



Understanding recreational anglers' perceptions of stock trend, status, and regime shifts in the western Baltic cod (*Gadus morhua*)

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Abstract The western Baltic Sea stock of Atlantic cod (*Gadus morhua*) collapsed in 2016 when its spawning stock biomass (B) fell below the reference point B_{lim} . Directed commercial harvest was prohibited on 1 January 2022 and recreational harvest on 1 January 2024. Both the stock collapse and the fishery closures can be viewed as regime shifts – broadly defined as long-lasting reorganisations in structure and function of a system. Whether anglers perceive

such changes as regime shifts or temporary fluctuations has implications for management support and compliance. We investigated whether German recreational cod anglers perceived changes in the cod fishery as regime shifts rather than gradual transitions and studied psychological predictors of these perceptions. An online survey of 3,957 anglers yielded 1,788 responses. Most anglers (83.7%) perceived a declining stock trend, 65.1% judged the stock in poor condition, and 72.5% reported at least one profound, decisive, lasting change in the fishery or stock (here, a regime shift) since they began fishing. Greater angling experience and stronger support for the view that cod require management regulations increased the likelihood that anglers reported a declining trend, judged the stock status as poor, and perceived one or more regime shifts in the fishery. Psychological commitment to fishing, the importance attached to catching and retaining cod, and trust in science had little influence on these perceptions. Overall, anglers with a long history of using the fishery were more likely to contextualise their experiences against salient scientific information, aligning with favourable attitudes towards proactive cod management.

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Introduction

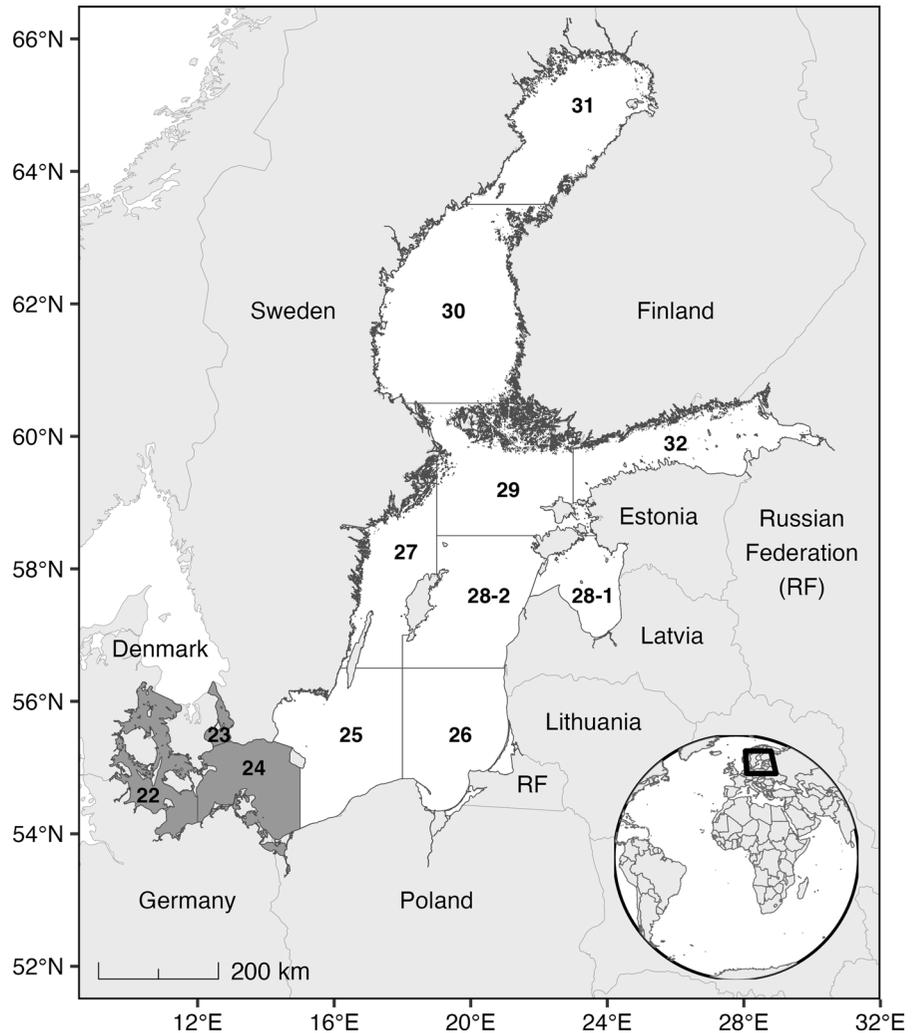
Recreational fisheries exemplify tightly coupled social-ecological systems shaped by dynamic interactions among fish populations, humans, and the broader aquatic and socio-political environment (Arlinghaus et al. 2017). In coastal areas of Germany and other industrialised nations, recreational fishers are today a key stakeholder group, whose economic and social impacts can exceed those of commercial fishing (Hyder et al. 2018; Strehlow et al. 2023; Barz et al. 2024). Both ecological and social-ecological systems can exhibit enduring reorganisations in structure and functioning, phenomena broadly termed regime shifts (Scheffer et al. 2001; Scheffer 2009). In regime shift theory, a regime shift refers to a persistent change in how a system is organised and functions, maintained by reinforcing feedbacks such that reversal to the previous configuration, if possible, typically requires different conditions from those that triggered the shift (Scheffer et al. 2001; deYoung et al. 2008; Conversi et al. 2015; Möllmann et al. 2015; Blöcker et al. 2025). The term regime shift is used with varying breadth in marine and social-ecological scholarship, and persistent reorganisations are not always associated with a single identifiable threshold (Conversi et al. 2015; Blöcker et al. 2025). Tipping points (critical thresholds; termed depensation points in the fisheries literature; Hutchings 2013) refer to threshold conditions beyond which relatively small changes in drivers can precipitate a rapid transition into a different regime (deYoung et al. 2008; Scheffer 2009; Milkoreit et al. 2018; Dakos et al. 2019; Blöcker et al. 2025). Ecological state transitions can lead to substantial social and economic impacts that are difficult and sometimes even impossible to reverse in the short term (deYoung et al. 2008; Conversi et al. 2015; Möllmann et al. 2015; Nayak and Armitage 2018; Otto et al. 2020; Wudrick et al. 2024). Although scientists debate how prevalent regime shifts and alternative stable states are in aquatic systems and whether such changes can be predicted *ex ante* (Lees et al. 2006; deYoung et al. 2008; Conversi et al. 2015; Möllmann et al. 2015; Hillebrand et al. 2023), overlooking regime shift dynamics when present heightens the risk of sudden fish stock collapse, threatening the ecological and economic viability of fisheries (Biggs et al. 2009; Sguotti et al. 2019b; Dao et al. 2023). To prepare

proactive fisheries management approaches that are sensitive to the potential for regime shifts, it is important to understand how key stakeholders, such as recreational anglers, perceive stock trends in abundance, stock status, and the potential for regime change in a fishery (deYoung et al. 2008; Österblom et al. 2010; King et al. 2015; Van Ginkel et al. 2020; Lewin et al. 2025).

The western Baltic cod (*Gadus morhua*) stock (Fig. 1) provides the opportunity to conduct a contemporary case study for examining fishers' perceptions of stock trend, status, and regime shifts. The stock experienced prolonged declines before its biological collapse was declared in 2016 (Reusch et al. 2018; Möllmann et al. 2021; ICES 2024; Möllmann 2025). The stock collapsed in part because fishing mortality was underestimated and quotas were routinely set above scientific advice. As a result, exploitation of western Baltic cod exceeded sustainable levels for decades (Froese et al. 2025; Möllmann 2025). Besides harvest, in recent decades, the combined impacts of eutrophication and climate change have negatively and pervasively affected natural recruitment (Eero et al. 2011), which has strongly reduced the compensatory ability of the western Baltic cod stock to deal with fisheries harvest (Möllmann et al. 2021; Möllmann 2025). These developments led to the closure of the directed commercial cod fishery in 2022 and the prohibition of the recreational cod harvest in 2024, respectively, leaving only a small commercial bycatch quota (ICES 2024).

The western Baltic cod stock (Fig. 1) has always been a popular target of marine recreational fishers in Europe generally and Germany more specifically (Hyder et al. 2018; Lewin et al. 2021; Weltersbach et al. 2021; ICES 2024). In conjunction with the stock decline and commercial quota cuts, for the first time in 2017, a daily bag limit of five cod per angler was implemented for recreational anglers to also regulate recreational cod angling harvest alongside quota cuts for commercial fishers (Lewin et al. 2021, 2023; Haase et al. 2022). This daily bag limit was further reduced over time (e.g., one cod per angler per day in 2022) until it was lowered to zero on 1 January 2024, effectively shutting down the harvest-oriented recreational fishery on western Baltic cod. In Europe, cod is a consumptive fish prized by recreational anglers for its culinary properties (Andrews et al. 2021; Bronnmann et al. 2023). Specifically in Germany, anglers

Fig. 1 International Council for the Exploration of the Sea (ICES) subdivisions 22–32 in the Baltic Sea and bordering countries. The management area for the western Baltic cod stock (subdivisions 22–24) is shaded in grey. These subdivisions border Germany, Denmark, Sweden, and Poland. The remaining Baltic Sea subdivisions (25–32) are shown in white. The inset indicates the Baltic Sea's global location. ICES subdivision boundaries (ICES 2016). Country boundaries made with Natural Earth (2025)



do not perceive any utility from catching and releasing cod, and instead primarily derive benefits from harvesting cod for food (Bronnmann et al. 2023). Therefore, the closure of the harvest opportunity for cod in the western Baltic Sea has created substantive welfare loss among anglers (Haase et al. 2022; Bronnmann et al. 2023; Lewin et al. 2025).

Some scientists interpret the recent western Baltic cod collapse as a regime shift caused by decades of overfishing in interaction with environmental changes that severely reduced contemporary recruitment, thus preventing rapid stock rebuilding despite the harvest moratorium (Sguotti et al. 2019a, 2019b; Möllmann et al. 2021; Möllmann and Voss 2022). Others argue that the cod decline in the western Baltic Sea reflects a prolonged history of overexploitation

and mismanagement (Froese et al. 2025; Möllmann 2025), while questioning the evidence for crossing a tipping point to a new low abundance stable state (Zimmermann and Kraft 2021). This ongoing discussion highlights broader debates on distinguishing regime shifts from gradual declines in fisheries resources (Hutchings 2013; Litzow et al. 2014; Wernberg et al. 2016). Despite varying views, there is broad agreement among scientists that the western Baltic cod is not well adapted to the impacts of ongoing climatic change (Moll et al. 2024) in conjunction with impacts arising from decades of poorly managed nutrient runoff from the land into the Baltic Sea causing eutrophication and an increase in number and size of anoxic zones (Reusch et al. 2018). As a result, stock recovery from the current collapse

remains uncertain (Möllmann et al. 2021; Receveur et al. 2022; Möllmann 2025). Understanding how recreational anglers perceive the prevalence of tipping points as opposed to transitory stock changes is important for the development of adaptive fisheries management policies. Anglers who interpret lasting declines as temporary fluctuations might underestimate the severity and resist prolonged restrictions. Those who recognise that a tipping point has been crossed, triggering a shift to a low-productivity regime from which stock recovery requires major intervention (Möllmann et al. 2021; Möllmann 2025), could be more likely to adjust their expectations and support precautionary measures (Blöcker et al. 2025). Misalignment between stakeholder perceptions and scientific assessments generates conflict and undermines compliance (Dean et al. 2023), whereas robust information on stock status fosters attitudes consistent with the ecological evidence (Lewin et al. 2025).

