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Potential biases in angler diary data: The impact of the diarist recruitment process on participation rates, catch, harvest, and effort estimates

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A R T I C L E I N F O

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A B S T R A C T

Angler diaries are common tools to collect recreational fishing data. The diarists can be recruited either from the general population or directly from the angling population, for example, by using angling licence registries. The recruitment process can lead to specific biases whose magnitude is largely unknown. The present study compared socio-demographic data as well as catch, harvest, and release rates obtained from diaries from German Baltic Sea cod anglers who were recruited from a list of angling permit holders (non-probability-based sample) with those who were recruited simultaneously during a probability-based representative telephone survey among the general population. The results indicated that recruiting diarists from the list of permit holders may be more successful in terms of participation rates than recruiting from a general probability-based population survey. Both groups of diarists were similar regarding their socio-demographic characteristics. Nevertheless, the differences between the two samples in avidity and between recalled and reported angling days suggest that sampling from the list of angling permit holders may increase the risk for avidity and recall biases. Catch and harvest rates were influenced by avidity, age and angling platform, release rates by angling season, angler residence, and number of caught fish. Catch, harvest, and release rates differed more between land-based and sea-based angling than between the two sample selection processes, suggesting that the angling platform should be given special consideration when extrapolating diary data to the population level. The low explanatory power of the regression analyses suggests that relevant factors beyond standard socio-demographic parameters that influence estimates of CPUE, HPUE, and RPUE were not captured in the survey. Future research should therefore focus on evaluating such factors (e.g., factors related to the human dimension) that could better correct for biases in estimates of catch, harvest, releases, and angling effort in recreational fisheries surveys.

1. Introduction

The magnitude of recreational fisheries catches can be comparable with or even exceed that of the commercial catches in some fisheries (Cooke and Cowx, 2006; Ihde et al., 2011; Radford et al., 2018) with potentially severe consequences for marine and freshwater fish stocks and ecosystems (Post et al., 2002; Lewin et al., 2006, 2019). The management of recreational fisheries, which intends to balance the societal values of recreational fisheries and the protection of fish stocks and shoreline habitats, requires reliable data of recreational angling effort as well as of catch and harvest rates.

Despite the need for reliable effort, catch and harvest rate data, these are rarely reported systematically, and this is complicated by the lack of national registries of recreational anglers (Venturelli et al., 2017; Hyder et al., 2018; Freire et al., 2020; Vølstad et al., 2020). The open access nature of recreational fisheries and the high levels of mobility, diversity, and diffuse spatial and temporal distribution of anglers, requires survey-based estimates of catch, harvest, and angling effort, which can be a time-consuming and expensive challenge (Hartill and Edwards, 2015; Zarauz et al., 2015; Arlinghaus et al., 2019). A commonly used and cost-effective approach to collect data on recreational fisheries are diary surveys (Connelly and Brown, 1995, 1996; Hartill et al., 2012; Bellanger and Levrel, 2017). In these, anglers are asked to personally record their angling activities on a daily basis over a period of time, for example in online forms or booklets (Pollock et al., 1994). Angler diaries, however, are prone to various biases because the data are self-reported (Pollock et al., 1994; Cooke et al., 2000). Participating anglers might not be representative of the general angler population if

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they are, for example, more avid than the average angler (Connelly and Brown, 1995; Bray and Schramm, 2001). Further biases may occur when diarists misreport fish releases, exaggerate the number or size of caught fishes (Sullivan, 2003), misidentify species (Page et al., 2012), under-report the catch of small or non-target species, or omit trips where no fish were caught (Cooke et al., 2000; Hartill and Thompson, 2016; Thurstan et al., 2016; Gundelund et al., 2020). Item non-response, recall, and angler specialization are also known to bias diary data (Tarrant et al., 1993; Connelly and Brown, 1995; Fisher, 1996; Cooke et al., 2000; Griffiths et al., 2013). Consequently, one of the most important influences on the quality of diary data stems from the diarists themselves and whether they are representative of the total angler population. The recruitment process therefore deserves the most attention when planning a diary survey, especially if the data are to be extrapolated to the population level (Cooke et al., 2000; Wise and Fletcher, 2013).

Generally, two forms of recruitment processes can be chosen: probability-based sampling and non-probability-based sampling. The probability-based sampling often relies on general population samples e. g., representative telephone screening surveys (National Research Council, 2006; Dorow and Arlinghaus, 2011; Rocklin et al., 2014). Those sampling schemes are costly and may yield low participation rates, especially if the survey focuses on specialised recreational fisheries that comprise a small minority of the angler population (Griffiths et al., 2010). Non-probability sampling, on the other hand, recruits diarists from, for example, voluntary panels of anglers, phone lists of anglers, or members of angling clubs to increase the number of participants (Connelly and Brown, 1995; Cooke et al., 2000; Lyle et al., 2005; Griffiths et al., 2010; Zarauz et al., 2015). The non-random nature of the latter sampling approaches raises the question of whether and to what extent participants recruited in this manner differ from those randomly recruited from a sample of the general angler population (Taylor and Ryan, 2020). This question will become even more important in the future because recruiting respondents through nonprobability-based sampling will likely increase with the availability of new technologies such as online diaries and angling apps (Griffiths et al., 2013; Papenfuss et al., 2015; Bradley et al., 2019). The expected increase of these sampling methods for the collection of recreational fisheries data within the next 5–10 years (Skov et al., 2021) thus requires an investigation of whether and how much this will affect recreational fisheries data.

The present study investigated whether there were significant differences between diarists recruited from the general population via random digit dialling and representative computer-assisted telephone interviews (CATI; hereinafter referred to as the CATI sample) and those who were recruited simultaneously from a list of German Baltic Sea anglers who had volunteered to participate in scientific research surveys when purchasing a Baltic Sea fishing permit (hereinafter referred to as the boost sample). The objective of the study was to identify potential sources of bias that should be considered when planning and designing recreational fisheries surveys. Therefore, demographic characteristics and data on angling effort (number of reported angling days), use of angling platforms (charter boat, private boat, shore angling), avidity (number of angling in the 12 months preceding the diary survey), as well as catch rates (CPUE), harvest rates (HPUE), and release rates (RPUE) of the two groups of German Baltic Sea cod (*Gadus morhua*) anglers were compared. Following the comparisons, boosted regression trees (BRT) and logistic regressions (LR) were calculated to investigate the extent to which estimates of catch, harvest, and release rates were affected by the sample source and by fishery-related and sociodemographic variables.

2. Material and methods

2.1. Study area and recreational fishing characteristics

The Baltic Sea is a large, semi-enclosed brackish sea located in Northern Europe with salinities increasing from the inner to outer coastal waters and from the east to the west (Lass and Matthäus, 2008). Including inner coastal lagoons and backwaters, the German Baltic coastline extends for over 2000 km and belongs to the two federal states Schleswig-Holstein (SH) and Mecklenburg-Western Pomerania (MV). With minimal tidal currents, the coastline offers alternating sandy beaches and rocky shores and provides various angling opportunities throughout the year. The main angling platforms are shore angling from beaches or piers, and boat angling from small private or rented boats, float tubes, kayaks, and from large charter boats (Strehlow et al., 2012).

