Received: 7 September 2020 | Revised: 10 June 2021 | Accepted: 21 June 2021

DOI: 10.1111/fme.12505

ARTICLE

Fisheries Management and Ecology WILEY

Using logbook-based catch-rate data to detect yellow eel population trends in the southern Baltic Sea

Malte Dorow[1] | Wolf-Christian Lewin[2] | Dietmar Lill[3] | Claus Ubl[4] | Jens Frankowski[1]

[1]State Research Centre for Agriculture and Fisheries Mecklenburg-Vorpommern, Institute of Fisheries, Rostock, Germany

[2]Thünen Institute of Baltic Sea Fisheries, Rostock, Germany

[3]NAWA GbR, Broderstorf, Germany

[4]German Fisheries Association, Hamburg, Germany

Correspondence
Malte Dorow, State Research Centre for Agriculture and Fisheries Mecklenburg-Vorpommern, Institute of Fisheries, Rostock, Germany.
Email: m.dorow@lfa.mvnet.de

Funding information
European Maritime and Fisheries Fund; State Mecklenburg-Vorpommern

Abstract

Within recent years, a slight but significant increase of European eel *Anguilla anguilla* (L.) recruitment has been documented, but it remains questionable whether or not the increased recruitment levels resulted in higher eel numbers at the regional scale. To detect the changes in yellow eel numbers, logbook data covering a 15-year time series of catch per unit effort (CPUE) data from the German Baltic Sea were analysed. Monthly mean catch rates were calculated for two different size classes for two passive gears: fyke and stationary trap nets. Change-point analysis was applied to discover changes in the catch data. After a period of decreasing or constant catch rates, the fyke net data indicated that yellow eel numbers increased slightly in recent years in the Baltic Sea. Besides increasing numbers of immigrating juvenile eels, other population dynamics or conservation efforts might have added to the observed positive stock trend.

KEYWORDS
Anguilla anguilla, change-point analysis, coastal waters, commercial fishery, eel management, European eel, stock dynamics

1 | INTRODUCTION

The recruitment of European eel *Anguilla anguilla* (L.) has declined severely since the 1970s (ICES, 2020) due to changes in oceanic conditions (Friedland, Miller, & Knights, 2007; Knights, 2003) and also due to various human-generated pressures during the continental (coastal and inland waters) part of the species' life cycle. These pressures include overfishing, habitat loss, habitat degeneration, parasitism and pollution. To counter this downward population trend, international eel conservation efforts included CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) listing in 2007 of European eel in Appendix II in order to prevent the trade of the eel outside of Europe. Furthermore, the European Commission adopted a regulation in 2007 that requires European member states to establish eel conservation management plans and member states were requested to monitor their conservation efforts outcomes (EC, 2007).

The robust evaluation of eel stock development requires data from the full range of aquatic habitats occupied by eels. As a facultative-catadromous species, yellow eels settle in coastal, brackish and inland aquatic habitats during their continental life phase (ICES, 2009), and the importance of such areas for the eel stocks has been highlighted by various studies (Daverat et al., 2006; ICES, 2009; Shiao, Ložys, Iizuka, & Zeng, 2006), although the contribution of small coastal streams to eel recruitment remains virtually unstudied (Copp, Daverat, & Bašić, 2021). Yellow eels that remain in coastal waters have faster growth rates (Daverat & Tomás, 2006; Simon, Ubl, & Dorow, 2013) and are less frequently infected by the swim bladder nematode *Anguillicoloides crassus* (Kuwahara, Niimi & Hagaki) (Jakob, Hanel, Klimpel, & Zumholz, 2009; Wysujack, Dorow, & Ubl, 2014) than eels in nearby fresh waters. Consequently, eels in coastal waters should be treated separately from those inhabiting fresh waters (ICES, 2009).

Ideally, abundance indices should be based on fisheries-independent data. Fisheries-independent data, for example, may provide abundance data of juvenile fishes, non-commercial or protected species as well as data obtained from sampling during closed seasons or inside restricted areas. The collection of fisheries-independent data is methodologically challenging and costly, in particular for yellow eels in coastal waters (ICES, 2009). As for many other fish stocks, the use of fisheries-dependent data may be an alternative. Most commonly collected are catch and effort data, which allow species-specific catch per unit effort (CPUE) calculation. This unit of measure is a function of true abundance and catchability, the latter being a function of the locomotive activity of a specific fish species and gear efficiency (Harley, Myers, & Dunn, 2001; Maunder et al., 2006). One basic requirement for scientific use of fishery-dependent CPUE data is the reliability of reporting.

The use of CPUE data as a measure of density is based on the assumptions that the catch is proportional to the product of number of fish captured per fishing effort (time or area) at small spatial scales, and that the locomotive activity of fish and the gear efficiency is constant over time (Maunder & Punt, 2004). Consequently, well-designed and coordinated fisheries-dependent monitoring programmes might be an opportunity to assess the stock development of yellow eels in coastal areas where fisheries-independent monitoring approaches are difficult to apply. In previous studies, eel-specific CPUE data have been used to investigate spatial and/or temporal trends in marine and freshwater eel stocks in the context of various research questions (Bernotas et al., 2016; Carss, Elston, Nelson, & Kruuk, 1999; Koed & Dieperink, 1999). Referring to these studies, the standardised documentation of yellow eel-specific CPUE data might provide a valid basis to analyse stock trends at a regional scale.

The present study evaluated the yellow eel stock trend in coastal waters of the German part of the southern Baltic Sea based on a 15 years CPUE time series. Shifts or non-linear patterns in the CPUE time series would reflect changes in the yellow eel abundance. With reference to the general recruitment development in the North Sea and Baltic Sea region (ICES, 2020), with a decreasing trend after 1990, a minimum level in 2010 and 2011, and an increasing trend afterwards (Supplement S1), catch rates of yellow eels were hypothesised to display a similar time-delayed trend. Lowest CPUE rates for legal-sized yellow eels should occur after the recruitment minimum (2010–2011). Referring to current minimum size limits and the mean growth rate of eels in the study area (cf. Simon et al., 2013), increasing catch rates for nearly legal-sized yellow eels should be detectable in recent years (2017–2018). The presented regional catch series for coastal waters will contribute to a better understanding of eel population dynamics in the Baltic Sea in particular and to eel stock dynamics in coastal waters in general.