To investigate recreational anglers' perceptions of the overall stock abundance trend over time, stock status, and the presence of regime shifts in the western Baltic cod stock or fishery (i.e., profound, decisive, lasting changes in either ecological or social/institutional conditions), we drew on research from the human dimensions of recreational fisheries and social psychology. This literature has identified multiple variables that consistently influence angler perceptions of environmental change, stock development and preferences for management, including personal attachment to the local fish species, psychological commitment to fishing, attitudes to the catch and retention aspects of fishing, years of fishing experience, education, age, and socio-economic status (Bryan 1977; Ditton et al. 1992; Arlinghaus and Mehner 2005; Carlin et al. 2012; Hunt et al. 2013; van den Heuvel et al. 2022). Past research has also shown that anglers are, on average, able to track stock trends reasonably well (Van Gemert et al. 2022; van den Heuvel and Rönnbäck 2023; Blyth et al. 2024) and that the more engaged anglers are, the more sensitive they are to the perception of fish stock declines (van den Heuvel and Rönnbäck 2023). Recreational fishers with long-term interactions with the environmental dynamics of their local angling spots can foster reasonably accurate perceptions of ecological cause-and-effect relationships driving stock dynamics, which can mirror the best scientific understanding (Gray et al. 2015; Aminpour et al. 2020). Research has also

shown that behaviourally and more socially involved recreational anglers have stronger media interactions (Ditton et al. 1992) and enhanced ecological knowledge and understanding (Morgan and Soucy 2009; Foster et al. 2023). Situational factors, such as exposure to information about stock declines, can significantly influence individuals' perceptions and can moderate the relationship between attitudes, perceptions, and behaviours (Whittaker et al. 2006; Arlidge et al. 2023).

Against this background, we undertook an exploratory study to test how a suite of psychological and demographic attributes (e.g., attitudes towards cod management and cod catch, centrality of fishing to the lifestyle of anglers, experience of fishing, education) influence German recreational cod anglers' perceptions of the stock trend and the current status of the western Baltic cod stock, and whether they perceive one or more profound changes that have had a profound, decisive, and lasting impact on cod fishing or the cod stock as a whole (i.e., regime shifts). The study objectives were to: (i) assess how anglers perceive the cod stock trend in abundance since they first started fishing, the current stock status, and the presence of regime shifts in the western Baltic cod fishery, and how their perceptions align with scientific assessments; and (ii) identify which psychological and demographic factors most strongly and consistently shape these perceptions.

Methods

Survey design

We conducted an online survey targeting recreational cod anglers in Germany that ran from November 2020 until May 2021. Respondents ($n=3,957$) were recruited via five channels: computer-assisted telephone interviews (CATI; $n=735$); email outreach ($n=76$); leveraging existing contacts among known cod anglers and in-person recruitment at harbours along the German Baltic coast ($n=17$); and advertisements placed in angling print media and on social media platforms ($n=3,129$). Data collection was administered by a professional survey institute. All questionnaires underwent predefined data-quality checks, including attention-check items, completion-time screening to detect speeding, and

response-pattern and internal-consistency checks (including detection of straight-lining and inconsistent answer patterns). Only questionnaires passing these checks were retained for analysis. The low number of anglers recruited in person was a result of restrictions related to the COVID-19 pandemic that prevented site visits at random locations at the German coastline of the Baltic Sea.

The CATI respondents were recruited from a list of anglers who had bought fishing permits for the Baltic coastal waters of the German federal state of Mecklenburg-Western Pomerania and voluntarily agreed to participate in scientific studies. Anglers were eligible for participation if they were aged 14 years or older and had previously fished for cod on the German Baltic coast at least once or were planning to do so within the next three years. Participation was incentivised with a €10 voucher for an online angling store for each completed interview, and participants were additionally entered into a raffle offering a chance to win one of three €500 gift certificates. The self-completion questionnaire employed questions with predefined response formats as well as open-ended questions enabling respondents to describe their perceptions of stock status and regime shifts and underlying ecological or social reasons verbally in their own words. Established scales of the field of human dimensions of recreational fisheries were incorporated to assess key psychological constructs that captured heterogeneity among individual anglers, such as those related to angler commitment, catch orientation, attitudes towards various cod management aspects, trust in science, and socio-demographics. The median completion time for the online questionnaire was 50 min.

Dependent variables

We assessed anglers' perceptions of the western Baltic cod stock trend and cod stock status using two closed questions with five-point rating scales. The first question captured anglers' perceptions of the abundance trend of cod in the western Baltic Sea since they first started fishing (stock trend; response options: decreased sharply, decreased, remained the same, increased, increased strongly, don't know – anglers with don't know responses were removed from the dataset for the predictive modelling portion of the analysis, see below). The second question

aimed to capture anglers' perception of the current status of the cod stock (stock status; response options: very good, good, neither good nor poor, poor, very poor, don't know – again, anglers with don't know responses were removed for predictive modelling). Respondents who rated the stock status as poor or very poor were asked a follow-up question with an open-ended response format: "*In your opinion, what led to the very poor or poor condition of the western cod stock?*". Responses were analysed using qualitative content analysis (Forman and Damschroder 2007). Coding categories developed inductively (i.e., emerged from responses rather than from a priori specification); responses were analysed until content saturation. The coding categories were later regrouped into a smaller set of recurring themes grouped into five major categories of potential drivers: (1) fishing pressure, (2) regulations, (3) compliance issues, (4) natural environmental change, and (5) anthropogenic environmental change. Fishing pressure included themes such as commercial overfishing or recreational angling harvest of cod. Regulations encompassed themes such as catch quotas, minimum-size limits, and impacts of a closed season. Compliance issues focused on enforcement, awareness, or adherence to existing regulations by both fishers and anglers. Natural environmental change spanned shifts in salinity or predator or prey abundance. Finally, anthropogenic environmental change covered themes like pollution, nutrient inputs, or the warming of the climate (Table S1). Only categories with at least 1% response frequency were retained for further analysis.

We then used an open-ended question to elicit respondents' perceptions of profound historical change in the western Baltic cod fishery: "*When you look back on the history of fishing for western cod, do you think there have been one or more profound changes that have had a decisive and lasting impact on cod fishing or the cod stock as a whole? These could be social, economic, technical or ecological aspects*". The term "regime shift" was not used in the question wording in order to avoid introducing unfamiliar scientific terminology to respondents; instead, the question elicited perceptions of profound changes with decisive and lasting impacts on the fishery system, spanning social, economic, technical, and ecological dimensions, without requiring respondents to infer the underlying dynamics (e.g., whether change was gradual or threshold-mediated). This wording

reflects key attributes emphasised in regime shift theory (major change in system structure and function that endures); accordingly, we interpret respondents' accounts as perceived regime shifts in the fishery system. For analysis, responses to this question were first recoded into a binary variable (change perceived versus no change perceived, including blank, "none", and "don't know" responses; for the full list of categorised responses see Supplementary Materials, Appendix A). Again, we analysed responses using qualitative content analysis, with coding categories emerging from the data rather than being predetermined. This time coding categories were grouped into four major factors: (1) fishing pressure, (2) regulations, (3) natural environmental change, and (4) anthropogenic environmental change (Table S1). As coding categories emerged from responses and no respondents mentioned any compliance-related points, compliance issues were not included in the regime shift major categories.

The resulting variables of anglers' perception of (i) the overall cod stock abundance trend over time, (ii) cod stock status (complemented by an open-ended follow-up question), and (iii) one or more regime shifts in the western Baltic cod fishery or the cod stock as a whole, served as the main three dependent variables for modelling anglers' perceptions (see the "Predictive modelling" subsection).

Independent variables

Predictor variables for anglers' perceptions of stock trend, stock status, and regime shifts were constructed from responses to other sections of the survey. These included measures of (i) attitudes towards cod, (ii) fishing involvement, (iii) cod fishing involvement, (iv) self-rated knowledge and trust in science, and (v) socio-demographic characteristics. Some predictors, such as whether a respondent's home state borders the Baltic Sea or not (residency), were generated directly from answers given in the survey. Other predictor variables were formed by aggregating the responses to multiple statements in the questionnaire (called "items") that respondents had to react to by means of a rating scale. Typically, we used five-point rating scales to assess, for example, fishing centrality to lifestyle or catch orientation (Kim et al. 1997; Anderson et al. 2007). If statements with similar content correlated highly with each other, we assumed that their

variation was driven by the same underlying construct (i.e., a latent psychological characteristic). This assumption was tested for all relevant items using an exploratory factor analysis (principal component analysis with varimax rotation) using the "psych" package (Revelle 2020). Aggregates of items loading high on one factor (> 0.4) were subsequently assessed for measurement reliability (Bland and Altman 1997; Irwing and Hughes 2018). We estimated Cronbach's alpha (α) as a reliability coefficient for aggregates of more than two items and considered an α value of 0.7 or higher an acceptable threshold (Lavrakas 2008). The responses to these items were averaged for each individual to create a construct score representing the latent variable. Where a construct was measured as the average of only two items, we corrected the empirical Pearson's correlation between them for attenuation using the Spearman-Brown prediction formula to estimate the composite score's reliability from that correlation. As acceptable, we considered a corrected correlation value of 0.7 or higher (Hair et al. 2010; Irwing and Hughes 2018). Items that were not deemed appropriate for combining into an aggregate construct were kept as single-item indicators. The scale scores of negatively worded items were reverse-coded before aggregation to ensure consistent directionality within each construct. Because the continuous predictors differed in scale, range, and skewness (Fig. S1), we z-standardised all predictors prior to modelling. The full item set with their assignments to the latent constructs, descriptive statistics, and psychometric properties are provided in the Supplementary Materials (Table S2).

Attitudes towards cod fishing and management.