German marine recreational fishing is concentrated in the Baltic Sea, where it takes place along the entire coastline. The number of German Baltic Sea anglers has been estimated at 161,000 spending approximately 1.2 million angling days per year (Weltersbach et al., 2021). Due to the comparatively small number of attractive recreational fisheries target species in the Baltic Sea, anglers mainly target western Baltic Sea cod, and recreational fishing for cod is specialized and largely consumption-oriented with little bycatch of other species (Weltersbach et al., 2019). In recent years, recreational removals of western Baltic cod have been estimated to be about 30 % of the total removals of western Baltic Sea cod by commercial and recreational fisheries, with German recreational cod catches accounting for the largest share of the total recreational cod removals from the western Baltic Sea (Strehlow et al., 2012; ICES, 2020). Other species such as herring (*Clupea harengus*), salmon (*Salmo salar*), sea trout (*Salmo trutta*), and flatfishes, especially flounder (*Platichthys flesus*), plaice (*Pleuronectes platessa*), and dab (*Limanda limanda*), were targeted to a lesser extent by German Baltic anglers (Weltersbach et al., 2021). At the time of the study, the recreational cod fishery was open access and regulated by fishing licence requirements and minimum landing sizes (Haase et al., 2022). In the federal state of MV, a coastal fishing permit is additionally required for the Baltic Sea.

2.2. Recruitment of diarists from a probability-based telephone screening survey (CATI sample)

The first group of diarists was recruited from the general population through computer-assisted telephone interviews. The telephone survey was carried out from May to October 2014 and was designed to identify marine anglers in the German population, to collect their socio-demographic parameters, and to estimate total marine recreational angling effort. Identified anglers who had been angling in German marine waters in the last 12 months or who planned to do so in the next 12 months and who were at least 14 years old were asked to participate in a one-year diary survey. For cost efficiency, the interviews were conducted in nine out of 16 German federal states that were located closest to the German coasts where marine anglers concentrate (Strehlow et al., 2012; Lewin et al., 2021). Random-digit-dialling was used to generate telephone numbers and contact households, with selection probabilities being proportional to the number of households per municipality. Up to eight attempts were made to contact a household. The household size and the number of persons in a marine angler household were determined. The telephone survey was carried out by an independent market and opinion research institute (USUMA GmbH, Berlin, Germany). During the 50,200 telephone interviews conducted, 562 German marine angler households were identified. All identified anglers were asked if they would keep a diary for the next 12 months after receiving it. This resulted in a total number of 348 diarists from the CATI sample (Weltersbach et al., 2021).

2.3. Recruitment of diarists from a list of angling permit buyers (boost sample)

The probability-based CATI sample was compared with an additional non-probability-based boost sample, whose participants were recruited from a list of marine anglers who had bought fishing permits for the Baltic coastal waters of MV and voluntarily provided their contact details to participate in scientific studies of the Thünen Institute of Baltic Sea Fisheries between 2011 and 2014. The contact data (n = 3008 persons) were provided by the State Office for Agriculture, Food Safety and Fishery of MV (LALLF). From the list of contact information, a total of 1554 anglers had valid telephone numbers (up to eight attempts were made to reach an angler), answered the phone, and completed the interview. Again, identified anglers who had been angling in German marine waters in the last 12 months or who planned to do so in the next 12 months and who were at least 14 years old were asked to participate in the diary survey. This resulted in a total number of 582 diarists from the boost sample (Weltersbach et al., 2021).

2.4. Angling diary

The diary was sent to all 930 anglers who agreed to participate in the one-year diary study after completing the telephone interview. All diarists were asked to report each individual angling day at the German coast, indicating the fishing area and the respective angling platform (charter boat, boat including float tubes and kayaks, shore) over an observation period of 12 months starting from the day they received the diary. The diary entries of both groups covered the period from May 2014 to October 2015. Furthermore, the target species and the number of fishes caught, harvested, and released by species had to be reported. Together with the diary, all participants received a personal introductory letter, a privacy policy statement, a pre-addressed, postage-paid envelope for the return of the diary at the end of the study and a tape measure for measuring the length of caught fish and as an incentive to minimize nonresponse (comp. Church, 1993). In addition, all diarists received a personalized letter with Christmas/New Year's greetings and another motivational letter, as well as a free German marine angling magazine at the end of the study period to encourage participation and increase response rates (comp. Willcox et al., 2010; Anderson et al., 2021). In order to retrieve the diary data and to reduce the potential for nonresponse bias by minimizing the attrition rate, all participants were contacted by telephone at quarterly intervals during the entire observation period. The quarterly telephone calls made it possible to control and save diary data at an early stage as well as to minimize panel mortality (Pollock et al., 1994; Lyle et al., 2002).

2.5. Data analysis

The obtained diary data originated from the period between April 2014 and October 2015. Originally, the diary survey investigated the German marine recreational fishery in the Baltic and North Sea including inner and outer coastal waters. Because the present study focusses on Baltic Sea cod anglers, only angling data from the outer Baltic coast, where cod angling concentrates (Strehlow et al., 2012), were considered. To avoid possible bias due to anglers' different geographic origins, only diary data from anglers in the boost sample who originated from the same nine German federal states where the CATI survey was conducted were used for this study. Data from diarists who reported angling trips to the North Sea and Baltic inner coastal waters and who fished for species other than cod or provided incomplete information were excluded from further data analysis. Incidental bycatch of fish species other than cod consisted mainly of flatfish but was comparatively low and therefore not analysed further.

2.6. Investigation of recall bias

The relationship between the number of angling days reported in the diary and the recalled number of angling days for the 12 months preceding the survey (avidity) was tested by multilevel correlation accounting for the sample origin, and the Wilcoxon signed rank test for paired samples was applied to test for differences between the reported and recalled numbers of angling days. A Mann-Whitney U (MW-U) test was conducted to test whether the difference between reported and recalled numbers of angling days differed between anglers from the boost and the CATI sample. Vargha and Delaney's A were calculated to indicate the corresponding effect size. For paired samples, the matched-pairs rank biserial correlation coefficients (rc) were calculated. It should be noted, however, that the comparison between recalled and reported angling days was conducted for two consecutive years and that we assumed that anglers reported all their angling days in the diary.

2.7. Cod catch, harvest, and release

Cod catch (CPUE), harvest (HPUE), and release rates (RPUE) were calculated as the number of caught, harvested, and released cod per angler and day. MW U tests and Vargha and Delaney's A values were used to test for differences in cod catch, harvest, and release rates and to indicate the effect sizes.

Boosted regression tree analyses (BRT) based on the Poisson distribution were used to model the influence of sample origin (boost or CATI sample), quarter, platform use (charter boat, boat, shore), angler age and avidity (number of angling days in the 12 months preceding the diary survey), residency (residents from the coastal states MW and SH, non-residents from other federal states), and employment (pupil/student, employee, public servant, self-employed, retired, without work) on cod catch and harvest rates. BRT models have been applied because they can handle outliers and missing values, automatically fit non-linear interactions between variables, and improve the performance of single regression trees by combining decision tree algorithms and a boosting procedure that adaptively builds a large number of tree models (Elith et al., 2008). In addition, BRT models incorporate stochasticity into the model through a "bag fraction'', which is the proportion of a random subset of the data that is selected at each step. Models were built with tenfold cross-validation and a bag fraction of 50 %, which has been shown to be appropriate (Elith at al, 2008; Natekin and Knoll, 2013, Ridgeway, 2020). The final models were run with a learning rate of 0.001 and a tree complexity of five. Both the learning rate and tree complexity were adjusted to build more than 1000 trees and maximize the explained variance (Elith et al., 2008; Nieto and Mélin, 2017). Model fits were verified by residual diagnostics and variance calculations.