2 | MATERIALS AND METHODS

2.1 | Eel management in the study area

The study area was situated along the German part of the southern Baltic Sea, part of the federal state Mecklenburg-Western Pomerania, extending eastward (ICES Baltic Sea Subdivision 24) from the Darss Sill peninsula and westward from the peninsula to the border of Poland (ICES Baltic Sea Subdivision 22) (Figure 1). The coastal waters and inner lagoons of this area represent an area of 365,500 ha (three nautical miles border) along a coastline length of 1360 km, and are characterised by pronounced salinity, temperature and oxygen gradients. The stratification of deep-water areas is primarily determined by the amounts and frequencies of saline water inflows through the narrow Danish Straits as well as by riverine freshwater inflows and net precipitation (Ojaveer et al., 2010). The coastal zone subdivides to various habitat types differing in

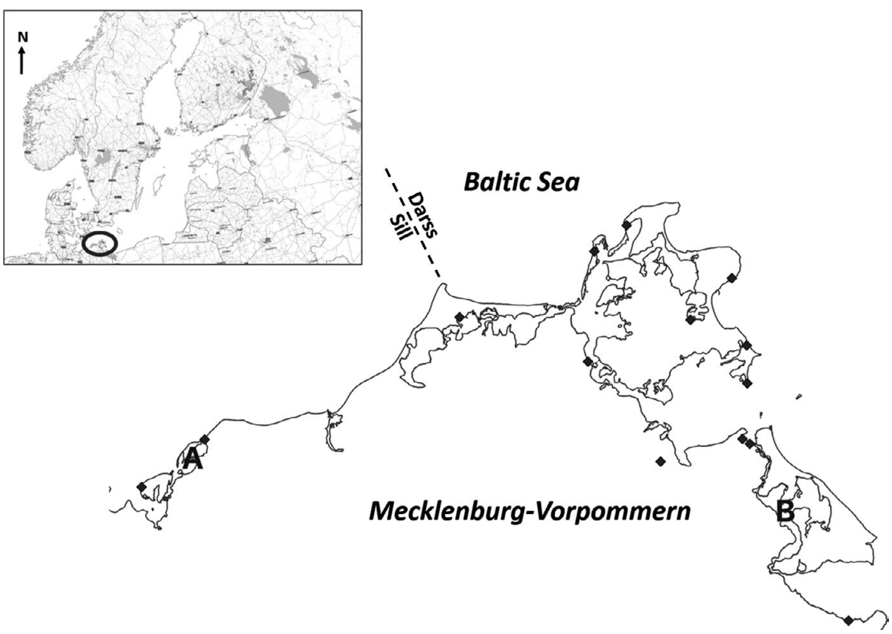

FIGURE 1 Map of the coastline of Mecklenburg-Western Pomerania, black squares indicate the location of resident harbours of participating fishers, letters highlight the areas of the glass eel stocking programme (A – Salzhaff; B – Peenestrom/Achterwasser)

depth, sediment type, degree of bottom structure, and trophic state (Winkler et al., 2007).

Yellow eel is found in all coastal habitats of this area (Winkler et al., 2007). Along the coast of Mecklenburg-Western Pomerania, the eel fishery has a long history and is still of commercial importance for the area's multispecies coastal fishery (Dorow, Lill, & Ubl, 2017). Between 1955 and 1970, annual eel harvest rates were as high as 1100 t (Dorow et al., 2017). Since the 1970s, annual eel landings have declined continuously, leading to a mean annual eel harvest of 81 t during the 1980s. The current mean annual commercial fishery harvest of eels during 2014–2018 was ≈41 t (LALLF, 2021a, Supplement S2). The number of registered full-time (mostly individual) fishers in the study area decreased between 2004 and 2018 from 407 to 220 (LALLF, 2021b; Supplement S2). Therefore, the annual eel landing data could result in biased eel stock assessments, as the eel-specific fishing effort varied within the last two decades. Against this background, CPUE-based data might be better suited to analyse eel abundance trends in the study area.

The largest part of coastal waters within the 3-mile zone of Mecklenburg-Western Pomerania falls into the Eel Management Unit of Warnow/Peene (Ubl & Jennerich, 2008), with a small part belonging to the Oder Unit. In recent years, various eel conservation measures were implemented in the coastal waters of Mecklenburg-Western Pomerania. Based on the European eel regulation, the minimum size limit was increased from 45 to 50 cm in 2009. Because of the differences in TL at the age of maturation (Tesch, 2003), the current minimum size limit led to a disproportionate commercial harvest of female eels. In 2017, a 3-month seasonal closure (November to January) for the commercial fishery was implemented. To assess the potential conservation effect of glass eel stocking, which was regularly carried out to increase the silver eel escapement in inland waters, 60 kg of marked glass eels (with Alizarin Red S) were stocked annually in the coastal areas Wismar Bay/Salzhaff and Peenestrom/Achterwasser (Figure 1) between 2014 and 2016 (Buck & Kullmann, 2020; Dorow & Schaarschmidt, 2014).

2.2 | Logbook study

To generate the eel-specific CPUE data, a voluntary logbook programme was initiated in 2004, with a starting sample size of 22 commercial fishers, which were representative for the multispecies full-time coastal fishery in Mecklenburg-Western Pomerania. Fishers taking part in the study received a small financial annual compensation for their efforts. Fyke net chains (FNCs) and stationary net traps (SNTs) were the primary passive fishing gears for eels. The FNCs consisted of double-chamber fyke nets, with leader nets between the fyke chambers that varied in length between 5 and 8 m. The larger SNTs mostly had a leader length between 50 and 100 m. Depending on the individual fisher's capacity, boat size and time, the FNCs consisted of between 40 and 200 large, double fyke nets connected in one chain. The FNCs were usually randomly deployed close to the harbour of the respective fisher, whereas SNTs were placed at fixed stations over a complete fishing season. Depending on weather conditions and time of the season, these gears were regularly emptied every 3 or 4 days. The knot-to-knot mesh size of FNCs varied from 14 to 16 mm. The SNTs had a knot-to-knot mesh size between 16 and 20 mm. These mesh sizes result in a full selectivity for eels with a TL of ≈45–50 cm for FNCs; and ≈55–65 cm for SNTs, respectively (Bevacqua, De Leo, Gatto, & Melià, 2009). To a lesser degree, participating fishers also used longlines with hook numbers of 1000–6000 hooks (mostly hook size 1/0) per longline. During the study period, hook size was not changed. Shrimp species [common shrimp *Crangon crangon* [L.]; Baltic shrimp *Palaemon adspersus* [Rathke]; rockpool shrimp *Palaemon elegans* Rathke] or sandeel species (small sandeel *Ammodytes tobianus* [L.]; great sandeel *Hyperoplus lanceolatus* (Le Sauvage)] were usually used as baits.