Anglers have been previously found to vary in their attitudes to the catch and harvest aspects of fishing along four subdimensions, namely, attitude towards (i) catching something, (ii) catching numbers of fish, (iii) catching large/trophy fish, and (iv) retaining fish for consumption (Anderson et al. 2007). The original "consumptive orientation" scale (now more commonly referred to as the "catch orientation" scale; Arlinghaus 2024) consisted of 16 statements (items). To reduce survey length, we used seven items from the original scale and translated them into German. Unlike Anderson et al. (2007), we adapted each item by explicitly referencing cod, allowing us to capture catch orientation specifically related to this target species (Table S2). Factor analysis followed by reliability

testing identified two items for aggregation into one composite-score indicator and five single-item indicators. The two-item measure reflected a preference for catching large fish (Spearman-Brown $\rho_{SB} = 0.708$). One example item from this construct is: “*The bigger the fish I catch, the better the fishing trip*”. The remaining five items did not load strongly onto shared factors and were retained as single-item indicators. Two of these items captured anglers’ catch orientation toward retaining fish, such as: “*I’m just as happy if I release the fish I catch (e.g., too small)*”. Another two aligned with an emphasis on catching numbers of fish, including: “*The more fish I catch, the happier I am*”. The final item represented a general catch motivation: “*A fishing trip can be successful even if no fish are caught*”.

More general attitudes towards cod management were ascertained with six ad-hoc items we constructed that assessed the support for cod management and attitudes towards a particular governance level in cod management (from local to EU scales). Factor analysis and subsequent reliability analyses did not justify summarising any of these items as latent constructs (Table S2). All six items remained as single-item indicators, including: “*Without effective measures, there is a risk that there will no longer be a usable cod population in the western Baltic Sea in the future*”, “*Compliance with cod management measures should be monitored more regularly*”, “*I support the EU’s cod management*”, “*Cod management should be organised in the individual EU member state and no longer at the EU level*”, “*Regulating the angling fishery makes sense so that the cod population recovers*”, and “*Regulating commercial fishing makes sense so that the cod population recovers*”.

Fishing involvement

We operationalised three behavioural dimensions of fishing involvement: (i) fishing experience, (ii) fishing centrality to lifestyle, and (iii) fishing avidity (as a measure of behavioural commitment; Table S2). Fishing experience was captured with a mean-years-of-fishing construct, calculated as the average number of years a respondent spent cod fishing and their total years spent fishing (Spearman-Brown $\rho_{SB} = 0.805$). We measured respondents’ fishing centrality to lifestyle using a five-item construct taken as a subset of the centrality to lifestyle scale (Kim et al. 1997;

Sutton 2003). The five items in the construct measure the integration of fishing in an individual’s lifestyle and their social networks using items such as “*A large part of my life revolves around fishing*” and “*Most of my friends are also involved in fishing*” (Cronbach’s $\alpha = 0.802$; Table S2). Fishing avidity was measured as the mean of two items: “*On how many days did you fish in total in Germany or abroad in 2019?*” and “*Approximately how many days did you fish in Germany in 2019, whether for cod or other species?*” (Spearman-Brown $\rho_{SB} = 0.962$).

Cod fishing involvement

Three measures of fishing involvement for cod were distinguished. Firstly, cod fishing avidity was derived from two items on cod-specific fishing: “*Approximately how many days did you specifically fish for cod in 2019, whether in Germany or abroad?*” and “*Approximately how many days did you fish specifically for cod on the German Baltic or North Sea coast in 2019?*” (Spearman-Brown $\rho_{SB} = 0.955$; Table S2). Secondly, we measured the relevance of cod as a prime target, based on a ranking of our respondents’ five most preferentially targeted fish species. This measure ranged from five, representing cod as the most preferred species, to zero, indicating that cod was not ranked among a given respondent’s top five species (Table S2). Thirdly, self-perceived cod catching skill was assessed using three items: “*I would describe myself as a fishing expert*”, “*My fishing skills are better than those of the average angler*”, and “*My cod fishing skills are better than those of the average cod angler*” (Cronbach’s $\alpha = 0.790$). Skill items were used because skill is one of the three facets of angler specialisation (Scott and Shafer 2001), alongside behavioural commitment (represented by avidity in our survey) and psychological commitment (represented by fishing centrality to lifestyle; Kim et al. 1997).

Self-rated knowledge/Trust in Science

Self-rated knowledge about cod management was measured using two survey items that were grouped together to form an “information certainty” measure: “*I am well informed about the current situation of cod in the western Baltic Sea*” and “*I am well informed about the EU cod management objectives*”

(Spearman-Brown $\rho_{SB}=0.775$; Table S2). Trust in science was assessed using a four-item measure based on self-constructed items: “*I trust that science will solve our environmental problems*”, “*I trust scientific calculations about cod stocks in the Baltic Sea*”, “*I believe fisheries biologists provide correct figures on cod stock status*”, and “*I trust scientific recommendations on cod management passed on to authorities*” (Cronbach’s $\alpha=0.850$).

Socio-demographics

We included several socio-demographic variables in the models (see below). Respondents indicated their political orientation using a simple ten-point rating scale in which “1” indicated left leaning and “10” indicated right leaning. This scale was recoded into five ordinal categories (1–2 = far left, 3–4 = centre-left, 5–6 = centre, 7–8 = centre-right, 9–10 = far right). Missing ($n=8$) and “don’t know” responses ($n=200$) were imputed using the scale’s mean value. Education level was recorded using seven ordered categories: (1) currently in school/no completed qualification; (2) secondary school leaving certificate or intermediate school leaving certificate; (3) polytechnic secondary school qualification; (4) vocational training qualification; (5) advanced technical qualification; (6) master craftsman or advanced professional qualification; and (7) university degree. Respondents selecting “other” were recoded to the appropriate category based on their free-text response. Following standard practice for ordinal predictors with multiple ordered categories, education was treated as a continuous variable in the regression models. Finally, residency status was coded as a binary variable, distinguishing “resident” anglers who were from the two states bordering the Baltic Sea (Mecklenburg-Western Pomerania, Schleswig–Holstein) from German “non-resident” anglers whose permanent residence was in one of the other German states.

Statistical analyses

All statistical analyses were conducted in R version 4.5.0 (R Core Team 2025). We first analysed the data descriptively to identify broad patterns in how cod anglers perceive the decline of the cod stock since they first started fishing, its current status, and potential regime shifts within the fishery. To correct

for potential biases in the self-selected online sample (e.g., overrepresentation of more avid anglers; Connelly et al. 2000; Griffiths et al. 2013), population-level estimates were weighted based on age, gender, education, state of origin, fishing effort, club membership, and fishing centrality to lifestyle (Kim et al. 1997) using pre-existing data from random telephone surveys of marine anglers in Germany (Weltersbach et al. 2021). Resident anglers from the federal states bordering the Baltic Sea and non-resident anglers (i.e., those not residing in states bordering the Baltic Sea) were descriptively analysed separately to see if they provide markedly different responses. Differences between resident and non-resident anglers in weighted means (continuous variables) and proportions (categorical variables) were tested using survey weighted t-tests and design-based Pearson χ^2 (Rao-Scott second-order correction), respectively (“survey” package; Lumley 2004). We excluded “don’t know” responses. Effect sizes for categorical comparisons are given as Cramér’s V (equivalent to ϕ for 2×2 tables). We adopted the conventional alpha threshold of 0.05 for significance.

To analyse the factors shaping anglers’ perceptions of cod stock trend, stock status, and regime shifts, we applied a regression-based modelling approach. All regression models presented in this study used unweighted data to avoid bias in hypothesis testing (Winship and Radbill 1994). Three separate models were estimated, one for each outcome variable, using the full set of predictors described above. All predictors were retained in each model to assess the consistency of their explanatory power across different perceptions; no variable selection was applied to prioritise parsimony. Each model’s assumptions and fit were evaluated using residual diagnostics, goodness-of-fit measures, and, for the ordinal models, the Brant test of proportional odds (Brant 1990).

For both ordinal outcomes, we estimated ordinal logistic regression using the “MASS” package (Venables and Ripley 2002). This approach is appropriate for ordered response (i.e., dependent) categories because it respects the ordering without assuming equal intervals between them. Categories were coded so that higher values reflect more pessimistic perceptions. For stock trend, 1 = “increased strongly” to 5 = “decreased sharply”. For current stock status, 1 = “very good” to 5 = “very poor”. The proportional odds assumption was evaluated with the Brant test. It

was not violated for perceived stock trend (Table S3). For perceived stock status, the omnibus Brant test was significant ($X^2=97.652$, $df=69$, $p=0.013$), with “More compliance monitoring” and “Commercial cod regulation” driving the departure (Table S4). This test result indicates that these predictors do not shift the odds uniformly across the response thresholds. We therefore estimated a partial proportional-odds model using the “ordinal” package that allowed these two predictors to vary across response categories while constraining all other predictors to a common slope. A likelihood-ratio test showed that this model fit the data significantly better than the standard proportional odds model ($LR=29.4$, $df=6$, $p<0.001$). For most predictors, an odds ratio greater than one signals a more pessimistic perception and this effect is constant across the response scale. For “More compliance monitoring” and “Commercial cod regulation”, threshold-specific coefficients adjust the threshold intercepts rather than the slope; here an odds ratio below one carries the same substantive implication (Table S4).

For the binary outcome modelling whether anglers perceived one or more regime shifts, we fitted a Generalised Additive Model (GAM; “mgcv” package; Wood 2011). GAMs extend standard logistic regression by allowing certain predictors to have flexible, non-linear relationships with the response variable rather than strictly linear ones. This flexibility was necessary here as we identified a non-linear relationship between fishing experience and anglers’ regime-shift perception. GAMs estimate such relationships using smooth functions on the predictors exhibiting non-linear relationships with the modelled dependent variable, which let the data reveal the shape of the effect rather than imposing a straight line. Residual diagnostic plots indicated no major departures from the model assumptions (Fig. S2).

Results

Sample information

Of the 3,957 anglers who started the survey, 1,788 completed all relevant questions for our analyses. Post-stratification weights were applied to these responses. The vast majority (96%) of respondents had already fished for cod, whereas the remaining

respondents (4%) intended to do so within the next three years (Table 1). The (weighted) distribution of marine anglers across German federal states highlighted that the density of cod anglers was highest in the states bordering the Baltic Sea (i.e., Mecklenburg-Western Pomerania, Schleswig-Holstein) while non-resident (tourist) anglers were more evenly distributed across the rest of the 16 federal states, particularly North Rhine-Westphalia and Lower Saxony. The vast majority of the surveyed anglers were male (95%), on average 50.3 years old (range: 14–82), with an average fishing experience of 35.6 years (range: 1–74) and 9.5 cod fishing days in 2019 (range: 0–250). Non-residents had a higher rate of angling organisation membership (63%) than resident anglers (46%). Fishing centrality to lifestyle was moderate and similar between resident (average score of 3.2 on a five-point scale) and non-resident (3.1) anglers.