The comparatively small number of anglers releasing cod prevented the application of BRT analysis for the RPUE data. Therefore, binomial logistic regression (LR) with a logit link function was applied to model the probability of cod releases. For all participating anglers, each angling day was binary coded as "0" if no cod was released and "1" if at least one cod was released. Predictor variables of the full model were age, avidity, cod catch (total number of cod caught by the same angler and during the same angling day), education level (levels: primary school, secondary school, applied science university qualification, general university qualification), residency, angling platform (most frequently used angling platform by the angler), angling location (SH or MV coast), and employment group. Non-significant variables were removed from the initial full model containing all predictor variables as long as their removal decreased the AIC without reducing the model fit. The model fits were examined by the AIC, residual diagnostic (QQ and residuals vs. fitted plots accompanied by tests for the residual distribution (Kolmogorov-Smirnov (KS) test)), dispersion, and outlier tests, ROC curves, and the classification performance. The number of correct and incorrect predictions was calculated as accuracy = (true positives + true negatives)/(true positives + true negatives + false positives + false negatives).

2.8. Software tools used

All statistical analyses were carried out using the R statistical software version 4.0.2 (R Development Core Team, 2008). The R packages "MASS" (Venables and Ripley, 2002) and "psych" (Revelle, 2019) were used for the correlation analysis and statistical comparisons. BRT and regression analyses were conducted using the R packages "dismo"

(Hijmans et al., 2020), “gbm” (Greenwell et al., 2020), “DHARMa” (Hartig, 2020), and “pROC” (Robin et al., 2011). The effect sizes were calculated using the package “effsize” (Torchiano, 2020).

3. Results

3.1. Participation in the diary survey

A large majority of anglers who completed the telephone interview agreed to participate in the diary survey. Nevertheless, the response rate of anglers from the boost sample was higher than the response rate of anglers from the CATI sample (96 % boost sample vs. 80 % CATI sample). Of the 930 anglers who received a diary, 53 % (586 anglers) returned a diary, and 37 % (344 anglers) had not returned their diary or any data by the end of the study despite repeated telephone and written contact. Return rates differed between the CATI sample (37 %) and the boost sample (55 %). The present study used data from 374 anglers who were from the nine northern German federal states, fished in the Baltic Sea in the survey year, and targeted cod. However, 28 anglers (10 boost and 18 CATI anglers) refused to participate in the one-year diary survey. As a result, 364 diaries from 346 participants were used for further analyses. Sixty-seven percent of these anglers (n = 232) were recruited from the boost and 33 % (n = 114) from the CATI sample. Some socio-demographic data of these non-participating anglers are shown in Table 1. The small number of non-respondents prevented valid statistical comparisons between groups and non-response analysis. However, differences in the socio-demographic parameters of age, household size, gender composition, education level, employment, and avidity were small (Table 1).

3.2. Comparisons of anglers from the boost and CATI sample

3.2.1. Socio-demography and platform use

Most diarists were men (97 %) with a mean age of 49 years. The mean household size was 2.5 persons per household. Fifty-two percent of diarists from the boost sample and 46 % from the CATI sample had completed secondary school and the majority of diarists from both samples were employees or workers (Table 1). Diarists from the boost and CATI sample did not differ significantly in terms of the gender distribution, age, household size, education level, and employment grouping. In contrast, the percentage of coastal residents (anglers living in the federal states SH and MW) was significantly higher among anglers from the CATI compared to those from the boost sample (Table 1). The anglers from the boost sample reported a total of 1353 angling days over the investigation period. Most angling days were boat angling days (45 %), followed by shore (33 %) and charter boat angling days (21 %), respectively. The CATI anglers reported a total of 453 angling days whereby the distribution of angling days among the angling platforms (50 % boat, 28 % shore, 22 % charter boat angling days) did not differ significantly from the boost anglers (Chi^2 test, Chi^2 = 4.9, p = 0.09). When grouping the anglers by the platform use, shore anglers were younger than boat and charter boat anglers (Table 2) and the majority of them were coastal residents regardless of the sample origin. In the boost sample, in contrast, 58 % of boat anglers and 69 % of the charter boat anglers came from inland federal states whereas 64 % of the boat anglers from the CATI sample were coastal residents. Although the percentage of residents among the charter boat anglers was higher in the CATI compared to the boost sample, most charter boat anglers (54 %) were non-residents (Table 2).

3.3. Reported and recalled angling days (avidity)

With a mean number of 5.8 (± 6.7 S.D.) angling days per angler and year, the diarists from the boost sample reported significantly more angling days than anglers from the CATI sample who reported a mean number of 4.0 (± 5.1 S.D.) angling days per angler and year (MW U test, U = 10,519, p = 0.002, Fig. 1). The effect size was relatively small (Vargha-Delaney A = 0.602). With a mean number of 11.9 (± 13.9 S.D.) angling days for the 12 months preceding the diary survey (avidity), anglers from the boost sample had a significantly higher avidity compared to those from the CATI sample (8.2 ± 11.7 S.D. angling days for the 12 months preceding the diary survey; MW U test, U = 10,484, p = 0.002; Fig. 1). The effect size was also small (Vargha-Delaney A = 0.604).

In both samples, the avidity of anglers (reported as recalled angling days for the 12 months preceding the diary survey) was significantly larger than the number of angling days that the same angler had reported in the diary (boost sample: Wilcoxon signed rank test for paired samples: V = 479,388, p = 0.0008, rc = −0.1; CATI sample: V = 834,565, p = 0.02; rc = 0.14). Nevertheless, effect sizes were relatively small. The Spearman multilevel correlation indicated that the number of angling days reported in the diary and recalled for the year preceding the diary survey were moderately correlated when accounting for the sample origin (r^2 = 0.42 (0.3, 0.5 95 % C.I.), p < 0.0001, Fig. 2). An additional MW U test confirmed that the difference between recalled

Table 1
Summary of the medians, means, standard deviations (S.D.), and results of statistical Mann-Whitney or Chi^2 tests of sociodemographic parameters and the numbers of reported angling days from diarists and non-diarists recruited from the boost and CATI sample.

	Boost sample diarists (n = 232)	CATI sample diarists (n = 114)	Statistical tests between both diarists from the boost and CATI sample	Boost sample non-diarists (n = 10)	CATI sample non-diarists (n = 18)
Age (years)	50, 49.3 ± 12.7	50, 49.0 ± 13.9	MW-U test, U = 13,165, p = 0.95	52, 50.3 ± 9.9	36.5, 43.4 ± 18.1
Male/female (%)	97/3	97/3	Chi^2-test, Chi^2 = 0.2, p = 0.8	80/20	94/6
Household members (number)	2, 2.4 ± 1.1	2, 2.6 ± 1.1	MW-U test, U = 12,090, p = 0.21	2, 2.3 ± 0.8	2, 2.8 ± 1.2
Non-residents/ residents (%) (residents: MV & SH)	61/39	44/56	Chi^2-test, Chi^2 = 9.3, p = 0.003	40/60	61/39
Highest education level (%)			Chi^2-test, Chi^2 = 3.8, p = 0.4		
Primary school	8	10		10	11
Secondary school	52	46		30	22
Applied sci. university qualific.	9	13		0	22
General university qualific.	30	28		50	28
Not specified	1	3		10	17
Employment (%)			Chi^2-test, Chi^2 = 6.7, p = 0.2		
Pupil/student	3	8		0	6
Employee/ worker	59	51		60	44
Public servant	4	7		10	11
Self-employed	18	16		10	0
Retired person, pensioners	14	16		20	22
Without work	3	3		0	6
Not specified	0	0		0	11
Avidity	6, 11.9 ± 13.9	4.5, 8.2 ± 11.7	MW-U test, U = 10,484, p = 0.002	NA	0, 4.2 ± 6.3
Number of reported angling days	4, 5.8 ± 6.7	3, 4.0 ± 5.1	MW-U test, U = 10,519, p = 0.002		–

Table 2
Medians, means ± standard deviations (S.D.), and results of statistical Mann-Whitney or Chi^2 tests of sociodemographic parameters, the numbers of reported angling days, cod CPUE, HPUE, RPUE, and flatfish bycatch from diarists recruited from the boost and CATI sample separated by angling platform. A = Vargha-Delaney A.