Based on temperature-dependent eel activity, the eel fishing season in the study area began in April and ended in October. Passive gear fishery is traditionally restricted to the area of the individual harbour of registry of a specific fisher. During the study period, the port of registry was constant, and participating fishers using passive gears did not switch to areas outside their ancestral fishing territory. By contrast, the longline fishery was conducted over a wider radius around the harbour of registry and mostly outside the three nautical mile border.

All participating fishers used a standardised protocol to generate trip-based data. The participants were asked to record number and total weight for yellow and silver eel life stages as well as for undersized eels. Eel life stage was assessed visually based on colour, shape, length of the pectoral fin and eye diameter (ICES, 2010; Tesch, 2003). For legal-sized yellow eel, three size groups were predetermined in a protocol based on the former German Democratic Republic (GDR) commercial eel sorting classes for the study area (Schlumberger, Lauterbach, & Falk, 1964: Size class I, >350 g; Size class II, 150–350 g; Size class III, <150 g). Undersized eels were classified by the minimum size limit of 45 or 50 cm, respectively. The participants recorded the number of used FNCs, SNTs or longline hooks, the fishing position (GIS point or specific names of the fishing locations) and the corresponding date for each fishing trip.

Each participant was visited at least once per year by an external supervisor to check the data recording quality and to collect the total length (TL) and weight data. For this purpose, the complete eel harvest or a representative proportion was measured. During each visit, the supervisor compared the data documented by the fisher with their own observed data. The visits also aimed to build a trustful relationship between fishers and the scientific staff. At the end of each fishing season, a face-to-face interview was additionally conducted with each participant. These interviews were used to clarify unclear data recordings as well as to reflect the past fishing season.

The study started with 22 fishers. Ten fishers dropped out of the logbook study due to retirement or relinquishment of the fishing business. To compensate the dropouts, two participants were added during the study period. The data analysis was based solely on the recordings of those 16 fishers who provided data over a period of at least 5 years. The logbook data as well as the supervision indicated that the targeted fishers did not change their eel-specific fishing behaviour during the observation period.

2.3 | Data analysis

To obtain an overall assessment of changes in yellow eel catch rates, data from the Warnow/Peene and Oder Eel Management Units were analysed together. Longline catch data were excluded from the change-point analysis because this fishing activity mostly took place outside the three nautical mile zone. The catch rates of FNCs and SNTs depend on the eel activity, which is primarily influenced by water temperature (Tesch, 2003). To improve the data comparability, only catch data at water temperatures above 10°C were considered.

Catch rates were not calculated for captured silver eels because they could have originated from feeding habitats outside the study area. Because of the increase of the minimum size limit in 2009, size group III and undersized eels were grouped in the category "undersized yellow eels" and were analysed together. The size classes I and II were also merged into the size class "legal-sized yellow eel" to generate a sufficient number of eels for the statistical analyses. The CPUEs per size class were calculated as the number of eels caught/trap/day.

To detect shifts in the CPUE data series, a change-point analysis was applied (Aminikhanghahi & Cook, 2017; Dette & Wied, 2016) to the multi-annual data series of catch data covering the periods from April to October. A change-point (aka breakpoint; compare Kováč, Copp, & Francis, 1999) is defined as a point in a data series when an abrupt change occurs (Aminikhanghahi & Cook, 2017; Dette & Wied, 2016; Mudelsee, 2009). In a data series $y_{1:n} = (y_1;...;y_n)$, a single change-point occurs when at a specific point $\tau \{1,....,n-1\}$, the statistical properties of $\{y_1,..., y_\tau\}$ and $\{y_{\tau+1},...,y_n\}$ differ. Taking this basic idea of single change-points allows the identification of multiple changes m with position in the data series $\tau_{1:m} = (\tau_1,...,\tau_m)$. Thus, m change-points will split the data series into $m + 1$ segments. Referring to the presented study, a change-point may reflect a step change, which is an abrupt CPUE change, or a trend change, which is an abrupt change in the temporal CPUE trend.

Preceding the change-point analysis, the trip-based CPUE data were combined to monthly means to reduce the variance. Before the change-point analyses, the CPUE data were tested for temporal autocorrelation that can influence the detection of change-points (Bruel & White, 2021) by plotting the autocorrelation functions. The Kolmogorov-Smirnov test was used to test for normal distribution of the CPUE data. For the normal distributed data, parametric change-point analysis was applied. The pruned exact linear time (PELT)-algorithm (Killick & Eckley, 2014) was used to detect changes in the mean and variance of the monthly CPUE data. Non-parametric change-point analysis with the PELT algorithms and a non-parametric cost functions was used in the case of non-normal distributed data (Haynes & Killick, 2019). Depending on the applied algorithm (compare Figures 2 and 3), the identified periods in the CPUE time series are shown by horizontal (parametric change-point analysis) or vertical lines (non-parametric change-point analysis). To confirm the results of the change-point analyses, the CPUE data (monthly medians) for the periods before, between and after the change-points

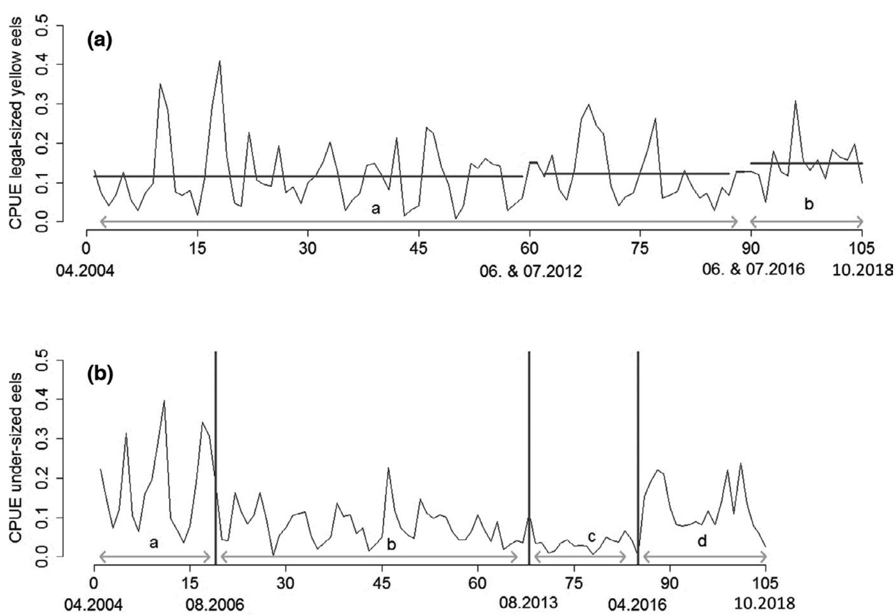

FIGURE 2 Monthly mean catch per unit effort (CPUE) from fyke net chains (FNCs) separated for two size classes, the mean CPUE is shown for 15-year time period. Seven months (April–October) were considered for each year, resulting in 105 data points; the CPUE is given as number of eels/trap/day. The horizontal lines represent time periods/change-points separated by changes in mean and variance derived from parametric change-point analysis. The vertical lines represent change-points separated by changes in the mean and variance derived from non-parametric change-point analysis. The letters and grey arrows above the *x*-axis indicate the time periods used for the monthly CPUE medians comparison: (a) FNC legal-sized yellow eels, (b) FNC undersized eel