Anglers’ perceptions of the stock trend and status of the western Baltic cod

Anglers predominantly expressed negative views about the stock trend since they started fishing and of the current state of the western Baltic cod stock. When asked to evaluate changes in cod abundance over time since they started fishing, 83.7% of anglers perceived either a strong decrease or a decrease (43.0% perceiving a strong decrease; Fig. 2). While 11.5% of anglers reported a stable trend, and 4.8% perceived an increasing or strongly increasing trend. The distribution of responses for the perceived trend did not differ significantly between resident and non-resident anglers ($\chi^2=3.643$, $df=3.11$, $p=0.319$). Similarly, assessments of the current state of the western Baltic cod stock were highly pessimistic overall; 65.1% of respondents rated the stock as poor or very poor, while 26.8% provided a neutral evaluation. Contrary to scientific consensus, 8.1% of respondents considered the stock condition to be in a good or very good condition (Fig. 2). No difference was observed in the distribution of the current stock status responses between resident and non-resident anglers ($\chi^2=1.216$, $df=3$, $p=0.749$).

Perceived factors leading to poor stock status

Among the 65.1% of anglers who rated the cod stock as “poor” or “very poor”, the most frequently

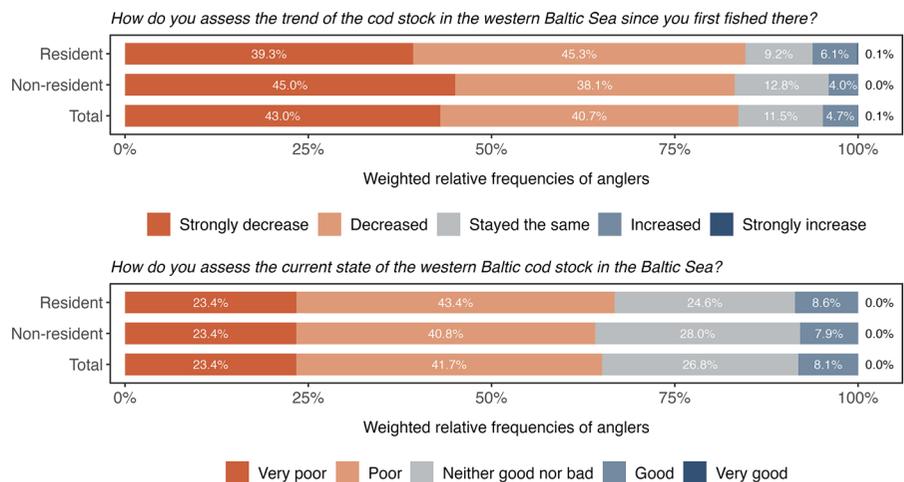
Table 1 Weighted mean, standard error, and design-based comparison tests for resident versus non-resident recreational cod anglers in Germany. Continuous variables were compared with survey-weighted t-tests; categorical variables with Rao–Scott second-order χ^2 tests. Effect sizes are Cramér’s V

(ϕ for 2×2); “–” indicates not applicable. All respondents are included; two non-specified gender cases and the single gender-diverse case are combined as “Diverse/not-specified”. s.e. = Standard error

Variable	Description	Residents (n = 654)		Non-residents (n = 1,134)		Total (N = 1,788)		p	ϕ/V
		Mean	s.e	Mean	s.e	Mean	s.e		
Age (years)	Mean age of anglers	48.1	1.1	51.4	0.8	50.3	0.7	0.018	–
Gender (male)	Per cent of male anglers	91.4	2.4	96.4	1.2	94.7	1.1	0.038	0.11
Gender (female)	Per cent of female anglers	7.8	2.3	3.3	1.1	4.9	1.1	0.052	0.1
Gender (diverse/not-specified)	Per cent of anglers identifying as diverse or not specifying gender	0.8	0.8	0.3	0.3	0.5	0.3	0.474 ^a	0.03
Fishing avidity	Mean annual fishing days (all types) in 2019	47.9	4.3	45.5	2.6	46.3	2.3	0.629	–
Cod fishing avidity	Mean annual days spent fishing for cod in 2019	13.2	1.4	7.6	0.8	9.5	0.7	<0.001	–
Fishing experience	Mean number of years since fishing for the first time	33.9	1.4	36.4	1.0	35.6	0.8	0.132	–
Angling organisation membership (yes/no)	Per cent of anglers who are members of a fishing club	45.6	4.1	63.1	2.9	57.1	2.4	0.001	0.17
Centrality of fishing in lifestyle (5-point scale)	Importance of fishing in the personal lives of anglers (higher value = more central)	3.2	0.1	3.1	0.1	3.1	0.0	0.204	–

^aExpected cell count < 5; unweighted Fisher’s exact test p = 0.626, $\phi/V = 0.03$

Fig. 2 Weighted relative frequencies of German recreational anglers’ perceptions of the trend in abundance (top) and the current state (bottom) of the western Baltic cod stock (5-point rating scales), shown for resident anglers, non-resident anglers, and total values for all anglers (n = 1,788)



perceived major factor category cited as leading to a poor condition of the western cod stock was fishing pressure (83.3%), followed by anthropogenic environmental change (44.8%), natural environmental change (23.9%), compliance issues (23.9%), and fisheries regulations (19.5%). Of the five major

factor categories compliance issues showed significant differences between residents and non-residents in relative frequency rates (residents = $31.9 \pm 4.9\%$, non-residents = $19.5 \pm 3.1\%$), suggesting that aside from this factor grouping, both resident and non-resident anglers broadly shared similar perceptions

regarding the primary causes of the cod stock’s poor status (Table 2). Within the major categories, five out of 22 sub-categories differed significantly between residents and non-residents: closed season (residents = $19.4 \pm 4.2\%$, non-residents = $8.6 \pm 2.2\%$), fishing tourism (residents = $2.2 \pm 1.5\%$, non-residents = $0.2 \pm 0.1\%$), climate change (residents = $14.6 \pm 3.6\%$, non-residents = $26.6 \pm 3.5\%$), oxygen content (residents = $22.0 \pm 4.4\%$, non-residents = $4.8 \pm 1.7\%$), and rules (overall) (residents = $30.3 \pm 4.8\%$, non-residents = $18.7 \pm 3.0\%$;

Table 2). Resident anglers cited closed season, fishing tourism, oxygen content and rule-related shortcomings more often, whereas non-residents were more likely to mention climate change.

Modelling perceived factors leading to the declining trend and poor cod stock status

Our analysis highlights the interplay of attitudes to cod management, commitment to fishing, and socio-demographic factors that underpin anglers’

Table 2 Weighted relative frequencies (\pm s.e.) of the factors recreational cod anglers perceive as contributing to the “very poor” or “poor” state of the western Baltic cod stock. Percentages and standard errors are weighted to represent the national

population of German recreational cod anglers; the estimates are calculated from the 65.1% of survey respondents who rated the stock status as “very poor” or “poor”

General category/subcategory	Total (N=1081)	Residents (n=404)	Non-residents (n=677)	χ^2 ^b	p-value	Cramér’s V
Fishing pressure	83.3 \pm 2.3	81.9 \pm 4.0	84.0 \pm 2.8	0.194	0.660	0.013
Overfishing general	79.0 \pm 2.5	76.0 \pm 4.5	80.6 \pm 3.1	0.756	0.385	0.026
Commercial fishing	55.0 \pm 3.1	56.9 \pm 5.1	54.0 \pm 3.9	0.211	0.646	0.014
Trawling nets	27.8 \pm 2.8	31.4 \pm 4.9	25.9 \pm 3.5	0.892	0.345	0.029
Bycatch	3.9 \pm 1.2	1.7 \pm 0.9	5.1 \pm 1.7	3.242	0.072	0.055
Cutter fishing	3.1 \pm 1.1	2.6 \pm 1.8	3.4 \pm 1.4	0.125	0.724	0.011
Fishing tourism	0.9 \pm 0.5	2.2 \pm 1.5	0.2 \pm 0.1	–	0.002*	0.101
Anthropogenic environmental change	44.8 \pm 3.1	42.2 \pm 5.1	46.3 \pm 3.9	0.405	0.525	0.019
Climate change	22.3 \pm 2.6	14.6 \pm 3.6	26.6 \pm 3.5	4.918	0.027*	0.068
Water warming	12.3 \pm 2.0	7.8 \pm 2.7	14.8 \pm 2.8	2.839	0.092	0.051
Oxygen content	10.9 \pm 2.0	22.0 \pm 4.4	4.8 \pm 1.7	17.934	<0.001*	0.129
Environmental pollution	8.4 \pm 1.7	7.8 \pm 2.6	8.8 \pm 2.2	0.071	0.790	0.008
Agriculture	7.9 \pm 1.7	11.8 \pm 3.4	5.8 \pm 1.8	2.898	0.089	0.052
Natural environmental change	23.9 \pm 2.7	24.3 \pm 4.6	23.6 \pm 3.3	0.013	0.909	0.003
Environmental conditions	7.4 \pm 1.6	9.7 \pm 3.2	6.2 \pm 1.8	1.039	0.308	0.031
Feed decline	7.4 \pm 1.6	6.0 \pm 2.4	8.1 \pm 2.1	0.391	0.532	0.019
Salinity	5.5 \pm 1.4	5.3 \pm 2.3	5.6 \pm 1.8	0.010	0.920	0.003
Predators	4.3 \pm 1.3	6.2 \pm 2.6	3.2 \pm 1.3	1.266	0.261	0.034
Spawning cod removal	3.3 \pm 1.2	2.6 \pm 1.8	3.7 \pm 1.5	0.185	0.668	0.013
Compliance issues	23.9 \pm 2.7	31.9 \pm 4.9	19.5 \pm 3.1	4.981	0.026*	0.068
Rules overall	22.8 \pm 2.6	30.3 \pm 4.8	18.7 \pm 3.0	4.532	0.034*	0.065
Non-compliance	2.4 \pm 0.9	4.5 \pm 2.2	1.2 \pm 0.8	2.988	0.084	0.053
Control	2.1 \pm 0.9	1.9 \pm 1.4	2.2 \pm 1.2	0.019	0.890	0.004
Fisheries regulations	19.5 \pm 2.5	26.0 \pm 4.6	15.9 \pm 2.8	3.792	0.052	0.059
Closed season	12.4 \pm 2.1	19.4 \pm 4.2	8.6 \pm 2.2	6.244	0.013*	0.076
Minimum size	7.9 \pm 1.7	8.6 \pm 3.0	7.5 \pm 2.0	0.094	0.759	0.009
Catch quotas	5.1 \pm 1.4	5.4 \pm 2.3	4.9 \pm 1.7	0.036	0.850	0.006