Variable	Boost sample diarists (n = 232)	CATI sample diarists (n = 114)	Test
Boat anglers			
Number of reported angling days per angler	2.0, 4.4 ± 5.9	3.0, 4.1 ± 5.4	MW test, U = 3788, p = 0.9, A = 0.63
Avidity (number of days fished in the last 12 months)	8.0, 13.3 ± 13.7	5, 9.6 ± 14.7	MW test, U = 2915, p = 0.01, A = 0.61
Cod CPUE	6.0, 8.4 ± 8.2	5.0, 6.4 ± 9.0	MW test, U = 3130, p = 0.049, A = 0.6
Cod HPUE	4.0, 5.7 ± 5.6	3.0, 4.0 ± 4.3	MW test, U = 3041, p = 0.03, A = 0.54
Cod RPUE	2.0, 3.0 ± 3.6	1.5, 2.8 ± 7.3	MW test, U = 1432, p = 0.1, A = 0.6
Cod release proportion (%)	27.1, 29.1 ± 22.9	20.3, 27.7 ± 27.4	MW test, U = 2532, p = 0.4
Summer angling days/winter angling days (%)	59/41	62/38	Chi^2-test, Chi^2 = 0.2, p = 0.8
Days with cod catch/zero catch days (%)	92/15	37/16	Chi^2-test, Chi^2 = 0.2, p = 0.6
Flatfish bycatch per day	0, 1.3 ± 5.6	0, 2.4 ± 6.4	MW test, U = 3392, p = 0.1
Age (years)	50, 49.3 ± 12.3 (n = 139)	50, 50.2 ± 14.9 (n = 55)	MW test, U = 3567, p = 0.5
Household members	2.0, 2.5 ± 1.2	2.0, 2.5 ± 1.1	MW test, U = 3754, p = 0.97
Male/female (%)	99/1	100/0	Chi^2-test, Chi^2 = 0.8, p = 0.4
Non-residents/residents (%) (residents: MV & SH)	58/42	36/64	Chi^2-test, Chi^2 = 7.1, p = 0.01
Charter boat anglers			
Number of reported angling days per angler	2.0, 3.1 ± 3.0	1.0, 2.1 ± 2.0	MW test, U = 1654, p = 0.02, A = 0.63
Avidity (number of days fished in the last 12 months)	5.0, 8.7 ± 10.7	4.0, 9.1 ± 15.9	MW test, U = 1895, p = 0.2, A = 0.6
Cod CPUE	8.0, 9.8 ± 7.7	6.0, 8.2 ± 8.3	MW test, U = 1824, p = 0.1, A = 0.6
Cod HPUE	6.0, 6.5 ± 5.2	4.0, 5.9 ± 6.2	MW test, U = 1898, p = 0.2, A = 0.53
Cod RPUE	2.5, 3.5 ± 3.8	1.1, 2.6 ± 3.4	MW test, U = 1549, p = 0.07, A = 0.52
Cod release proportion (%)	29.0, 31.2 ± 25.3	23.0, 25.3 ± 26.0	MW test, U = 1620, p = 0.2
Summer angling days/winter angling days (%)	54/46	60/40	Chi^2-test, Chi^2 = 0.5, p = 0.5
Days with cod catch/zero catch days (%)	28/10	37/16	Chi^2-test, Chi^2 = 0.4, p = 0.6
Flatfish bycatch per day	0, 0.4 ± 2.0	0, 1.4 ± 4.8	NA
Age (years)	50.0, 49.7 ± 13.1	51.0, 51.2 ± 13.7	MW test, U = 2055, p = 0.6
Household members	2.0, 2.3 ± 1.0	2.0, 2.4 ± 1.1	MW test, U = 2124, p = 0.9
Male/female (%)	95/5	96/4	Chi^2-test, Chi^2 = 0.1, p = 0.8
Non-residents/residents (%) (residents: MV & SH)	69/31	60/40	Chi^2-test, Chi^2 = 1.2, p = 0.3
Shore anglers			
Number of reported angling days	3, 5.7 ± 6.1	2, 2,9 ± 3.1	MW test, U = 1147, p = 0.002, A = 0.74
Avidity (number of days fished in the last 12 months)	8, 14.6 ± 15.4	7, 9.4 ± 15.4	MW test, U = 1280, p = 0.03, A = 0.64
Cod CPUE	1.4, 3.5 ± 5.9	1.2, 2.0 ± 2.5	MW test, U = 1107, p = 0.1, A = 0.6
Cod HPUE	0.7, 2.1 ± 3.7	0.5, 1.2 ± 1.4	MW test, U = 1107, p = 0.1, A = 0.51
Cod RPUE	0.8, 1.8 ± 2.9	1.0, 1.5 ± 1.9	MW test, U = 708, p = 0.8, A = 0.4
Cod release proportion (%)	40, 39.9 ± 31.8	36.5, 34.6 ± 30.9	MW test, U = 673, p = 0.6
Summer angling days/winter angling days (%)	41/59	51/49	Chi^2-test, Chi^2 = 1.4, p = 0.3
Days with cod catch/zero catch days (%)	188/42	60/48	Chi^2-test, Chi^2 = 4.5, p = 0.04
Flatfish bycatch per day	0.8, 2.4 ± 5.1	0, 1.8 ± 2.9	MW test, U = 1520, p = 0.3
Age (years)	48, 46.9 ± 12.4	50, 48 ± 13.9	MW test, U = 1539, p = 0.4
Household meanglingmbers	2, 2.5 ± 1.2	2, 2.6 ± 1.1	MW test, U = 1576, p = 0.5
Male/female (%)	95/5	98/2	Chi^2-test, Chi^2 = 0.5, p = 0.7
Non-residents/residents (%) (residents: MV & SH)	44/56	40/60	Chi^2-test, Chi^2 = 0.3, p = 0.7

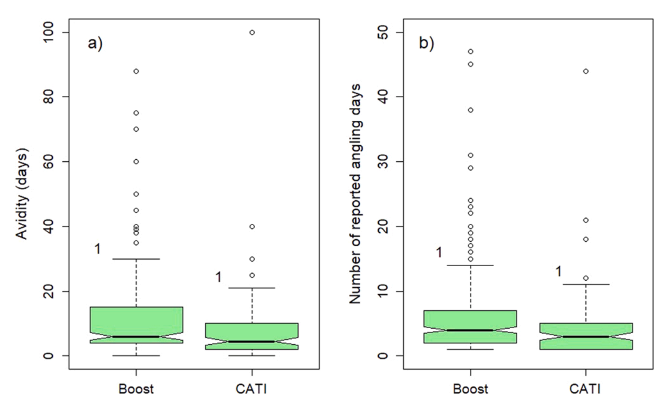

Fig. 1. a) Avidity (number of recalled angling days in the past 12 months) and b) number of reported angling days in the diary survey of diarists from the non-probability-based (boost) and the probability-based (CATI) sample targeting Baltic Sea cod. The same numbers above the boxplots indicate significant differences according to Mann-Whitney U tests: recalled angling days (avidity): U = 10,484, p = 0.002, reported angling days: U = 10,519, p = 0.002. Please note the different scale of the y-axis for plot 1 b.

and recorded angling days was significantly higher among boost anglers (7.8 ± 11.1 angling days, mean ± S.D.) compared to CATI anglers (5.8 ± 8.5 angling days, mean ± S.D.; MW U test, U = 12.3, p = 0.009) but the effect size was relatively small (Vargha-Delaney A = 0.603).