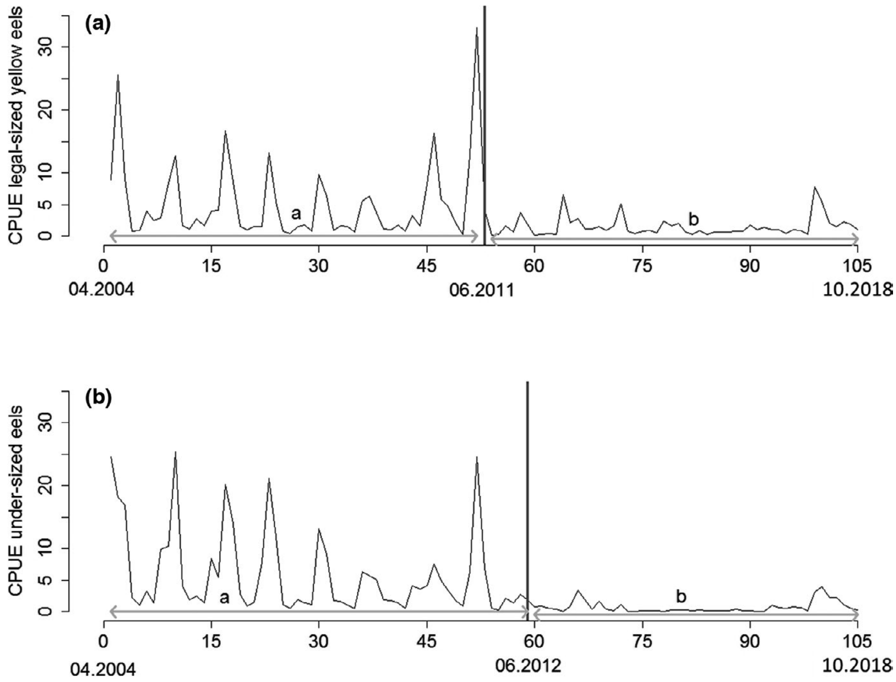

FIGURE 3 Monthly mean catch per unit effort (CPUE) from stationary net traps (SNTs) separated for two size classes, the mean CPUE is shown for 15-year time period. Seven months (April–October) were considered for each year, resulting in 105 data points; the CPUE is given as number of eels/trap/day. The vertical lines represent change-points separated by changes in the mean and variance derived from non-parametric change-point analysis. The letters and grey arrows above the *x*-axis indicate the time periods used for the monthly CPUE medians comparison: (a) SNT legal-sized yellow eels, (b) SNT undersized eel

were tested for significant differences. For a single detected change-point, a Mann-Whitney *U* test (M-W test) was used. In the case of multiple change-points, a Kruskal-Wallis test (K-W test) followed by M-W tests with Bonferroni correction was applied to confirm significant differences in the separated CPUE time series.

SPSS 21 was used for the descriptive data analysis. The software R 4.0.5 (R Core Team, 2020) and the packages changepoint (Killick & Eckley, 2014; Killick, Haynes, & Eckley, 2016) and changepoint.np (Haynes & Killick, 2019), were used for the change-point analysis.

3 | RESULTS

The data retained were collected from 16 fishers derived from 10,695 fishing trips, of which 4797 employed FNCs and 4643 employed SNTs. Longlines were used to a lesser degree (n = 1255). The documented fishing locations relating to the FNC data showed that the individual fishers had only a small fishing radius of <10 km around the port of registry and did not changed their fishing area during the study period. The SNT stations fished also did not change during the study period.

Including longlines eel catches, 10,687 undersized and legal-sized eels were individually measured during the on-site visits between 2004 and 2018 (see Supplement S4). Independent of the fishing gear, the mean TL and weight of the undersized yellow eels were 45.1 cm (±3.4 SD) and 149.8 g (±36.9), respectively. The mean TL and weight for legal-sized yellow eel were 59.2 cm (±6.5) and 392.4 g (±170.6), respectively. Total lengths of legal-sized yellow eels differed significantly (M-W test, U = 350613.0, $p < 0.05$) between both passive fishing gears. Smaller, legal-sized yellow eels were caught with FNCs (58.0 cm ± 6.2) compared with SNTs (62.6 cm ± 9.4). In the case of undersized eels, no differences in TL (M-W test, U = 86959.0, p = 0.08) were detected between FNCs (45.5 cm ± 3.2) and SNTs (45.2 cm ± 3.2).

The overall mean CPUE from FNCs for the legal-sized and undersized yellow eel during the fishing period were 0.15 (±0.27) and 0.13 (±0.24) fish/fyke net/day, respectively. The CPUEs for SNTs for legal-sized and undersized yellow eels were 3.24 (±9.78) and 3.46 (±11.28) fish/trap/day, respectively.

The calculation of monthly mean catch rates resulted in 105 data points (15 years with 7 months included each year). Independent of eel size group and fishing gear, the monthly mean catch rates varied within a fishing season. Elevated monthly catch rates occurred mostly during the summer time. For example, catch rates of legal-sized yellow eels (/fyke net/day) harvested in summer with various FNCs revealed peaks with over 0.3 eels/fyke net/day.

3.1 | CPUE data series for FNCs and SNTs

The autocorrelation plots revealed a low seasonality of the CPUEs of undersized and legal-sized yellow eels (Supplement S3). The temporal autocorrelation of all CPUE data, however, was weak; indicating a minor relationship between nearby data points (Supplement S3).

For legal-sized yellow eels, four change-points, resulting in five periods with varying monthly mean values were detected in the CPUE time series from FNCs (Figure 2a). Generally, the mean monthly CPUE values increased over the 15 years period by 28%. Between April 2004 and June 2012, a period of constant catch rates was observed. Afterwards, the increases occurred in a stepwise manner, but included a period with a decreasing trend (Figure 2a). The monthly catch rates before and after July 2016 (Figure 2a, period a *vs* period b) differed significantly (M-W test, $U = 451$, $p < 0.05$).