^bDesign-adjusted (Rao-Scott second-order) χ^2 statistic. For factors with expected weighted counts <5, the Rao-Scott test is replaced by a Monte-Carlo Fisher exact test (10,000 replicates); χ^2 values are left blank in those rows. Cramér’s V is always calculated from the (design-adjusted) χ^2 and the total weighted N. “–” indicates not applicable

perceptions of stock status and stock trend (Figs. 2, 3). For both models, anglers’ attitudes towards cod management emerged as a critical determinant (Tables S5, S6). Respondents perceiving a need for cod management were significantly more likely to report a declining stock trend ($\beta=0.515$, $SE=0.056$, $t=9.117$, $p<0.001$) and poor stock status ($\beta=0.478$, $SE=0.093$, $z=5.162$, $p<0.001$; Fig. 3). In the partial proportional-odds model predicting cod stock status (in which the dependent variable is an ordinal categorical variable), more compliance monitoring functioned as a threshold predictor with significant negative coefficients across three of the

four cut-points (e.g., “poor” to “very poor” (-0.397 , $SE=0.123$, $z=-3.229$, $p=0.001$; Fig. 3). These significant negative estimates indicate that anglers who perceived a stronger need for more compliance monitoring predominantly shifted their rating of the cod stock towards worse status categories. However, the cut-point of “good” to “neither good nor bad” was not significant. By contrast, the “commercial cod regulation” threshold predictor only had a significant effect at the transition from “poor” to “very poor” (-0.362 , $SE=0.097$, $z=-3.717$, $p<0.001$), suggesting that anglers seeing a need for commercial cod regulation were more likely to classify the stock as “very

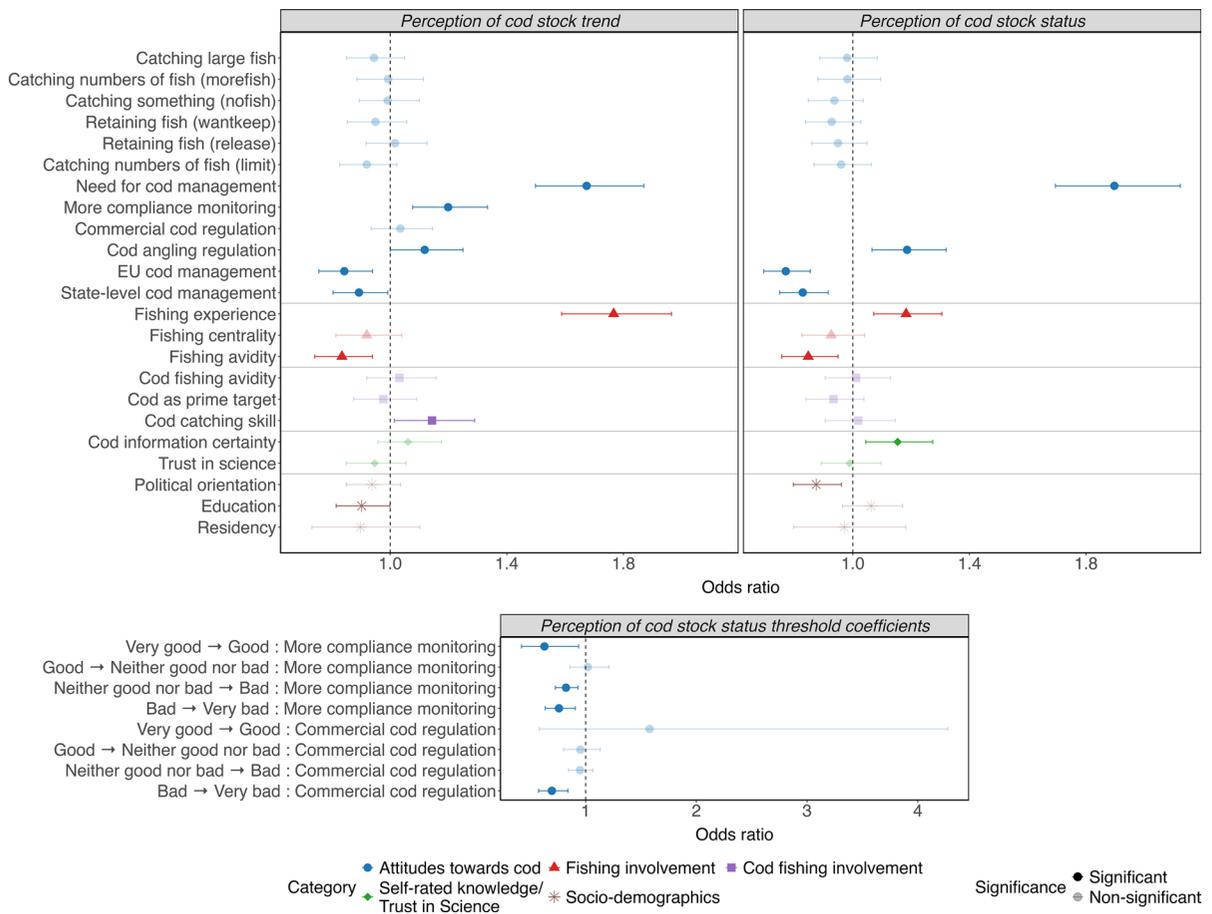


Fig. 3 Odds ratios (logit scale, 95% CIs) for predictors of German recreational anglers’ perceptions of western Baltic cod abundance trend and the current stock status. The top-left panel presents the proportional-odds model for perceived trend ($n=1658$); the top-right panel shows common-slope coefficients from the partial proportional-odds model for current stock status ($n=1688$); the lower panel, displays thresh-

old-specific effects for the two predictors that violated the parallel-lines assumption. In the upper panels, an odds ratio > 1 indicates a more pessimistic prediction; in the lower panel, an odds ratio < 1 carries the same implication. The dashed vertical line marks an odds ratio of 1; filled symbols indicate $p<0.05$. Symbol shapes and colours denote predictor categories. The full model summaries are provided in Tables S5–S6

poor,” rather than “poor.” The other threshold coefficients for this predictor were not statistically significant. No significant effect of commercial cod regulation was found for perceptions of a declining trend ($\beta=0.034$, $SE=0.052$, $t=0.654$, $p=0.513$). Perceiving a need for regulation of cod angling was associated with a higher likelihood of reporting a declining trend ($\beta=0.112$, $SE=0.057$, $t=1.976$, $p=0.048$) and poor stock status ($\beta=0.170$, $SE=0.055$, $t=3.117$, $p=0.002$). In contrast, perceiving a need for EU cod management was associated with a reduced likelihood of reporting both a poor stock status ($\beta=-0.270$, $SE=0.053$, $t=-4.924$, $p<0.001$) and a declining trend ($\beta=-0.171$, $SE=0.056$, $t=-3.077$, $p=0.002$). Similarly, perceiving a need for state-level cod management was associated with a declining trend ($\beta=-0.113$, $SE=0.053$, $t=-2.120$, $p=0.034$) and a lower likelihood of reporting poor stock status ($\beta=-0.191$, $SE=0.051$, $t=-3.737$, $p<0.001$). All five measures across the four catch orientation dimensions had no influence on perceptions of cod trend or status.

Several fishing involvement predictors played a prominent role in shaping perceptions of cod stock trend and status (Fig. 3). Anglers with more fishing experience were significantly more likely to report both a declining trend ($\beta=0.569$, $SE=0.054$, $t=10.470$, $p<0.001$) and a poor stock status ($\beta=0.170$, $SE=0.050$, $t=3.371$, $p=0.001$). Similarly, anglers with higher fishing avidity were more likely to report a negative stock assessment, with significant relationships identified for both stock trend ($\beta=-0.181$, $SE=0.061$, $t=-2.986$, $p=0.003$) and status ($\beta=-0.165$, $SE=0.058$, $t=-2.848$, $p=0.004$). Fishing centrality to lifestyle showed no influence on perceptions of cod trend or status.

Of the cod fishing involvement predictors, cod catching skill significantly influenced perceptions, with anglers who scored higher in this self-assessed expertise more likely to report a declining trend ($\beta=0.134$, $SE=0.061$, $t=2.186$, $p=0.029$). We found no influence of cod catching skill on anglers' perceptions of cod stock status, and neither cod fishing avidity nor cod as a prime target had a significant effect on either perceived cod stock status or trend.

Among the self-rated knowledge and trust in science predictors, higher information certainty about cod was associated with a greater likelihood of perceiving poor stock status ($\beta=0.142$, $SE=0.051$,

$t=2.788$, $p=0.005$), but not a declining trend. Trust in science had no significant effect in either model.

Of the socio-demographic factors, political orientation showed a small but significant effect: more conservative respondents were less likely to perceive poor stock status ($\beta=-0.135$, $SE=0.048$, $t=-2.818$, $p=0.005$). Education also had a significant negative effect on anglers' perceptions of a declining stock trend ($\beta=-0.103$, $SE=0.052$, $t=-1.980$, $p=0.048$). Residency status showed no significant effects.

Perceptions of regime shifts in the cod stock or the cod fishery

Overall, 72.5% of anglers perceived one or more regime shifts in the cod stock or the cod fishery. Among resident anglers, 76.7% reported a regime shift, compared to 70.3% of non-residents; a non-significant difference ($\chi^2=2.027$, $df=1$, $p=0.155$).

Perceived factors that had a decisive and lasting impact on the cod fishery or stock

Among anglers who perceived one or more regime shifts, the most frequently cited change that has had a decisive and lasting impact on the cod fishery or stock was fishing pressure (66.7%), followed by anthropogenic environmental change (25.7%), fishing regulations (22.0%), and natural environmental change (17.4%; Table 3). Resident anglers were significantly more likely to mention fishing pressure factors than non-residents (residents = $74.8 \pm 4.0\%$, non-residents = $62.1 \pm 3.5\%$), while no significant differences were found for the other three major categorisations of change: regulations, natural environmental change, or anthropogenic environmental change (Table 3). Within the major categories of change, four of the 21 sub-categories showed significant differences between resident and non-resident angler relative frequency rates: closed season (residents = $8.8 \pm 2.8\%$, non-residents = $3.5 \pm 1.3\%$), overfishing (residents = $68.8 \pm 4.3\%$, non-residents = $52.4 \pm 3.6\%$), commercial fishing (residents = $52.2 \pm 4.7\%$, non-residents = $36.7 \pm 3.4\%$), and environmental conditions (residents = $8.8 \pm 2.8\%$, non-residents = $3.0 \pm 1.1\%$). In every instance, more resident anglers cited these factors as having a decisive and lasting impact on the cod fishery or stock than non-resident anglers.