When considering the angling platform, the avidity of anglers from the boost sample was highest for shore anglers, followed by boat and charter boat anglers (Table 2). The avidity differences between angling platforms from the CATI sample were less pronounced compared to those from the boost sample. The avidity of shore and boat anglers from the CATI sample was significantly lower than the avidity of the

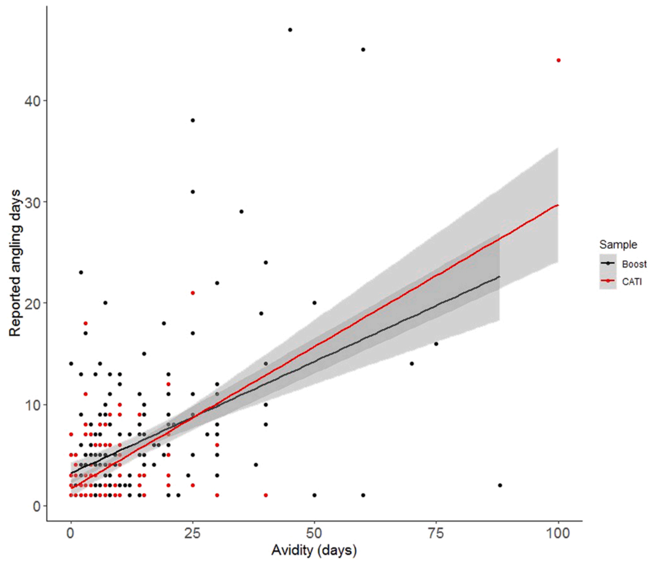

Fig. 2. Correlation between the numbers of angling days reported in the diary and recalled for the year preceding the diary survey (avidity) of anglers recruited from the nonprobability-based boost (black) and the probability-based CATI (red) sample. The grey shades represent the standard errors.

corresponding angler groups from the boost sample. In contrast, the avidity of charter boat anglers from both samples did not differ significantly (Table 2). In both, the CATI and the boost sample, most charter boat and boat angling took place during summer, whereas most shore angling took place during the winter half year (October to March) Fig. 3.

3.4. Comparison of cod catch, harvest, and release rates between the boost and the CATI sample

With mean numbers of 7.5 (± 9.1 S.D.), 4.8 (± 6.3 S.D.), and 3.5 (± 4.3 S.D.) cod per angler and angling day, anglers from the boost sample caught, harvested, and released slightly more cod than anglers from the CATI sample who reported catches, harvests, and releases of 5.8 (± 7.1 S.D.), 4.1 (± 5.0 S.D.), and 2.3 (± 4.0 S.D.) cod per angler and angling day, respectively. However, the corresponding effect sizes were small, with values of $A = 0.54$, 0.51, and 0.53. Accordingly, the BRT analyses indicated that sample origin per se explained only a very small portion of the variance in catch and harvest estimates. Both estimates were largely influenced by avidity, angling platform, and age, with catch and harvest rates increasing with avidity (Figs. 4 and 5). In both samples, charter boat anglers caught and harvested more cod than boat and shore anglers (Table 2). The number of caught and harvested cod did neither differ between charter boat nor between shore anglers from the boost and CATI sample, respectively (Table 2, Fig. 3). In contrast, boat anglers from the boost sample caught and harvested significantly more cod per day compared to those from the CATI sample. The influence of the other socio-demographic factors was comparably small. The most important interaction identified by both models

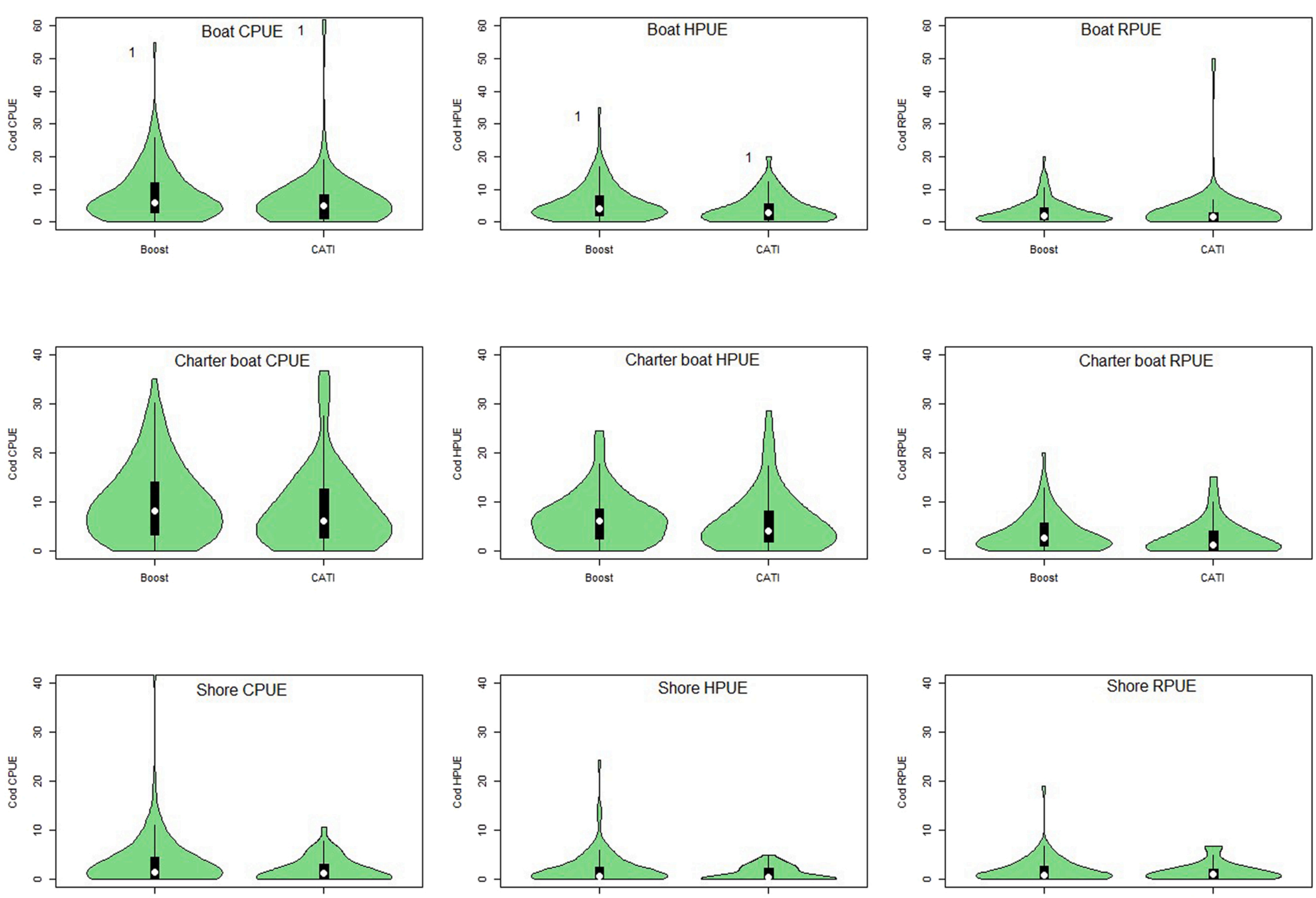

Fig. 3. Violin plots showing the cod catch (CPUE), cod harvest (HPUE), and cod release (RPUE) per angler and angling day for boat, charter boat and shore anglers. The same numbers above the violins indicate significant differences according to Mann-Whitney U tests. Please note the different scales of the y-axes of the plots for charter boat and shore anglers compared to boat anglers. See Table 2 for details of the statistical results and effects sizes.