Three change-points were observed in the FNC data series for undersized yellow eels (Figure 2b), whereby the catch rates differed significantly between periods (K-W test, $\chi^2 = 41.06$, $p < 0.05$). Overall, the highest CPUE occurred between April 2004 and August 2006. The CPUE decreased stepwise afterwards with the lowest mean values between August 2013 and April 2016. Afterwards, the CPUE increased significantly (Figure 2b; period c *vs* period d, M-W test, $U = 13$, $p < 0.05$) and corresponded to nearly 70% of the mean CPUE recorded at the beginning of this data series.

One change-point was detected for legal-sized yellow eel harvested with SNTs (Figure 3a). The monthly CPUEs between April 2004 and June 2011 were significantly higher (M-W test, $U = 672.5$, $p < 0.05$) than the catch rates between July 2011 and October 2018. After July 2011, the CPUEs decreased on average by 70%. A visible peak in 2018 indicated increasing catch rates.

One change-point occurred in the CPUE data series of SNTs for undersized eels (Figure 3b). After the change-point in June 2012, the monthly catch rate declined on average by nearly 90%. The monthly CPUEs differed significantly (M-W test, $U = 281$, $p < 0.05$) between both periods. The monthly mean catch rates increased slightly in the beginning of 2018.

4 | DISCUSSION

In the absence of fishery-independent data, logbook-based commercial fishery data represent an alternative for the detection of eel population trends. Change-point analysis revealed constant or decreasing yellow-eel catch rates for passive gears between 2004 and 2015. Thereafter, increasing CPUE values in the FNC data series provided evidence for a slight, but significant increase in yellow eel numbers in the coastal waters during the recent years. This trend in FNC catch rates is supported by the development of the annual eel landings in the study area (LALLF, 2021a, compare Supplement S2). After a period of decreasing annual eel landings between 2004 until 2016, increasing total landings were reported in 2017 and 2018.

In the case of undersized eels, the positive trend was more pronounced in the FNC data than the SNT data. A similar pattern was observed for the legal-sized yellow-eel catch rates. The more pronounced effects in the FNC data series could be mainly attributed to the mesh size differences between both gears. In terms of size selectivity, the FNCs had a minor full selectivity for TLs of yellow eels relative to the SNTs (Bevacqua et al., 2009). Positive trends in the yellow eel numbers should be firstly detectable in the FNC catch rates, which is in accordance with observed differing trends between both gear types.

Generally, the observed catch rates were higher during the summer. Yellow eel movement rates and forage activities increase at higher water temperatures (e.g. Tesch, 2003; Verhelst et al., 2018). By assuming an equable distribution of eels in the fishing areas of the participating fishers using FNCs or SNTs, the probability of catching eel with passive gears therefore varies within the eel fishing season, which is reflected by eel fishing with passive gears traditionally lasting from April to October.

Similar FNC catch rates were observed in coastal waters. For example, Bernotas et al., (2016) reported mean catch rates between 0.0–0.2 eels/fyke/day as well as a general decline of the CPUE values until 2014 in Estonian coastal waters. A general decline between 2004 and 2016 and a positive slope in the subsequent years were detected in the yellow eel index series provided by the Working Group on Eels (WGEEL) of the International Council for Exploitation of the Seas (ICES, 2020). Moreover, increasing yellow eel landings in the Baltic Sea in recent years were also reported for the Danish coastal fishery (ICES, 2020), which supported the observations from the analysed logbook data.

A major factor that influences the development of regional eel abundance could be the number of immigrating juvenile eels. The recruitment series for the North Sea region indicated a decreasing appearance of juvenile eels between 1990 and 2011 (ICES, 2020; Supplement S1). The overall recruitment minimum in 2010 and 2011 corresponds to 0.6% of the pre-1980 level (ICES, 2020). Afterwards, the recruitment level increased and the annual mean of the recruitment corresponded to 1.5% (mean for 2012–2019) to the pre-1980 level (ICES, 2020). The general progress of the FNC and SNT catch rates is in line with the development of the recruitment index for the North Sea Region as, for example, time-delayed constant (FNC legal-sized eels) or decreasing (FNC undersized) CPUE values were associated with decreasing recruitment between 1990 and 2011. In the case of the SNTs, lower catch rates for legal-sized and undersized yellow eels were detected after the recruitment minimum in 2011 compared with before 2011 period. Further, in the FNC time series for legal-sized and undersized eels, the change-point analysis indicated higher catch rates after 2015. This increase could reflect increased recruitment after 2011, as more juvenile eels immigrated and settled in coastal waters of the Baltic Sea.

In contrast to the observed increase of the FNC catch rates, the recruitment slope for the North Sea region after 2011 was relatively small but significant, and the index values were quite variable (ICES, 2020; Supplement S1). The North Sea recruitment index is based on various time series (ICES, 2019). According to ICES (2019) sampling methods, the targeted development stages and the fished habitat type differ between the included time series in the North Sea index. For example, only a minor part of the North Sea index series is generated in marine or coastal waters; most samplings take place in transitional (brackish) or freshwater areas (ICES, 2019). Assuming a density-dependent migration behaviour of juvenile eels (Feunteun et al., 2003; Lasne, Acou, Vila-Gispert, & Laffaille, 2008), the current number of arriving glass eel initially settling in coastal waters of the North or Baltic Sea might be not sufficient to trigger a more pronounced migration into transitional or freshwater habitats (Edeline, 2007). Owing to the low sample sizes in marine and coastal waters, the ICES index for the North Sea might therefore underestimate settlement in coastal waters, which might explain the differences between the FNC catch rates and the ICES recruitment series.

Female yellow eels in the study area tend to reach the minimum size limit of 50 cm after 7–8 years on average (Simon et al., 2013). Increased recruitment rates after 2011 should not lead to higher catch rates of legal-sized eels before 2019. Likewise, pronounced effects on undersized eel should not occur before 2017. Indicated by the change-points, the FNC catch rate of legal-sized eel increased before 2019. In addition, the change-point for undersized eels appeared earlier than expected. The SNT data series showed a peak for legal-sized yellow eels in 2018. These unexpected effects may be related to locally increased growth rates of eels during the first years of their continental life. Recent studies (Buck & Kullmann, 2020; Simon, Dorow, Ubl, Frankowski, & Schaarschmidt, 2017) revealed increased individual growth rates of eels in the coastal waters of the study area compared with growth rates documented by Simon et al., (2013). For example, the mean TL of a 4-year-old yellow eel was ≈45 cm, and fast-growing individuals could reach the minimum size limit after three years (Buck & Kullmann, 2020). The increase of individual growth rates may be linked to low intraspecific competition for food resources and space, as well as recent environmental changes in the coastal waters of the southern Baltic Sea with higher annual mean water temperatures, lack of ice cover during the winter and eutrophication (Eilola, Mårtensson, & Meier, 2013; Meier et al., 2012).