Table 3 Weighted relative frequencies (%) ± standard errors of the factors German recreational cod anglers perceived as having undergone one or more profound changes that produced a decisive and lasting impact on either cod fishing practices or the western Baltic cod stock (i.e., regime shifts). Percentages

and standard errors are weighted to adjust the sample to the national population of German recreational cod anglers; the estimates are based on the 72.5% of survey respondents who reported one or more profound changes, spanning social, economic, technical, or ecological aspects

General category/subcategory	Total (N=1280)	Residents (n=483)	Non-residents (n=797)	χ^2 ^c	p-value	Cramér's V
Fishing pressure	66.7 ± 2.7	74.8 ± 4.0	62.1 ± 3.5	5.240	0.022*	0.063
Overfishing	58.4 ± 2.8	68.8 ± 4.3	52.4 ± 3.6	7.996	0.005*	0.078
Commercial fishing	42.3 ± 2.8	52.2 ± 4.7	36.7 ± 3.4	7.044	0.008*	0.074
Trawling nets	21.2 ± 2.3	22.1 ± 3.9	20.7 ± 2.9	0.077	0.782	0.008
Fishing pressure	12.6 ± 1.9	15.8 ± 3.5	10.7 ± 2.2	1.641	0.200	0.035
Fishing technique	3.9 ± 1.1	1.4 ± 1.0	5.4 ± 1.7	3.319	0.069	0.050
Bycatch	2.6 ± 0.9	1.4 ± 1.0	3.4 ± 1.3	1.183	0.277	0.030
Tourism	1.7 ± 0.7	1.6 ± 1.1	1.7 ± 0.9	0.002	0.964	0.001
Anthropogenic environmental change	25.7 ± 2.5	23.3 ± 4.0	27.2 ± 3.1	0.569	0.451	0.021
Climate change	15.4 ± 2.0	10.3 ± 2.8	18.3 ± 2.7	3.606	0.058	0.053
Agriculture	5.8 ± 1.3	7.7 ± 2.5	4.7 ± 1.5	1.219	0.270	0.031
Environmental pollution	5.7 ± 1.3	5.3 ± 2.1	5.9 ± 1.6	0.050	0.823	0.006
Oxygen	5.0 ± 1.3	4.8 ± 2.1	5.1 ± 1.6	0.011	0.915	0.003
Water warming	2.1 ± 0.8	1.2 ± 1.0	2.6 ± 1.1	0.671	0.413	0.023
Natural environmental change	17.4 ± 2.2	19.0 ± 3.8	16.4 ± 2.7	0.336	0.562	0.016
Environmental conditions	5.1 ± 1.3	8.6 ± 2.8	3.0 ± 1.1	4.940	0.026*	0.062
Salinity	5.0 ± 1.3	3.7 ± 1.8	5.8 ± 1.7	0.618	0.432	0.022
Spawning conditions	4.2 ± 1.1	4.5 ± 1.9	4.0 ± 1.4	0.038	0.845	0.005
Decline in food supply	3.0 ± 1.0	1.4 ± 1.0	3.9 ± 1.4	1.674	0.196	0.036
Predators	1.2 ± 0.6	2.2 ± 1.4	0.7 ± 0.6	1.312	0.252	0.032
Fisheries regulations	22.5 ± 2.4	24.8 ± 4.0	21.2 ± 2.9	0.558	0.455	0.021
Quota	11.8 ± 1.8	12.1 ± 2.9	11.6 ± 2.3	0.022	0.883	0.004
Bag limit	6.2 ± 1.4	7.2 ± 2.5	5.6 ± 1.6	0.297	0.586	0.015
Closed season	5.4 ± 1.3	8.8 ± 2.8	3.5 ± 1.3	4.033	0.045*	0.056
Minimum size	3.3 ± 1.0	4.3 ± 1.8	2.7 ± 1.1	0.645	0.422	0.022

^cDesign-adjusted (Rao-Scott second-order) χ^2 statistic. Cramér's V is always calculated from the (design-adjusted) χ^2 and the total weighted N

Modelling anglers' perceptions of the occurrence of regime shifts

We identified three significant predictors that explained variations in anglers' perceptions of regime shifts (Fig. 4, Table S5). Anglers' perceived need for cod management was positively associated with regime shift perception ($\beta=0.175$, $SE=0.080$, $t=2.171$, $p=0.030$). Similarly, perceived information certainty of cod management emerged as a significant positive predictor for regime shift perceptions ($\beta=0.415$, $SE=0.061$, $t=6.832$, $p<0.001$). Mean fishing experience, modelled as a smooth term in the

GAM, exhibited a highly significant (i.e., non-linear) positive relationship with regime shift perception (EDF = 1.677, $X^2=31.354$, $p<0.001$; Fig. 4). Holding other predictors at reference values, an angler with 25 years of fishing experience is about 1.5 × as likely to have perceived one or more regime shifts in the cod stock or the fishery than an angler with five years of experience, whereas an angler with 50 years of experience is about 3.5 × as likely to have perceived shifting regimes.

None of the other predictors tested – attitudes toward cod management, cod fishing involvement, general fishing involvement, trust in science, or

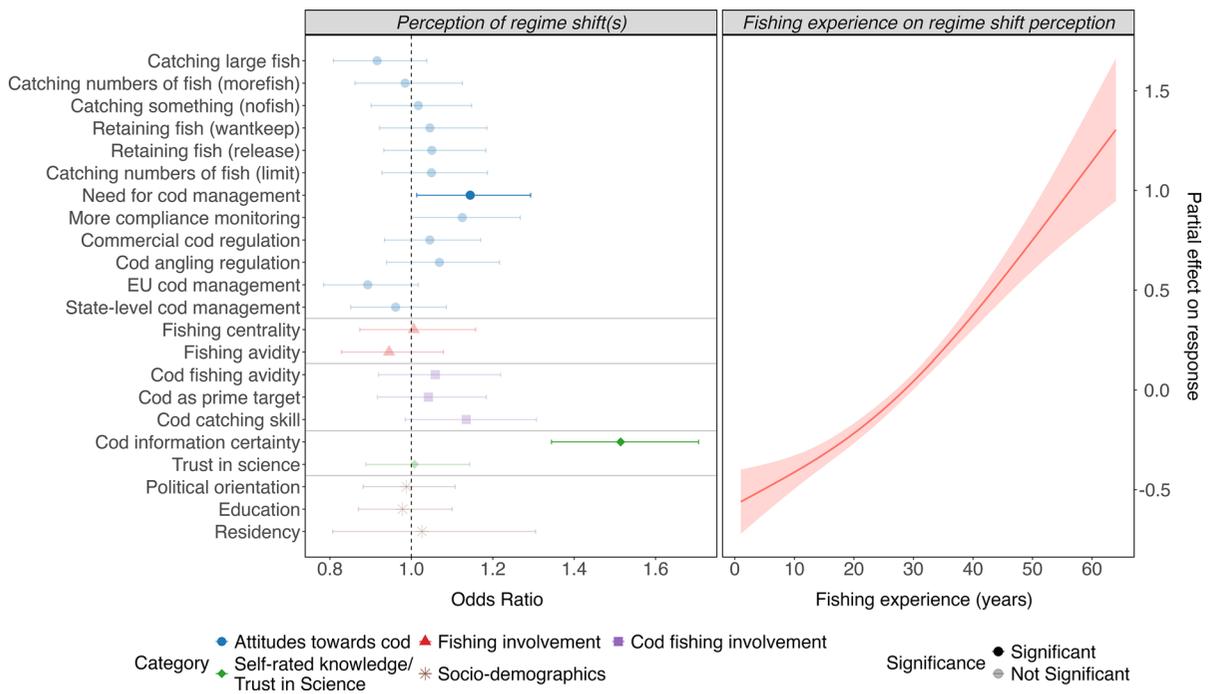


Fig. 4 Odds ratios of independent variables from the model predicting anglers’ perception of one or more profound changes that had a decisive and lasting impact on the cod fishery or the cod population as a whole (i.e., regime shift; $n=1,788$). The dashed line at 1 represents no effect, with values above 1 indicating a positive association with perceiving one or more regime shifts, and values below 1 indicating

a negative association. Symbol shapes and colours denote predictor categories. Mean fishing experience was fitted as a smooth term because its influence on regime shift perception is non-linear; the smooth term was statistically significant and its partial effect (solid curve) with 95% confidence band (shaded area) is shown in the right-hand panel. The full model summary is provided in Table S7

demographics – showed a significant association with perceptions of regime shifts, and overall, far fewer predictors emerged in the model explaining regime shifts (Table S7) than in the models explaining stock status and trends (Tables S5, S6).

Discussion

A vast majority of anglers in our study reported a decline in the cod stock since they first started fishing, a current poor stock status, and one or more regime shifts. Anglers overwhelmingly attributed the cod stock’s poor condition to fishing pressure, which they also identified as a key factor that has had a sudden, decisive, and lasting impact on cod fishing or the cod stock as a whole. These findings align with existing stock assessments and scientific information about the western Baltic cod (Sguotti et al. 2019b; Möllmann et al. 2021; ICES 2024; Froese et al. 2025;

Möllmann 2025). Because we defined regime shifts broadly, our assessment of anglers’ perceptions of them could have encompassed a wide range of structural changes in the cod fishery or the cod stock. These might include transformative societal changes such as German reunification (Cannarella 1997), ecological stock collapse (Möllmann et al. 2021), or more recent changes in daily bag limits and harvest opportunities as examples of institutional regime shifts (Lewin et al. 2021, 2023; Haase et al. 2022). This broad framing of regime shifts stands in contrast to the predominantly ecological focus on the western Baltic cod in the fisheries literature.

Perceptions of cod stock status

When respondents who rated the stock poorly were asked about causes, the vast majority pointed to excessive fishing pressure, particularly general overfishing and commercial overfishing, echoing scientific

evidence that historically high exploitation rates are the primary driver of the cod stock decline in the Baltic Sea (Möllmann et al. 2021; Froese et al. 2025; Möllmann 2025). Nearly 45% of anglers identified additional broader anthropogenic factors, predominantly those related to climate change and warming waters. This finding reflects the results of other studies, which point to warming sea surface temperature in combination with impacts of eutrophication as impairing cod recruitment and increasing cod mortality – a process that exacerbates the effects of overfishing (Reusch et al. 2018; Sguotti et al. 2019b; Möllmann et al. 2021; Moll et al. 2024). Nearly a quarter (23.9%) of respondents identified natural environmental changes as leading to the cod stock's poor condition currently, most prominently a decline in the cod prey base and salinity changes (which can affect cod recruitment in the brackish waters of the Baltic Sea; Hüseyin et al. 2015; Receveur et al. 2022). This minority perspective aligns with the broader scientific consensus that, while environmental variability does influence cod dynamics, it tends to be overshadowed by the more dominant effects of overfishing in interaction with rising sea surface temperatures (Sguotti et al. 2019b; Möllmann et al. 2021; Froese et al. 2025; Möllmann 2025). In line with attributions by German anglers, salinity fluctuations, prey base declines, and episodic shifts in primary productivity have all been reported to affect Baltic cod (Nissling and Westin 1997; Kristiansen et al. 2011; Kijewska et al. 2016; Koenigstein et al. 2018). Around one quarter of respondents cited compliance issues such as “non-compliance with rules” and “awareness of rules” as causes of poor stock status, which most likely exist in the cod fishery but have not been scientifically assessed thoroughly. Furthermore, nearly one fifth of surveyed anglers linked regulatory factors such as inappropriate catch limitations to the poor stock status, underscoring a perceived gap between regulations and their practical efficacy (Bergseth and Roscher 2018; Bergseth et al. 2023) as well as a tendency for general mismanagement in the Common Fisheries Policy of the EU (Froese et al. 2025; Möllmann 2025).

