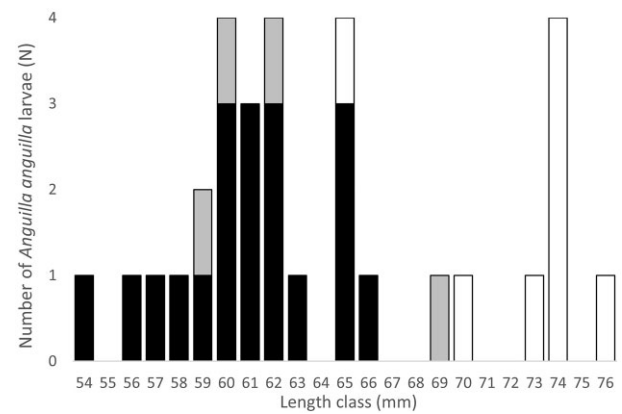


Figure 3. Length frequency of *A. anguilla* larvae in three different regions. White bars = western Iberian Peninsula, black bars = west and inside the Strait of Gibraltar, and gray bars = Alboran Sea.

pelecanoides (Eurypharyngidae, $N = 4$), *Aldrovandia oleosa* (Halosauridae, $N = 1$), and one heavily damaged specimen that could neither be identified morphologically nor be identified genetically due to repeated PCR amplification failure. Details are provided in Table 3 (length data) and Table S2 (sampling locations).

Discussion

Along the western and southern Iberian Peninsula, the large number of sampling stations that met the methodological requirements for a comparison with historical surveys (gears, sampling sites, time of the year) suggest that the catch data obtained in late 2022 represent a reliable dataset for the abundance of *A. anguilla* larvae in this region. Sixteen stations between Cap Finisterre and the western entrance of the Strait of Gibraltar met the requirements for a comparison with historical data (i.e. IKMT night-time hauls in the upper 100 or 200 m), and the low catch quantities in 2022 therefore indicate that the abundance of European eel larvae was considerably lower in this region compared to the sampling period from 1982 to 1991. While the corrected mean abundance between 1982 and 1991 ranged from 2.2 to 9.5 eel larvae per hour of trawling, the 2022 survey resulted in only 0.4 larvae h^{-1} (Fig. 2, Table S3). This strong decrease of late-stage larval abundance from the 1980s until today is in the same order of magnitude as the decline of the “ICES Elsewhere Europe Index” (ICES 2023) during this time period (Fig. 2), supporting the hypothesis that changes in eel larval abundance along the European continental slope correspond to changes in glass eel recruitment (Tesch 1980). These findings further corroborate the assumption that the recruitment decline from before the 1980s until today is well reflected by the reduction of late-stage eel larvae in the eastern Atlantic (Tesch et al. 1986). Although this survey must be regarded as a snapshot of the current situation, requiring careful interpretation to determine whether it reflects the overall trend, an obvious decline in the abundance of late-stage larvae in this area is notable. Repeated investigations, however, would clearly increase the reliability of this observation.

From the Bay of Biscay, historical catch data were available for the years 1973–77, 1982–88, and 1991. While in the 1970s eel larval abundance in this region showed a high interannual variability, with alternating years of high and low

Table 2. Body lengths of *A. anguilla* larvae in different regions

	Number of larvae (N)	Mean length (mm)	SD (mm)	Range (mm)
Western Iberian Peninsula	8	72.5	3.5	65–76
West of and inside Strait of Gibraltar	19	60.9	3.2	54–66
Alboran Sea	4	62.5	4.5	59–69

Table 3. Number and length of leptocephalus larvae caught during M185

Species	Number of larvae (N)	Mean length (mm)	SD (mm)	Range (mm)
<i>Anguilla anguilla</i>	31	64.1	6.1	54–76
<i>Aldrovandia oleosa</i>	1	NA	NA	>100
<i>Conger conger</i>	30	74.6	18.7	45–115
<i>Cyema atrum</i>	5	25.2	4.0	22–32
<i>Eurypharynx pelecanooides</i>	4	16.7	1.2	16–18
<i>Gnathophis</i> sp.	5	64.3	8.0	56–72
<i>Pseudopichthys splendens</i>	1	NA	NA	NA
<i>Synphobranchus kaupii</i>	8	71.8	8.9	65–93
Not identified ^a	1	NA	NA	NA

^aHeavily damaged.

larval abundance (Tesch 1980), abundance in the 1980s was much lower and more stable among years, with an increasing trend from 1982 to 1988 (corresponding to a small increase in the “ICES Elsewhere Europe Index”) (Fig. 2). In 2022, unfavorable weather conditions hindered extensive sampling in the Bay of Biscay and only five hauls could be made under comparable settings, preventing a reliable assessment of eel larval abundance from this region. Nonetheless, while also in historical surveys the density of eel larvae in the Bay of Biscay was usually lower than that in the west of the Strait of Gibraltar (Tesch et al. 1986), the absence of any eel larvae from this region in 2022 might still indicate a reduced abundance of *A. anguilla* larvae also in this region. Although zero-catch stations were not documented properly in most historical studies, Tesch et al. (1983) stated that between 1973 and 1977 zero catches “very rarely occurred” in the Bay of Biscay. At the same time, occasional high larval catches were reported with single hauls containing up to 140 and 41 individuals in the Bay of Biscay in 1975 and 1977, respectively (Tesch 1980). In 1982, only one haul in each of the two surveys conducted that year contained no eel larvae (Tesch et al. 1983), and in October 1991, Antunes and Tesch (1997) reported 10 zero-catch hauls out of 31 (32.3%) in the Bay of Biscay and west of the Iberian Peninsula and a maximum catch of 24 eel larvae in one haul.