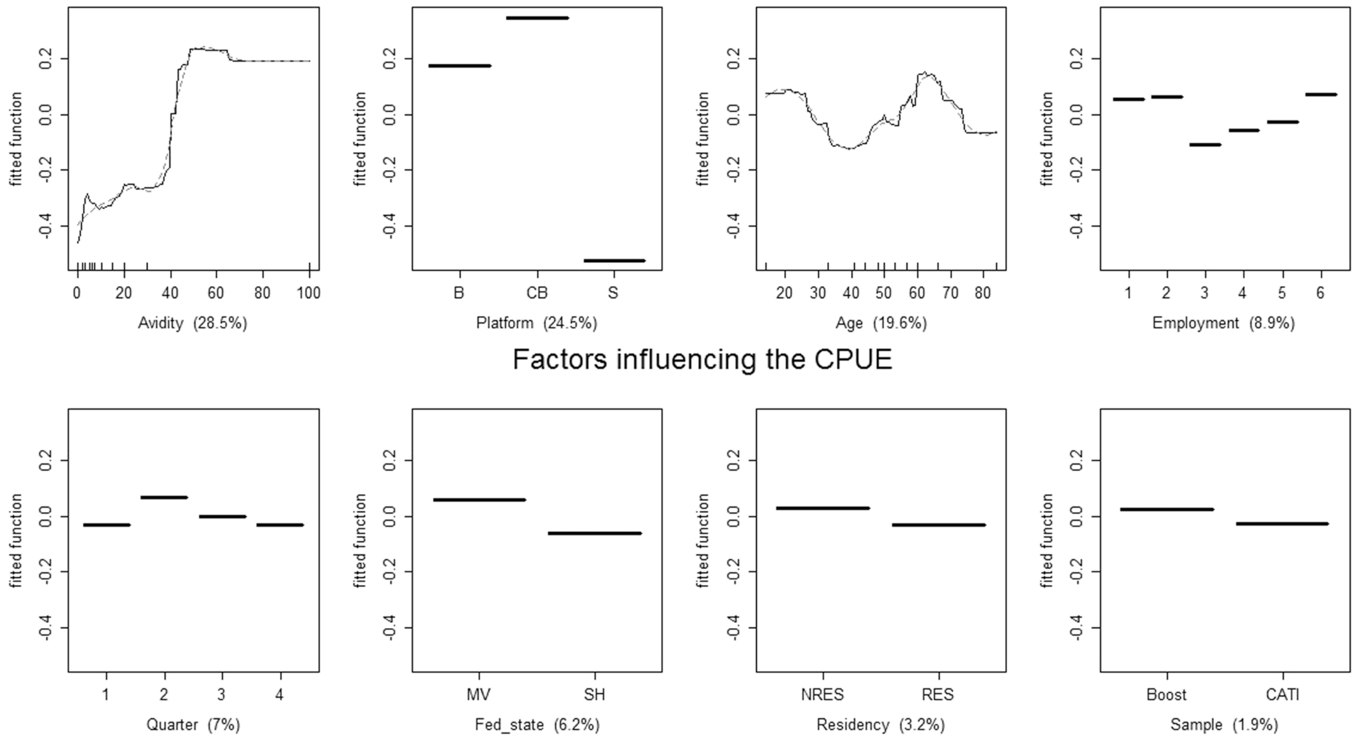

Fig. 4. Partial dependence plots relating cod CPUE (number of caught cod per angler and angling day) to angler avidity, angling platform, angler age, employment group, quarter, angling location (federal state), residency, and sample origin resulting from boosted regression tree (BRT) modelling. Each plot shows the effect of the particular variable on the CPUE. The y-axis shows the fitted function: positive values suggest that the CPUE responds favourably and negative values suggest the opposite. The relative importance of each independent factor for the tree models is given below each plot. The x-axis shows the factor levels. Tick marks at the x-axis indicate the deciles (10 % quantiles) of the observed distribution of continuous predictor variables. The dashed line shows the smoothed representation of the plots. B: boat, CB: charter boat, S: shore; Employment group, 1: pupil/student, 2: employee, 3: public servant, 4: self-employed, 5: retired, 6: without work; Fed_state: angling location along the German Baltic coast, MV: Mecklenburg-Western Pomerania, SH: Schleswig-Holstein; Residency, NRES: non-residents, RES: residents.

occurred between avidity and platform use. The models for CPUE and HPUE explained approximately 26 % and 32 % of the deviance, respectively, indicating that other factors that might have influenced catch and harvest rates were not captured in the present study. Fit parameters and plots for the BRT model are shown in the Supplementary material (Supplement Figs. 1, 2).

In both samples, the cod release proportions were highest for shore anglers followed by charter boat and boat anglers (Table 2). The logistic model confirmed that the release probability increased with the number of caught cod and was higher for anglers from the boost compared to those from the CATI sample. Neither avidity nor the platform use and their interaction were significant so that both were removed from the final model (Table 3, Suppl. Table 1). The release probability was slightly higher for residents and there was a trend that anglers fishing in the federal state of SH were more likely to release cod (Table 3). The final regression model showed a reasonable model fit with KS, dispersion, and outlier tests being non-significant, an AUC (area under the curve) of 0.8 and an accuracy of 93 % (Table 3; Supplement Fig. 3).

4. Discussion

While the need for reliable recreational fisheries data is widely accepted (Hyder et al., 2018; 2020), there is an ongoing debate about the development of efficient sampling approaches that minimize potential biases (Bellanger and Levrel, 2017). This study found some sources of bias that could be attributed to the recruitment process. Anglers from the CATI sample reported fewer angling trips and had a lower avidity than anglers from the boost sample, indicating that sampling from the list of fishing permit holders may increase the risk of bias related to avidity, nonresponse, and differences in recall between the two groups.

The age, gender composition, and education level of the diarists described in this study were comparable to those found in other recreational fisheries surveys (Dorow and Arlinghaus, 2011; OECD, 2014) and differed little between the two samples. The small difference in socio-demographic parameters suggests that angler diary participation and catch, harvest, and release rates were influenced by factors other than socio-demographics. These factors are more likely to be described by human dimensions such as avidity, specialisation, commitment, and skill (Ditton et al., 1992; Oh and Ditton, 2006; Beardmore et al., 2013; Gundelund et al., 2020).

4.1. Potential for nonresponse bias

High participation rates in scientific surveys are desirable to reduce the risk of bias due to differences between those persons who participate and those who cannot or will not participate, provided that the reasons for non-participation are related to the topic of the survey (Fuchs et al., 2013). This study confirmed observations from other studies that direct sampling of angler registries can be more efficient than sampling of general telephone directories in terms of participation rates (e.g., Taylor and Ryan, 2020). Response rates for both samples were higher than in other diary surveys (Connelly and Brown, 1995; Dorow and Arlinghaus, 2011; Rocklin et al., 2014; Van der Hammen et al., 2016), while dropout rates were similar to those observed by others (Connelly and Brown, 1996; Hunt et al., 2007; Dorow and Arlinghaus, 2011). Several factors may have encouraged angler participation. First, the survey focussed on German cod anglers living in nine federal states that are relatively close to the Baltic Sea coast. Anglers living farther away in the remaining seven southern federal states, with long travel distances and presumably lower avidity, and anglers fishing for fish other than cod were not included in this study. Furthermore, the combination of personalized