Resident and non-resident anglers offered statistically indistinguishable ratings within each of the five-point scale questions enquiring about the cod stock's trend and status, indicating broad consensus and similar general perceptions about the cod stock.

However, among those who judged the stock state negatively, narratives concerning the causes of the decline diverged: residents foregrounded the closed season, fishing tourism, low oxygen content, and rule-breaking, whereas non-resident anglers more prominently highlighted the effects of climate change. Place attachment theory holds that frequent users develop a strong sense of place that heightens attention to site-specific stressors and management failings, while lowering one's willingness to attribute problems to distant factors instead of local explanations (Manning 1999). Consistent with this theory, residents, who fished for cod more frequently than non-residents and who are likely to have stronger bonds to the Baltic Sea, emphasised proximate and, in their view, externally caused pressures (commercial overfishing, visiting anglers, rule non-compliance; Table 1). By contrast, non-residents with likely weaker place ties invoked broad-scale climate changes that lie beyond local control. Similar differences in attribution have been reported in other recreational fisheries studies. For instance, in the lagoon pike fishery of Rügen, northern Germany, resident anglers were less supportive of tighter bag limits and quotas than visitors (Slaton et al. 2023). Likewise, in Western Australia, non-resident boat fishers were more likely than residents to attribute changing catch patterns to climate change (Ryan et al. 2021).

Overall, the broad consensus about underlying reasons among all anglers illustrates how German cod anglers see fishing intensity followed by other anthropogenic factors as central drivers of the cod stock's downturn, agreeing with the scientific consensus on the topic. Anglers citing natural environmental changes as drivers of poor stock status (16.5%) suggest a less widespread awareness of intrinsic ecological variability among some anglers, including oceanographic fluctuations and predator–prey dynamics, which can interact with anthropogenic pressures to induce regime shifts in fish stocks (Conversi et al. 2015; Rocha et al. 2015).

Perceptions of regime shifts

Nearly three-quarters (72.5%) of anglers perceived the occurrence of regime shifts in the cod fishery based on coding of open-ended responses describing profound and lasting changes to the stock (see Methods; the technical term “regime shift” was not used in

the questionnaire). Among those respondents identifying one or more regime shifts, the majority considered fishing pressure to have had a decisive and lasting impact on the cod fishery or stock (66.7%). This finding corroborates scientific evidence that intensive fishing, which has been excessive for decades due to poor management in the Baltic (Froese et al. 2025; Möllmann 2025), disrupts ecosystem balance and precipitates regime shifts in the Baltic Sea (Möllmann et al. 2021). Just over a quarter of surveyed anglers saw irreversible changes in factors associated with anthropogenic environmental change, such as climate change and habitat degradation. These factors are increasingly acknowledged in the scientific literature as critical components affecting cod populations globally (Pörtner et al. 2008; Sguotti et al. 2019b; Möllmann et al. 2021; Wudrick et al. 2024). Nearly 45% of anglers blamed broad anthropogenic pressures for the cod stock's poor condition, whereas only a quarter judged those pressures to have had a decisive and lasting impact on the cod fishery or stock – a discrepancy that could reflect the slow, cumulative nature in which multiple fisheries impacts on fish populations can unfold, ultimately making them harder to recognise as distinct regime shifts. Short-term or more localised declines are often viewed by people as direct outcomes of specific stressors (e.g., a heat wave, fish kill, or a pollution event), whereas regime shifts are typically emergent phenomena involving multiple interacting drivers, which are harder to comprehend holistically (Aminpour et al. 2021). Mental-model research underscores the fact that stakeholders develop cognitive maps from their knowledge and experiences, often capturing only portions of complex systems (Aminpour et al. 2020). When anglers perceive or interact with resources in different ways, these mental models can fragment understanding of complex processes like those involved in regime shifts (Gray et al. 2020). Accordingly, although anglers link cod declines to human activities, they are less likely to connect diffuse interacting pressures with the idea of a regime shift; this might explain why anthropogenic factors featured less prominently in regime shift responses than in stock status responses. However, we found resident German anglers to have perceived lasting changes in harvest regulations, almost as frequently as those reporting anthropogenic changes. The salience of overfishing and especially the recent regulatory changes (e.g.,

reduction of daily bag limits to zero) in anglers' daily experiences might have led to a stronger association of these factors with the regime shift topic, whereas the gradual and less observable impacts of climate change and other anthropogenic changes such as eutrophication through nutrient inputs into the Baltic Sea might not be as readily connected to broader ecosystem transformations (Schwermer et al. 2021).

Among anglers who perceived one or more regime shifts, residents were significantly more likely than non-residents to identify overfishing, commercial fishing, the closed season, and deteriorating environmental conditions (e.g., episodic hypoxia) as profound changes that have had a decisive and lasting impact on the cod stock. Similar to the intra-group differences observed for perceived causes of the poor stock status of the western Baltic cod, resident anglers displayed heightened sensitivity to site-specific stressors and management failings than non-residents (Manning 1999), while also apportioning blame to commercial fishers. Numerous studies have shown that fishers have a tendency to blame other fishing groups or outgroups and downplay their own harvest impacts (ingroup versus outgroup bias; Dorow et al. 2009; Boucquey 2017; Arlinghaus et al. 2022; Lewin et al. 2025).

Shared drivers: key predictors for stock decline, poor stock status, and regime shifts

In each of the three models predicting anglers' perceptions of cod stock decline, poor stock status, and the occurrence of one or more regime shifts, two variables consistently emerged as significant positive predictors: (i) fishing experience, and (ii) stronger attitudes favouring cod management. These findings suggest that, on average, anglers with a long personal history in the fishery and those who hold more favourable attitudes about the need for cod management are more likely to perceive the cod stock as in decline, to perceive a poor stock status, or to identify a regime shift. Our findings corroborate evidence from studies which show that anglers with longer personal histories in a fishery tend to perceive contemporary stock declines more strongly than newer participants, consistent with a shifting-baseline effect (Griffin et al. 2023; van den Heuvel and Rönnbäck 2023). A positive correlation between fishing experience and the likelihood of regime shift perception in

fisheries has been documented in other studies. For example, Gulf of Maine lobster fishers who entered the industry before the early-1990s ground-fish collapse still recognise that the same coastal ecosystem once centred on cod and has since shifted to lobster dominance. In contrast, newer entrants, whose careers began after the collapse, do not recall any such change (McClenachan and Neal 2023). Our finding that a positive attitude towards cod management is a strong predictor of anglers' perceptions of stock decline, poor stock status, and regime shifts is also consistent with recreational fishery studies focused on Baltic cod as well as other European demersal fisheries. For example, workshops with different interest groups held during the western Baltic cod collapse led to anglers advocating for stricter controls (Lewin et al. 2025). Similarly, Irish sea-bass anglers readily accepted tighter bag limits after years of decline (Grilli et al. 2019). We also suggest that anglers endorsing cod management measures might exhibit a heightened sense of cod stewardship making them particularly attentive to signs of stock deterioration (Shephard et al. 2023; Golden et al. 2025). This implies that experienced anglers with pro cod management attitudes might represent a crucial constituency for future management efforts (Slaton et al. 2023). This is not only because anglers with these attributes recognise the severity of cod declines, but also because they might be more inclined to advocate for stronger regulatory action.

Partial drivers: factors influencing some but not all perceptions

The models explaining stock trend and status produced a broader set of significant predictors than those for regime shift perceptions. This likely reflects the greater clarity and salience of the stock trend and status questions, which may have elicited more consistent responses than the more abstract and cognitively demanding regime shift question. As a result, these models offered stronger explanatory power. Two attitudinal variables, support for EU cod management and preference for state-level management, were significantly and negatively associated with perceiving a declining cod stock and poor current stock status, yet did not predict regime shift perceptions. One interpretation for this finding is that the surveyed anglers might have confidence in decentralised

governance structures or believe that regulating the commercial sector will suffice to improve cod conditions. Throughout the history of human dimensions research in recreational fisheries, a common finding is that anglers prefer to regulate or constrain their perceived direct competitors (e.g., commercial fishers) rather than enacting regulations on themselves (Arlinghaus 2006; Dorow et al. 2009). Similarly, anglers, and people more generally, can feel reservation about top-down regulations by authorities, such as the institutions of the EU, in which they feel little involved (Drupp et al. 2019; Dixon et al. 2024). Cod angling regulation, meaning support for stricter limits or rules on recreational cod anglers, was a significant predictor of anglers' perceptions of cod stock decline and poor stock status, but did not correlate with regime shift perceptions. Anglers who endorse stricter self-regulation could be keenly aware of the western Baltic cod's vulnerability and the possibility that angling harvest also affects cod, yet they do not necessarily see these declines as evidence of a tipping point and longer-term regime shift.

For the models predicting anglers' perceptions of stock trend and status, general fishing avidity was a significant negative predictor, meaning anglers who fish more often or more avidly are less likely to judge the western Baltic cod stock as having declined since they started fishing or view it in a poor state currently. One possible explanation for this finding is that more avid anglers are more skilled than less avid anglers and are therefore better at catching fish (Ward et al. 2013; Monk and Arlinghaus 2018; Futamura et al. 2025). Thus, more avid anglers might experience stock declines later than their less avid counterparts or not at all. Similarly, anglers who fish more often, across different locations while targeting multiple species, might still achieve satisfactory catches, leaving them less inclined to recognise or emphasise cod-specific declines (Monk and Arlinghaus 2018; Dean et al. 2023; Futamura et al. 2025). Temporary local concentrations of cod can lead experienced anglers to encounter higher-density patches more often than less avid anglers. Such dynamics can produce catch impressions that remain relatively high despite declining overall abundance, consistent with hyperstability and the "illusion of plenty" described for recreational fisheries that target aggregations (Erisman et al. 2011). More avid anglers might also feel cognitive dissonance as they continue to fish a dwindling

resource and therefore cognitively discount feelings that the fish stock in question is in trouble (Festinger 1957; Finn and Loomis 2001; Haase et al. 2022; Lewin et al. 2025). Highly avid anglers can, however, be more conflict-prone when their perception of stock declines and need for conservation misaligns with the view of policy-makers (Slaton et al. 2023).