Density-dependent mechanisms may have contributed to the catch rate development in addition (Acou et al., 2011; Andersson, Florin, & Petersson, 2012; Svedäng, 1999). Generally, the survival rate and the proportion of female eels increase at low or decreasing eel densities. Compensatory density dependence can induce, for example, stable numbers of riverine silver eel escapement rates despite yearly varying recruitment levels (Lobón-Cerviá & Iglesias, 2008). Similarly, density-dependent effects could partly explain the stable FNC catch rate of legal-sized yellow eels, despite declining recruitment levels (ICES, 2020). At a greater temporal scale, density-dependent effects might also have changed the sex ratio for eels in the study area. In the early 1960s, the percentage of female eels varied between 20% and 70% depending on the coastal region (Schlumpberger et al., 1964). By contrast, female eels dominated the current yellow eel stock in coastal waters in the German Baltic Sea (Buck & Kullmann, 2020).

Furthermore, changes in the CPUE might also be influenced by eel conservation activities including eel stocking or changes in eel-specific fishing regulations. Poland, for example, released juvenile on-grown eels in the Szczecin Lagoon (T. Nermer, personal communication). Assuming size-dependent and density-dependent migration tactics for juvenile eels (Imbert, Labonne, Rigaud, & Lambert, 2010; Laffaille, Acou, & Guillouët, 2005; Shiao et al., 2006), these Polish stocking activities with on-grown eels might have only influenced the eel harvest in the German part of the Szczecin Lagoon, although to an unknown degree. Furthermore, glass eel stocking took place annually in two inner coastal waters of the study area between 2014 and 2016 (Dorow & Schaarschmidt, 2014). Recaptures revealed, however, that a major proportion of the stocked eels remained in the stocked area (Buck & Kullmann, 2020) indicating that glass eel stocking should have had a minor influence on the observed overall CPUE trend. Additionally, the increase of the minimum size limit in 2009 could positively influence the yellow eel abundance by lowering the overall fishing mortality. Considering the complex population dynamic and the conservation efforts, it is likely that the number of immigrating juvenile eels does not link directly to yellow eel abundance in the study area.

Several studies raised doubts about the use of CPUEs as an index of abundance based on the assumption of a linear proportionality between CPUE and fish density (e.g. Harley, Meyers, & Dunn, 2001; Maunder & Punt, 2004). For a proportional relationship between abundance and CPUE, fishing effort must be random (Dunn, Harley, Doonan, & Bull, 2000). The present case study used CPUE data for a passive gear fishery with a limited fishing radius. Indicated by the logbook data, fishers using FNCs stayed in one area within a season and did not change their fishing area (radius <10 km). In the case of the FNC data, there was no aggregation in one fishing location, and fishing effort was placed randomly in the fisher-specific fishing areas. All documented SNT data were based on fixed fishing spots that did not change during the study period. Accordingly, the likelihood of yellow eels being captured with FNCs as well as SNTs depended primarily on eel abundance and gear catchability. For both passive gears, a constant catchability and equal distribution of yellow eels in the fished area were assumed. Additionally, as yellow eels have a fixed home range (Verhelst et al., 2018; Walker, Godard, & Davison, 2014), fish aggregation effects should not have had an influence on the CPUE data as has been shown for some marine fish stocks. Given the limited regional scale of the present study and the specific circumstances of the yellow eel fishery with passive gears, the CPUE data from the logbook-based fishery were assumed to provide at least an indication of changes in yellow eel abundance in coastal waters of the study area.

In conclusion, different eel life history traits (Daverat et al., 2006) associated with differences in growth rates (Simon et al., 2013) or health status (Wysujack et al., 2014) resulted in different population dynamics between eels growing up in coastal waters and those growing up in neighbouring inland waters (ICES, 2009). These differences should be addressed in eel conservation efforts and monitoring activities by distinguishing, at the very least, between coastal and freshwater areas. By using a fishery-dependent FNC data series, the present study provided evidence that the yellow eel abundance in the southern Baltic Sea increased slightly in the recent years, which might indicate a time-delayed relationship between recruitment and local yellow eel numbers. Primarily caused by the mesh size differences, recent undersized and legal-sized eel SNT catch rates were lower than those observed in April 2011 and June 2012, respectively. However, in both SNT series, positive signs in recent years were detectable.

In agreement with Bernotas et al., (2016), standardised fyke net-based CPUE data are suitable for monitoring yellow eel stock trends in the Baltic Sea. To test the robustness of the fishery-dependent CPUE data in greater detail, they could be compared with fisheries-independent monitoring data. For yellow eels in coastal waters, the 1-ha enclosure approach of Ubl and Dorow (2015) seems to hold promise. As the yellow eel-specific catchability is known (Dorow et al., 2019, 2020), the standardised use of the enclosure approach would allow the detection of trends in yellow stocks as well as transferring observed densities data to true yellow eel density estimates. In the context of the discussion about the validity of fishery-based logbook data, the presented survey can be seen as an example of how well-designed studies could help to follow regional fish population trends in a cost-efficient manner.

ACKNOWLEDGEMENTS

We thank all fishers for their participation in our logbook study. Without their efforts, this study would not have been possible. We like to thank R. Lemcke, who started the logbook study in 2004, and T. Schaarschmidt, who kept it running for many years, J. Simon, H. V. Strehlow as well as K. Wysujack for their comments on an earlier version of the manuscript, and O. Krüger for generating the map. Figure 1 was generated by using openstreetmap.org. The manuscript is benefited significantly from the helpful comments of three anonymous reviewers and the editor. The study was founded by the federal state Mecklenburg-Vorpommern and the European Maritime and Fisheries Fund (EMFF).

REFERENCES

Acou, A., Rivot, E., Van Gils, J.A., Legault, A., Ysnel, F. & Feunteun, E. (2011) Habitat carrying capacity is reached for the European eel in a small coastal catchment: evidence and implications for managing eel stocks. *Freshwater Biology*, *56*, 952–968.

Aminikhanghahi, S. & Cook, D.J. (2017) A survey of methods for time series change point detection. *Knowledge and Information Systems*, *51*, 339–367.