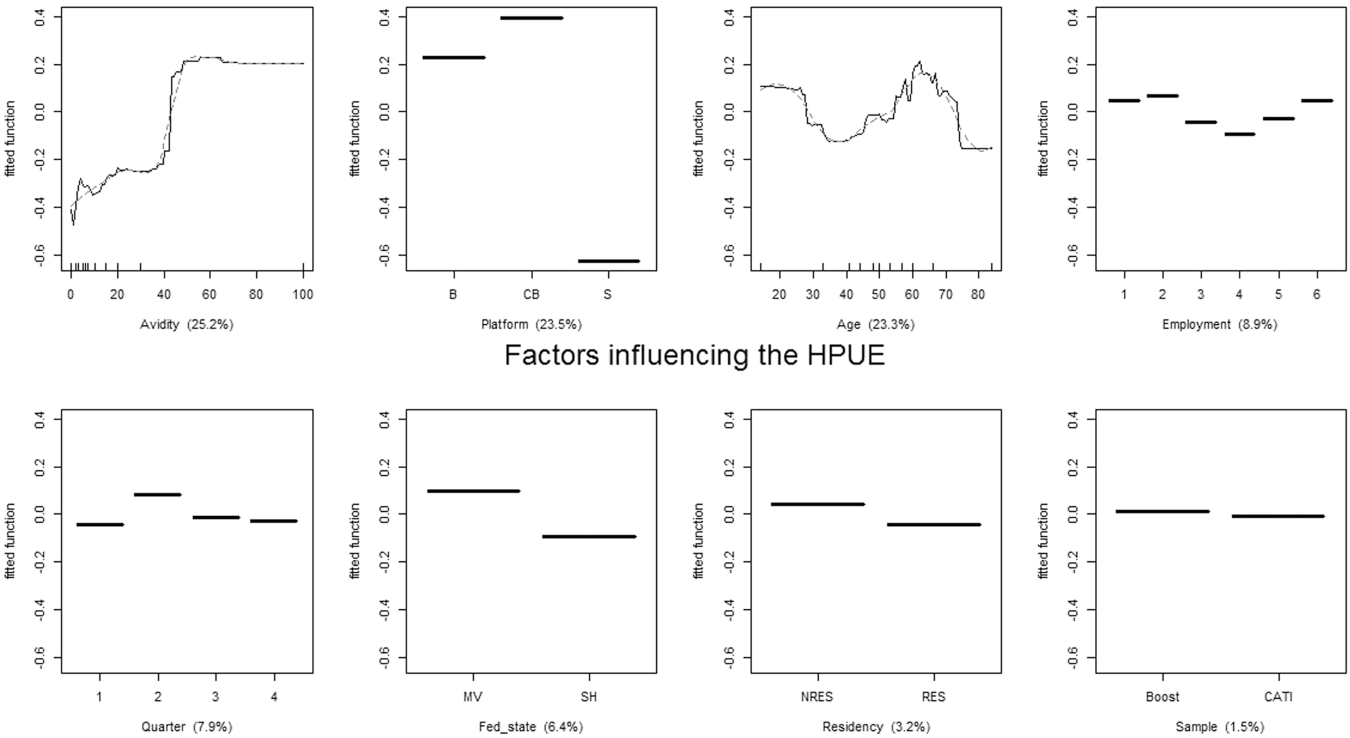

Fig. 5. Partial dependence plots relating cod HPUE (number of harvested cod per angler and angling day) to angler avidity, angling platform, angler age, employment group, quarter, angling location (federal state), residency, and sample origin resulting from boosted regression tree (BRT) modelling. Each plot shows the effect of the particular variable on the HPUE. The y-axis shows the fitted function: positive values suggest that the HPUE responds favourably and negative values suggest the opposite. The relative importance of each independent factor for the tree models is given below each plot. The x-axis shows the factor levels. Tick marks at the x-axis indicate the deciles (10 % quantiles) of the observed distribution of continuous predictor variables. The dashed line shows the smoothed representation of the plots. B: boat, CB: charter boat, S: shore; Employment group, 1: pupil/student, 2: employee, 3: public servant, 4: self-employed, 5: retired, 6: without work; Fed_state: angling location along the German Baltic coast, MV: Mecklenburg-Western Pomerania, SH: Schleswig-Holstein; Residency, NRES: non-residents, RES: residents.

Table 3
Summary of the results of the final logistic regression model estimating the influence of sociodemographic characteristics on the release probability of Baltic Sea cod. S.E.: standard error of the estimate, Exp. B: Exponent β, 2.5 %, 97.5 %: confidence intervals, reference levels: quarter = quarter 1, sample = boost sample, platform preference = boat, federal state angling location = MV.

	Estimate	S.E.	2.5 %	97.5 %	*z*	Exp. *B*	2.5 %	97.5 %	*p*
(Intercept)	-1.45	0.39	-2.22	-0.70	-3.77	0.23	0.11	0.49	0.0002
CATI sample	-0.79	0.24	-1.26	-0.33	-3.34	0.45	0.28	0.72	0.0008
Angling platform charter boat	-0.23	0.25	-0.72	0.25	-0.94	0.79	0.49	1.29	0.3
Angling platform shore	0.48	0.26	-0.04	1.00	1.80	1.61	0.96	2.72	0.07
Quarter 2	0.27	0.33	-0.39	0.91	0.80	1.30	0.68	2.49	0.4
Quarter 3	0.69	0.33	0.04	1.34	2.08	1.99	1.04	3.84	0.04
Quarter 4	0.48	0.32	-0.16	1.11	1.48	1.61	0.85	3.03	0.1
Residency	0.57	0.22	0.15	1.00	2.63	1.77	1.16	2.73	0.009
Federal state SH	0.41	0.23	-0.04	0.86	1.78	1.50	0.96	2.37	0.07
Cod catch	0.29	0.03	0.23	0.35	8.97	1.33	1.26	1.42	<0.0001
	Min.		Med.		Max.		AIC	590	
Deviance residuals	-3.2	-0.8	0.3	0.8	1.7				
Null deviance	748	*d.f.*	641	Residual deviance	570	*d.f.*	632		
AIC	590								
Cox & Snell pseudo r^2	0.24		0	1	Corr. pred.				
Nagelkerke pseudo r^2	0.4	False	81	40	0.79				
AUC (area under curve)	0.8	True	92	429					

invitation letters, well-designed diaries in booklet form, regular follow-up calls, provision of stamped envelopes for diary return, and non-monetary incentives during the study period may have been successful in maintaining participation, as other studies have also shown (Church, 1993; Cooke et al., 2000; Willcox et al., 2010; Griffiths et al., 2013; Singer and Ye, 2013; Brick, 2018; Anderson et al., 2021).

Various studies indicated a general prevalence of more avid anglers in diary surveys (Thomson, 1991; Connelly and Brown, 1995; Dorow and Arlinghaus, 2011; Griffiths et al., 2013) because occasional anglers, for example, do not see the need of intensive reporting (Fisher, 1997; Bellanger and Levrel, 2017). The small number of non-participating anglers in our study prevented valid comparisons between participating and non-participating anglers, and thus this study focus on comparing participating anglers recruited from the different groups.

4.2. Potential for recall bias

In line with other studies (Bray and Schramm, 2001; Griffiths et al., 2013), the number of angling days reported in the diary correlated positively with the number of recalled angling days for the 12 months preceding the diary survey in both the boost and the CATI sample. In both samples, the number of angling days reported in the diary was significantly lower than the number of recalled angling days reported by the same anglers in the telephone survey for the preceding 12 months. Assuming that anglers reported all angling days in the diary and that the average number of angling days per year is similar for two consecutive years when considering the population (Connelly and Brown, 1995), the observed differences could be attributed, at least in part, to recall bias. This bias likely occurs when anglers provide effort or catch data retrospectively several weeks or months after the actual fishing occurred while not exactly remembering details of their fishing activities. The recall often tends to overestimate the effort, catch, or expenditures whereby the magnitude of the bias increases with the length of the time period between event and data collection (Fisher et al., 1991; Tarrant and Manfredo, 1993; Tarrant et al., 1993). In our study, the number of recalled and reported angling days differed by approximately 50 % and the standard errors of the angling days were about twice as high for the recalled as for the reported angling days. These results were in line with other studies. For example, Connelly and Brown (1995) showed that a recall period of one year led to an overestimation of angling trips of approximately 45 %. Osborn and Matlock (2010) found that the number of reported and recalled angling days differed according to the length of the recall period not in accuracy but in precision as indicated by higher standard errors. This result indicated that effort estimates based on angler diary data may be more reliable than estimates based on retrospective telephone survey data at least when the recall period extends over several months. Connelly and Brown (1995) also observed a relationship between an overestimation of past angling days and avidity. Accordingly, the present study indicated that the more avid anglers from the boost sample reported also more fishing days in the diary, which agrees with results from other studies (Griffiths et al., 2013). The difference between recalled and reported angling days was lower for anglers from the CATI sample, which might have resulted from the fact that the rarity of events is known to improve the recall (Golden et al., 2013) while the probability of overestimating events increases with the actual participation (Chase and Harada, 1984). The influence of the sample origin on the difference, however, was moderated when the angling platform was considered.