Cod information certainty emerged as a positive predictor of anglers' perceptions of a poor cod stock status and the occurrence of one or more regime shifts. This pattern underscores the critical influence that clear, credible cod-related information can have on stakeholder perceptions, reinforcing the need for targeted communication and outreach to align angler awareness with observed ecological realities (Lewin et al. 2023, 2025). Cross-national findings reveal that public trust in scientists is, in general, moderate to high (Cologna et al. 2025). In Germany, however, trust levels fall slightly below the global average, highlighting the importance of well-designed engagement strategies to bolster trust and promote science-informed resource management (Cologna et al. 2025).

Our findings show that more fundamental cod specific management attitudes, such as the perceived necessity for targeted cod management, explain variation in anglers' perceptions of stock trend, stock status, and to a lesser degree regime shifts, more effectively than traditional measures of angler heterogeneity, such as fishing involvement (e.g., fishing centrality to lifestyle as a measure of psychological commitment, or measures of catch orientation; Kim et al. 1997; Anderson et al. 2007). The nature of the dependent variable could help explain this finding. The social-psychological principle of compatibility holds that an attitude predicts psychological or behavioural outcomes most strongly when both attitude and outcome match on four dimensions: attitude object, action, context, and time, so that they are assessed at the same level of specificity (Ajzen and Fishbein 1977; Fishbein and Ajzen 2010; Albarracín and Johnson 2018). Consistent with the cognitive-hierarchy framework, which links broad values to domain-specific beliefs and ultimately to context-specific attitudes and perceptions (Homer and Kahle 1988; Fulton et al. 1996; Vaske and Manfredo 2012), those proximal cod management related attitudes were the most salient predictors of perceived declining abundance, poor stock status, and regime shifts – dependent variables assessed at the same level of

specificity as the attitudinal predictor. By contrast, traditional angler specialisation and involvement metrics, although highly predictive of attitudes to specific regulations or management preferences of anglers in other studies (Bryan 1977; Ditton et al. 1992; Arlinghaus and Mehner 2005; Hunt et al. 2013; van den Heuvel et al. 2022), were generally non-significant predictors in our models. Our dependent variables operated at a higher level of generality than specific harvest-regulation preferences (e.g., preferences for daily bag limits), hence cod-management related attitudes and perceived information proved the most compatible psychological constructs for prediction. It is likely that fishing involvement and catch orientations would instead predict specific preferences or attitudes to very specific angling-related harvest regulations, and in this context variables related to the attitudes to cod management would most likely exert less influence. This is not to say that predictors of classical angler characteristics had no significant effects. For instance, cod catching skill had a significant positive effect when predicting anglers' perception of a declining stock trend. Because attitudes are more malleable than basal values (Manfredo et al. 2017), they can shift when trustworthy science-based information is provided (Fujitani et al. 2017). Therefore, improving the clarity and credibility of stock-status messaging – messaging that reinforces anglers' favourable attitudes to cod management and strengthens their perceptions of information certainty – should be a priority for managers. Such management approaches could help form favourable attitudes to cod management, which we showed consistently help explain angler perceptions of stock trends and regime shifts.

Additional drivers: single-model or non-significant factors

Anglers with higher self-reported cod catching skill were more likely to perceive a declining trend in the western Baltic cod stock. Research has repeatedly shown that anglers, who often have higher skill, tend to possess enhanced ecological knowledge that can, at times, mirror the best scientific understanding (Morgan and Soucy 2009; Gray et al. 2015; Monk and Arlinghaus 2018; Aminpour et al. 2020; Löki et al. 2023). Highly skilled anglers' ability to detect shifts in stock conditions can also reflect a heightened

alertness to the ecosystem dynamics that directly affects their primary target species (McClenachan and Neal 2023; van den Heuvel and Rönnbäck 2023).

Political orientation significantly influenced anglers' attribution of a negative stock status, with left-leaning individuals more likely to recognise factors such as climate change and habitat degradation. This finding is consistent with the environmental psychology literature, which indicates that politically left-leaning individuals generally prioritise nature conservation and are more receptive to scientific consensus on ecological issues (Gifford and Nilsson 2014; Klein et al. 2019). Similarly, we found that higher educational attainment makes anglers likelier to judge the cod stock trend as unchanged or declining, and less likely to see it as increasing. It is important, however, to note that political orientation and education had limited predictive power overall, as they were only significant in the stock status and stock trend model, respectively. The limited role of formal education identified in our study, for example, could reflect the stronger influence of fishing experience and favourable attitudes to cod management, outweighing the impact of education levels as a main effect in the model (Geiger et al. 2019).

Our measure of trust in science did not emerge as a significant predictor. One possible explanation is that our domain-specific measure of "cod information certainty", which directly gauged how well-informed anglers feel about cod management, better captured the local knowledge that influences anglers' perceptions of stock trend, stock status, and regime shifts. Another explanation is that overall, trust in science was overshadowed by more direct, experienced-based factors, such as personal fishing success or cod-specific policy attitudes. Nevertheless, research consistently shows that building trust through transparent, participatory processes, remains pivotal in enhancing acceptance of regulatory measures (Figus et al. 2017).

Study limitations

Although we applied post-stratification weights to account for potential opt-in survey bias, the sample might still be skewed toward more avid anglers (Table 1). These individuals tend to be more engaged and informed, and their perceptions can differ from those of less involved anglers. This potential bias is well-documented in the literature, which shows that

opt-in surveys often overrepresent highly committed recreational fishers (Connelly et al. 2000; Griffiths et al. 2013). In our case, electronic recruitment methods, such as email and social media outreach, might have further amplified this skew, as these channels tend to reach more active or connected anglers (Trinnie and Ryan 2024). Thus, even despite our correction for self-selection bias against a set of avidity related characteristics, the strong perceptions of stock decline, poor cod stock status, or regime shifts found in our study could still possibly reflect some overrepresentation of avid, more critical anglers, and an underrepresentation of less engaged, less critical anglers, relative to Germany's general cod angler population. Another limitation of our study lies in our reliance on qualitatively coded responses to identify regime shifts. Because the concept is challenging to convey even to specialists, the open-ended framing we used could have been difficult for respondents to interpret (Appendix A). This might partly explain why the regression models for regime shift perceptions yielded fewer significant predictors than those for stock trend and status.

Nevertheless, these limitations do not undermine the value of our findings. If anything, the overrepresentation of highly involved anglers makes the observed perceptions particularly relevant for policy, as these individuals are more likely to be vocal stakeholders and influence public discourse or compliance. Moreover, the high level of ecological knowledge and engagement among avid anglers means that their perceptions can serve as a meaningful proxy for early warning signals or stakeholder awareness of system-level change. Finally, our combination of structured modelling and open-ended analysis offers a novel lens on how different forms of change, gradual decline versus regime shift, in fisheries are understood by those most directly involved.

Conclusions and implications

Our findings indicate that recreational cod anglers are highly aware of the critical state of the western Baltic cod stock as well as the potential for largely irreversible regime shifts in multiple dimensions. Anglers, therefore, not only identify a poor state of the stock, but are also aware of possibly irreversible state changes. We identified key psychological factors,

spanning individual experiences, attitudes and socio-political influences, which can help stakeholders acknowledge ecological decline and the possible need for fishery closures.

At the same time, our results suggest that not all psychological orientations or demographic characteristics are equally relevant. For instance, catch orientation and general trust in science did not significantly predict stock or regime shift perceptions, underlining the importance of issue-specific attitudes and first-hand experience as more actionable entry points for management interventions.

By recognising and harnessing these “entry levers” in outreach and communication efforts, fisheries management can more effectively align stakeholder perspectives with ecological realities, foster both the acceptance of immediate constraints, and the development of adaptive future-proof strategies in the face of complex environmental change. We underscore the importance of tailored communication strategies and inclusive governance in fisher communities, ideally at local or regional levels, two approaches that can align stakeholder perceptions with ecological realities, encourage acceptance of immediate constraints, and enable adaptive management over the long term (Reed 2008; d’Armengol et al. 2018; Arlidge et al. 2020, 2021). Dedicated science communication about cod issues, community workshops (Lewin et al. 2025), and transparent dialogue about governance decisions can also enhance ecological literacy, build trust, and ensure socially equitable management measures (Armitage et al. 2010; Alexander et al. 2016; Partelow et al. 2021). Moreover, meaningful stakeholder participation in decision-making processes can mitigate feelings of disenfranchisement, build a sense of ownership, help develop ecological understanding, and support management decisions that are both ecologically effective and socially acceptable (Fujitani et al. 2017; Mease et al. 2018; Lewin et al. 2025). These gains hinge on our understanding that cultivating favourable attitudes to cod management, particularly among the most experienced anglers, fosters understanding of stock development and the potential for regime shifts.

Transparent and adaptive communication of scientific information about fish stock health and the likelihood of regime shifts is essential not only for inclusive governance approaches in the western Baltic cod fishery, but also for other fisheries facing similar

ecological and socio-political challenges. Effectively communicating such information, including uncertainties, can help shape favourable attitudes towards cod management and foster feelings of information certainty – both of which we identified as significant predictors of stock status perception and regime shift awareness. Anglers with a longer history with a given fishery can develop stock perceptions and understanding of reasons underlying stock changes that closely match the best scientific understanding. Therefore, these anglers should be particularly targeted with education and outreach effort in order to build favourable ecologically-informed attitudes that can help the system avoid regime shifts or deal with recovery once they have occurred. This study highlights the value of stakeholder perception data not just as a reflection of awareness, but as a diagnostic tool for adaptive management, helping to identify leverage points, emerging consensus, and potential resistance to change across a key natural resource user group.

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Author contributions R.A. designed the study. R.A. and J.B. designed the questionnaire. Open-ended responses used in the analysis were coded inductively by O.B., with categories verified by R.A. W.A. performed the statistical analysis with input from C.R. and R.A. W.A. and R.A. wrote the first draft of the paper. All authors contributed to revising the manuscript text.

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Data availability All the data and R code underpinning the analysis presented in this article are publicly available in a reproducible format, archived on Zenodo (<https://doi.org/10.5281/zenodo.16338019>), which was created from the following GitHub repository: https://github.com/williamarlidge/anglers_perceptions_codstock_regimeshifts

Declarations

Conflicts of interest The authors declare no competing interests.

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