Andersson, J., Florin, A.B. & Petersson, E. (2012) Escapement of eel (*Anguilla anguilla*) in coastal areas in Sweden over a 50-year period. *ICES Journal of Marine Science*, *69*, 991–999.

Bernotas, P., Vetemaa, M., Saks, L., Eschbaum, R., Verliin, A. & Järvalt, A. (2016) Dynamics of European eel landings and stocks in the coastal waters of Estonia. *ICES Journal of Marine Science*, *73*, 84–90.

Bevacqua, D., De Leo, G.A., Gatto, M. & Melià, P. (2009) Size selectivity of fyke nets for European eel *Anguilla anguilla*. *Journal of Fish Biology*, *74*, 2178–2186.

Bruel, R. & White, E.R. (2021) Sampling requirements and approaches to detect ecosystem shifts. *Ecological Indicators*, *121*, e107096.

Buck, M. & Kullmann, L. (2020). *Glasaalbesatz in Küstengewässern als Managementoption – Evaluierung eines großskaligen Besatzversuches*. Rostock: State Research Center for Agriculture and Fisheries Mecklenburg-Vorpommern. Scientific Report, pp. 27.

Carss, D.N., Elston, D.A., Nelson, K.C. & Kruuk, H. (1999) Spatial and temporal trends in unexploited yellow eel stocks in two shallow lakes and associated streams. *Journal of Fish Biology*, *55*, 636–654.

Copp, G.H., Daverat, F. & Bašić, T. (2021) The potential contribution of small coastal streams to the conservation of declining and threatened diadromous fishes, especially the European eel. *River Research & Applications*, *37*, 111–115.

Daverat, F., Limburg, K.E., Thibault, I., Shiao, J.C., Dodson, J.J., Caron, F. et al. (2006) Phenotypic plasticity of habitat use by three temperate eel species, *Anguilla anguilla*, *A. japonica* and *A. rostrata*. *Marine Ecology Progress Series*, *308*, 231–241.

Daverat, F. & Tomás, J. (2006) Tactics and demographic attributes in the European eel *Anguilla anguilla* in the Gironde watershed, SW France. *Marine Ecology Progress Series*, *307*, 247–257.

Dette, H. & Wied, D. (2016) Detecting relevant changes in time series models. *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, *78*, 371–394.

Dorow, M., Jünger, J., Frankowski, J. & Ubl, C. (2020) Application of a 3-pass removal experiment to assess the yellow eel specific capture efficiency of a 1-ha enclosure. *Fisheries Research*, *221*, e105409.

Dorow, M., Lill, D. & Ubl, C. (2017) Die Aalfischerei in den Küstengewässern von Mecklenburg-Vorpommern zwischen 1955 und 2015. *Mitteilungen der Landesforschungsanstalt für Landwirtschaft und Fischerei M-V*, *58*, 61–76.

Dorow, M. & Schaarschmidt, T. (2014) Effektivität von Aalbesatz in Küstengewässern – Vorstellung eines neuen wissenschaftlichen Projektes. *Fischerei & Fischmarkt in Mecklenburg-Vorpommern*, *14*(2), 41–42.

Dorow, M., Schulz, S., Frankowski, J. & Ubl, C. (2019) Using a telemetry study to assess the boundary net efficiency of enclosure system utilized for yellow eel density monitoring. *Fisheries Management and Ecology*, *26*, 70–75.

Dunn, A., Harley, S.J., Doonan, I.J. & Bull, B. (2000). *Calculation and Interpretation of catch-per-unit-effort (CPUE) indices: New Zealand Fisheries Assessment Report 2000/1*. Wellington: NIWA, p. 44.

EC. (2007) Council Regulation (EC) No 1100/2007 of 18 September 2007 establishing measures for the recovery of the stock of European eel. *Official Journal of the European Union L*, *248*, 17–23.

Edeline, E. (2007) Adaptive phenotypic plasticity of eel diadromy. *Marine Ecology Progress Series*, *341*, 229–232.

Eilola, K., Mårtensson, S. & Meier, H.E.M. (2013) Modeling the impact of reduced sea ice cover in future climate on the Baltic Sea biogeochemistry. *Geophysical Research Letters*, *40*, 149–154.

Feunteun, E., Laffaille, P., Robinet, T., Briand, C., Baisez, A., Olivier, J.M., Acou, A. (2003) A review of upstream migration and movements in inland waters by anguillid eels: toward a general theory. In: Aida, K., Tsukamoto, K. & Yamauchi, K. (Eds.) *Eel Biology*. Tokyo: Springer, pp. 191–213.

Friedland, K.D., Miller, M.J. & Knights, B. (2007) Oceanic changes in the Sargasso Sea and declines in recruitment of the European eel. *ICES Journal of Marine Science*, *64*(3), 519–530.

Harley, S.J., Myers, R.A. & Dunn, A. (2001) Is catch-per-unit-effort proportional to abundance? *Canadian Journal of Fisheries and Aquatic Science*, *58*, 1760–1772.

Haynes, K. & Killick, R. (2019) *Changepoint.np: methods for nonparametric changepoint detection*. R package version 1.0.1. Available at https://CRAN.R-project.org/package=changepoint.np

ICES. (2019) Joint EIFAAC/ICES/GFCM Working Group on Eels (WGEEL). *ICES Scientific Reports*, *1*(50), 177. https://doi.org/10.17895/ices.pub.5545

ICES. (2020) Joint EIFAAC/ICES/GFCM Working Group on Eels (WGEEL). *ICES Scientific Reports*, *2*(85), 223. http://doi.org/10.17895/ices.pub.5982

ICES. (2009). *Report of the Study Group on Anguillid Eels in Saline Waters (SGAESAW)*, 16-18 March 2009, Sackville, Canada; 3-5 September Gothenburg, Sweden. ICES. CM/DFC:06. Copenhagen: International Council for Exploitation of the Seas, pp. 183.

ICES. (2010). *Report of the 2010 session of the Joint EIFAC/ICES*. Working Group on Eels, Hamburg, Germany, 9-14 September 2010. Copenhagen: International Council for Exploitation of the Seas, pp. 201.

Imbert, H., Labonne, J., Rigaud, C. & Lambert, R. (2010) Resident and migratory tactics in freshwater European eels are size-dependent. *Freshwater Biology*, *55*, 1483–1493.

Jakob, E., Hanel, R., Klimpel, S. & Zumholz, K. (2009) Salinity dependence of parasite infestation in the European eel *Anguilla anguilla* in northern Germany. *ICES Journal of Marine Science*, *66*, 358–366.