The observed correlation between late-stage larval and glass eel abundances over a time span of almost 50 years indicates the potential of ichthyoplankton investigations as a fisheries-independent data source for eel recruitment, particularly in regions that are currently not covered by ICES recruitment series. The Strait of Gibraltar, despite its complex hydrographic conditions, could be a model example for a larval eel monitoring site, due to its bottleneck function for eel recruitment into the Mediterranean Sea (Freese et al. 2025). An assessment of yearly changes in eel larval abundance in the Strait of Gibraltar could be a proxy for recruitment changes for a large marine ecosystem and an important part of the species’ distribution area. Furthermore, the extension of recruitment information to areas with lim-

ited data availability would enhance the ability to detect or rule out potential regional shifts in eel recruitment over time.

Another important challenge in eel management is the identification and quantification of mortality factors responsible for the recruitment decline. A comparative assessment of changes in abundance among different life stages, habitats, and/or regions can help defining areas or life phases with increased mortalities. A good example for this approach is a study by Westerberg et al. (2018), which compared changes in fisheries landings, larval abundance in the spawning area, and glass eel recruitment over time. The eel stock decline is, though on a less reliable data basis than for glass eel recruitment, also reflected by a reduction in eel landings (Dekker 2003, Westerberg et al. 2018) and by an abundance decline of early-stage eel larvae in the spawning area of the species, where a long-term decline of larval densities becomes evident when comparing recent and historical abundance data from the Sargasso Sea (Hanel et al. 2014). However, this observed decline appears to be lower than the decline of glass eels as assessed by the recruitment time series, suggesting that oceanic factors are at least partly responsible for the recruitment collapse and/or that geographical shifts of larval recruitment have occurred that are not fully reflected by the existing recruitment time series (Westerberg et al. 2018). Following this approach, the results of this study, which show similar declines of late-stage larval abundance and glass eel recruitment, suggest that no disproportionately increased mortalities have occurred during metamorphosis into glass eels and during the final part of the migration across the continental shelf.

Regarding the geographical distribution of larval lengths, the clear northward increase, as observed in this study, is in line with former findings (Tesch 1980, Tesch et al. 1986, Bast and Strehlow 1990, Tesch and Niermann 1992, McCleave et al. 1998). This consistently observed pattern has caused extensive speculations on potential oceanic drift trajectories of eel larvae, with Tesch et al. (1986) and Bast and Strehlow (1990) concluding that the observed increase in larval length with latitude is also reflecting an increase in age, indicating that eel

larvae from southern areas move into a northern direction. On the basis of the same data, Bast and Strehlow (1990) proposed that larvae at least partly migrate actively into an east-northeastward direction and that the importance of the Gulf Stream as a transport medium for European eel larvae might thus be overrated. McCleave et al. (1998) strongly questioned this hypothesis and suggested that the cline in length instead could be caused by higher growth rates due to higher productivity in cooler waters in the north. However, while the catches of eel larvae along the Gulf Stream leave no doubt on its importance as a major route for eel larvae toward Europe (e.g. Miller et al. 2015), a direct eastward transport of larvae via frontal counter-currents might still be an additional migration route for larvae from the eastern part of the Sargasso Sea toward northeastern Atlantic and Mediterranean coasts (McCleave 1993, Kettle and Haines 2006, Miller et al. 2015). Miller et al. (2015) assumed that despite a lack of sampling to test this hypothesis, the smaller size of the larvae along this potential route indicates that they were not transported via the Gulf Stream but were directly transported eastward from the eastern part of the spawning area. A comprehensive analysis of glass eels from different locations in Europe again showed that the length and weight distributions were unimodal, suggesting that they do not belong to different cohorts or use migration routes that differ significantly in length (Briand et al. 2019). Thus, whether the observed differences in larval length are the result of different transport routes remains unclear.

Late-stage eel larvae are known to make extensive vertical migrations, with preferred depths in the upper 200 m during night and between 300 and 600 m during daytime (Tesch 1980). To account for this behavior, hauls that were made under daylight conditions during M185 were performed down to depths of 400–600 m (Table S1). However, only one European eel leptocephalus larva was caught during daylight (station 35-3), suggesting that the greater dispersal over depth combined with low abundance makes it highly unlikely to catch eel larvae during the day. The same applies to the leptocephalus larvae of other Elopomorph species with only five specimens being caught under daylight conditions during this survey.

In summary, this study indicates that changes in late-stage European eel larval abundance reflect changes in glass eel recruitment over time suggesting that the assessment of larval abundance at geographical key locations could provide valuable recruitment information for regions that are not sufficiently covered by glass or yellow eel recruitment monitoring. However, since this study only provides a single-shot observation of the present situation, repeated investigations are needed to confirm consistency over time and validity also for other regions.

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Author contributions

L.M., R.H., and K.W. conceptualized the study. All authors were involved in data assessment. T.B. conducted the genetic analyses. L.M. analyzed the data and wrote the original manuscript draft. All authors reviewed and edited the manuscript and provided additional text.

Supplementary data

Supplementary data is available at the *ICES Journal of Marine Science* online.

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Data availability

Data generated and/or analyzed during this study are available from the corresponding author on request.

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