4.3. Cod catch (CPUE), harvest (HPUE), and release (RPUE) rates

The reported cod catch, harvest, and release rates were within a similar range as observed by earlier studies on German Baltic Sea cod angling (e.g., Strehlow et al., 2012; Ferter et al., 2013). The BRT analysis indicated that the CPUE and HPUE increased with avidity. This relationship was primarily shaped by the angling platform. Several studies found a positive relationship between avidity and catch rates (Griffiths et al., 2013; Gundelund et al., 2020) indicating that angling experience and skill might increase with avidity (Van der Hammen et al., 2016). While the avidity of anglers from the boost sample was slightly but significantly higher than the avidity of anglers from the CATI sample, CPUE and HPUE differed significantly only between the boat anglers, with statistical analyses showing a small effect size. The interactions between avidity and angling platform shown by the BRT analyses confirmed that the connection between avidity and CPUE and HPUE was shaped by the angling platform. The effect of sample origin on boat anglers' CPUE and HPUE can be explained in part by the fact that the avidity of boat and charter boat anglers did not differ significantly between the boost and the CATI samples, and that shore anglers' catch rates were generally low and independent of their avidity. The higher catches of charter boat anglers compared to shore anglers may partly result from the fact that charter boat trips are guided by experienced skippers whose large boats can reach promising offshore fishing grounds. Adult cod usually avoid shallow coastal waters with higher water temperatures in particular during summer (Funk et al., 2020), which may explain the comparably low catch rates of shore anglers.

The release probability was higher for anglers from the boost than from the CATI sample, but was additionally influenced by residency, angling season, and in particular by the number of cod caught by the corresponding angler. According to other studies (Gaeta et al., 2013), the avidity did not influence the release probability. The influence of catch numbers, angling platform, and angling location on release rates may be explained by differences in regional harvest regulations. Successful anglers and in particular successful shore anglers may have caught many fish below the minimum landing size that differs between the federal states of MV (35 cm) and SH (38 cm).

4.4. Conclusions, study limitations, and future research needs

The results of the study indicate that recruiting diarists from a list of angling permit holders might be more successful in terms of participation rates than recruiting diarists following a general probability-based population survey. This may be particularly important in countries and regions with a low proportion of recreational anglers in the total population, as is the case in Germany (Arlinghaus et al., 2015).

The small socio-demographic differences between the two samples suggest that diarists from a list of angling permit holders are representative of the general angler population, at least with respect to the variables considered. The avidity differences between anglers from non-probability-based and probability-based samples, however, may increase the risk of avidity bias and lead to the overestimation of avidity-related data when avidity and catch or harvest rates are positively correlated (cf. Wise and Fletcher, 2013). The small differences in catch and harvest estimates between the boost and the CATI samples observed in the present study indicated, however, that both recruitment methods can provide relatively accurate results, but also that factors such as the respective fishing platform should be considered when estimating catch and harvest rates. The development of a weighting procedure to correct for avidity bias was beyond the scope of this study. Nevertheless, several procedures, e.g., iterative proportional fitting can be applied to correct for varying probabilities of selection in recreational fisheries surveys (e.g., Weltersbach et al., 2021).

Although recall bias was not directly measured in the present study, the difference between the number of angling days reported in the diary and the number of recalled angling days for the preceding year in both groups of diarists indicated that collecting recreational fisheries data based on recall surveys may result in substantial overestimates. The smaller standard error of angling days documented in the diary suggests that diary data may be more accurate than recalled data in estimating angling effort. The larger difference between reported and recalled angling days for anglers in the boost sample indicated that probability-based sampling frames may reduce the risk of recall bias. It should be noted, however, that possible confounding effects of year-to-year variability in the number of recalled and reported angling days could not be ruled out (comp. Connelly and Brown, 1995). Furthermore, we assumed that angler diaries provided accurate information on actual participation (comp. Connelly and Brown, 1995), and we could not rule out the possibility that anglers did not report all angling trips, catches, or releases.

Moreover, uncertainties result from the fact that the present study could not assess which sample is biased to what extent because no benchmark estimates were available. However, probability-based samples have a comparably high degree of representativeness (Cornesse and Bosnjak, 2018) and other authors suggested that diary surveys are as effective as on-site surveys for documenting regional angler behaviour (Gaeta et al., 2013). Nonetheless, diary surveys should be accompanied by complementary on-site surveys to increase the reliability of the estimates (Hartill et al., 2012; Wise and Fletcher, 2013). On-site surveys tend to allow reliable estimates of harvest rates (Roach et al., 1999) provided that appropriate temporally and spatially stratified proportional sampling strategies are applied (Pollock et al., 1994; Llompart et al., 2012). It has to be noted, however, that estimates of catch and release rates from on-site surveys may also be biased if only the retained fish can be seen and counted, whereas the number of released fishes can only be asked, but not controlled, by observers. In addition, on-site surveys are susceptible to length of stay and/or avidity bias (Thomson, 1991; Bellanger and Levrel, 2017).

The low explanatory power of our regression models suggested that relevant factors influencing the estimates of CPUE, HPUE, and RPUE were not covered in the survey. The importance of human dimensions including motivation, skill level, specialisation, or involvement of anglers (Fedler and Ditton, 1994; Sutton and Ditton, 2001; Sutton, 2003; Beardmore et al., 2011; Monk and Arlinghaus, 2018) for the investigation of recreational fisheries has widely been accepted (Hunt et al., 2013) but more research is needed to identify key parameters capturing angler heterogeneity in recreational fisheries data collections.

In conclusion, the present study showed that avidity, as well as catch, harvest, and release rate estimates obtained from probability- and non-probability-based sampling can differ whereby the differences can be shaped by several angling related factors such as, for example, the angling platform. Furthermore, only cod were caught in the recreational fishery investigated in this study, and bycatch is low. To avoid biased estimates of catch, harvest, and release rate in multispecies fisheries, additional efforts are needed to distinguish between trips targeting different species (e.g., Stephens and MacCall, 2004). It is also important to consider that multispecies fisheries attract anglers whose consumption orientation may vary (Fedler and Ditton, 1994). If this diversity is not considered, extrapolation of catch and harvest rates may be subjected to additional biases. These aspects should be considered when extrapolating recreational fisheries data, and future research should focus on evaluating additional human dimension related factors to correct for these biases in catch, harvest, release, and effort estimates.

CRediT authorship contribution statement

Wolf-Christian Lewin: Conceptualization, Formal analysis, Writing – original draft. **Marc Simon Weltersbach:** Conceptualization, Formal analysis, Writing – review & editing. **Kevin Haase:** Writing – review & editing. **Carsten Riepe:** Writing – review & editing. **Harry V. Strehlow:** Funding acquisition, Conceptualization, Formal analysis, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fishres.2022.106551.

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