Killick, R. & Eckley, I. (2014) changepoint: an R package for changepoint analysis. *Journal of Statistical Software*, *58*(3), 1–19.

Killick, R., Haynes, K. & Eckley, I.A. (2016) *Changepoint: a R package for changepoint analysis*. R package version 2.2.2. Available at https://CRAN.R-project.org/package=changepoint

Knights, B. (2003) A review of the possible impacts of long-term oceanic and climate changes and fishing mortality on recruitment of anguillid eels of the Northern Hemisphere. *Science of the total Environment*, *310*, 237–244.

Koed, A. & Dieperink, C. (1999) Otter guards in river fyke-net fisheries: effects on catches of eels and salmonids. *Fisheries Management and Ecology*, *6*, 63–69.

Kováč, V., Copp, G.H. & Francis, M.P. (1999) Morphometry of the stone loach, *Barbatula barbatula*: do mensural characters reflect the species' life history thresholds? *Environmental Biology of Fishes*, *56*, 105–115.

Laffaille, P., Acou, A. & Guillouët, J. (2005) The yellow European eel (*Anguilla anguilla* L.) may adopt a sedentary lifestyle in inland waters. *Ecology of Freshwater Fish*, *14*, 191–196.

LALLF. (2021a). *Landing statistic for coastal waters of Mecklenburg-Vorpommern*. Available at www.lallf.de/fischerei/statistik/fangstatistik-kuestengewaesser/ [Accessed 7th February 2021].

LALLF. (2021b). *Statistic on number of fulltime fishery enterprises in the coastal fishery*. Available at www.lallf.de/fischerei/statistik/fischer-und-fahrzeuge/. [Accessed 7th February 2021].

Lasne, E., Acou, A., Vila-Gispert, A. & Laffaille, P. (2008) European eel distribution and body condition in a river floodplain: effect of longitudinal and lateral connectivity. *Ecology of Freshwater Fish*, *17*, 567–576.

Lobón-Cerviá, J. & Iglesias, T. (2008) Long-term numerical changes and regulation in a river stock of European eel *Anguilla anguilla*. *Freshwater Biology*, *53*, 1832–1844.

Maunder, M.N., Sibert, J.R., Fonteneau, A., Hampton, J., Kleiber, P. & Harley, S.J. (2006) Interpreting catch per unit effort data to assess the status of individual stocks and communities. *ICES Journal of Marine Science*, *63*, 1373–1385.

Maunder, M.N. & Punt, A.E. (2004) Standardizing catch and effort data: a review of recent approaches. *Fisheries Research*, *70*, 141–159.

Meier, H.E.M, Hordoir, R., Andersson, H.C., Dieterich, C., Eilola, K., Gustafsson, B.G. et al. (2012) Modeling the combined impact of changing climate and changing nutrient loads on the Baltic Sea environment in an ensemble of transient simulations for 1961–2099. *Climate Dynamics*, *39*(9–10), 2421–2441.

Mudelsee, M. (2009) Break function regression. *The European Physical Journal Special Topic*, *174*, 49–63.

Ojaveer, H., Jaanus, A., Mackenzie, B.R., Martin, G., Olenin, S., Radziejewska, T. et al. (2010) Status of biodiversity in the Baltic Sea. *PLoS One*, *5*(9), e12467.

R Core Team. (2020) *R: A language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing. Available at www.R-project.org/

Schlumpberger, W., Lauterbach, R. & Falk, K. (1964) Jahresfischereibericht 1963 – Teil 5: Innere Küstengewässer. *Fischerei-Forschung*, *2*, 135–163.

Shiao, J.C., Ložys, L., Iizuka, Y. & Tzeng, W.N. (2006) Migratory patterns and contribution of stocking to the population of European eel in Lithuanian waters as indicated by otolith Sr: Ca ratios. *Journal of Fish Biology*, *69*(3), 749–769.

Simon, J., Dorow, M., Ubl, C., Frankowski, J. & Schaarschmidt, T. (2017) Altersbestimmung von Aalen (*Anguilla anguilla*) in den Binnen- und Küstengewässern von Mecklenburg-Vorpommern und deren Validierung. *Mitteilungen der Landesforschungsanstalt für Landwirtschaft und Fischerei M-V*, *58*, 89–101.

Simon, J., Ubl, C. & Dorow, M. (2013) Growth of European eel *Anguilla anguilla* along the southern Baltic coast of Germany and implication for the eel management. *Environmental Biology of Fishes*, *96*, 1079–1086.

Svedäng, H. (1999) Vital population statistics of the exploited eel stock on the Swedish west coast. *Fisheries Research*, *40*, 251–265.

Tesch, F.W. (2003) *The eel*. Oxford: Blackwell Publishing.

Ubl, C. & Dorow, M. (2015) A novel enclosure approach to assessing yellow eel (*Anguilla anguilla)* density in non-tidal coastal waters. *Fisheries Research*, *161*, 57–63.

Ubl, C. & Jennerich, H.J. (2008) *Eel management plan for the EMU Warnow/Peene*. Rostock: State Research Center for Agriculture and Fisheries Mecklenburg-Vorpommern, pp. 27.

Verhelst, P., Reubens, J., Pauwels, I., Buysse, D., Aelterman, B., Van Hoey, S. et al. (2018) Movement behaviour of large female yellow European eel (*Anguilla anguilla* L.) in a freshwater polder area. *Ecology of Freshwater Fish*, *27*, 471–480.

Walker, A.M., Godard, M.J. & Davison, P. (2014) The home range and behaviour of yellow-stage European eel *Anguilla anguilla* in an estuarine environment. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *24*, 155–165.

Winkler, H.M., Waterstraat, A., Hamann, N., Schaarschmidt, T., Lemcke, R. & Zettler, M. (2007) *Verbreitungsatlas der Fische und Rundmäuler, Goßmuscheln und Großkrebse in Mecklenburg-Vorpommern*. Rangstorf: Natur und Text.

Wysujack, K., Dorow, M. & Ubl, C. (2014) The infection of the European eel with the parasitic nematode *Anguillicoloides crassus* in inland and coastal waters of northern Germany. *Journal of Coastal Conservation*, *18*, 121–130.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

How to cite this article: Dorow, M., Lewin, W.-C., Lill, D., Ubl, C. & Frankowski, J. (2021) Using logbook-based catch-rate data to detect yellow eel population trends in the southern Baltic Sea. *Fisheries Management and Ecology*, 00, 1–9. https://doi.org/10.1111/fme.12505