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Species-specific preference heterogeneity in German freshwater anglers, with implications for management

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ABSTRACT

We used a stated choice experiment answered by 1335 German anglers and fit latent class models to understand preference heterogeneity where context was accounted for by species choice. Information theoretic approaches were used for model ranking, indicating that a three-class latent class model provided the best fit to the data. The three angler classes differed in centrality to life-style and harvest orientation as well as in the general utility experienced by fishing as opposed to not fishing. Moreover, the three angler types varied in their aversion towards cost, collectively suggesting that the three anglers classes differed by psychological commitment to fishing. The three angler types differed in the importance they attached to a range of attributes across several target species, most notably in relation to cost of fishing, catch-related angling qualities and crowding. Both catch rate and average size of the fish in the catch showed evidence of diminishing marginal utility returns, while the probability of catching trophy fish did not. Although not consistently significant across all target species, the most committed angler class benefited most consistently from size of fish, and the intermediately committed angler group from both catch numbers and size. By contrast, the least committed angler group was largely indifferent to many attributes of the fishing experience. Preferences for catch-related attributes and crowding were most pronounced in experiences targeting pike, carp, eel, zander and “other species”. There were no significant preferences for harvest regulations, stocking frequency and the composition of the catch in terms of wild vs. hatchery fish in any of the three angler types, independent of which species was targeted. Collectively, our study reveals the presence of substantial preference heterogeneity, most notably related to catch-related aspects of the fishing experience, crowding and cost of fishing. These preferences, however, are species- and angler-type dependent.

Management implications: Angler populations are heterogeneous with respect to preferences. Thus, one-size-fits-all policies are unlikely to be optimal for all. Managing freshwater fisheries for high catch rates, large sizes in the catch and limited crowding aligns well with the preferences of more committed anglers across most species and can thus be considered generic management objectives that safeguard high angler well-being of more specialized anglers. Alternatively viewed, alteration of catch prospects and to a lesser degree increased crowding is bound to produce disutility to more specialized anglers, particularly when fisheries move to low catch rates and small fish sizes as fishing pressure rises. Such changes are unlikely to cause large aversion to casual anglers, but this angler group is in the minority compared to more committed fishers, at least in our sample.

1. Introduction

Angler diversity has been a frequent topic in the human dimensions of recreational fisheries since the advent of the field in the mid-20th century (Arlinghaus, 2004). Early survey research was motivated by the observation that an average angler only exists in research reports (Aas & Ditton, 1998) and that the availability of a diversity of fishing opportunities is essential for the satisfaction of the varying expectations of a population of diverse anglers (Ditton, 1996; Driver, 1985; Hendee, 1974). Heterogeneity among anglers also matters from a conservation

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perspective, because the presence of variation in skill, fishing intensity and harvesting behaviors across different angler types implies that anglers differ in their biological impact on fish resources and ecosystems (Johnston, Arlinghaus, & Dieckmann, 2010; Fenichel & Abbott, 2014; Ward et al., 2016, Carruthers et al. 2019, Matsumura et al. 2019). Thus, sustainable fisheries management depends on accounting for angler heterogeneity (Johnston et al., 2010, Matsumura et al. 2019).

Research on angler heterogeneity has either followed a sociopsychological research tradition (traditionally termed "human dimensions") or has been based on modeling preferences and demand through economic approaches, mostly using variants of travel costs or choice modeling. In the sociopsychological research tradition, angler diversity has been described by variables such as mode of fishing (e.g., gear type, Teisl, Boyle, & Roe, 1996, Aas, Haider, & Hunt, 2000, tournament or non-tournament fishing, Loomis & Ditton, 1987, Siemer & Brown, 1994, Wilde, Riechers, & Ditton, 1998), preferred fishing location (e.g., Arlinghaus & Mehner, 2004; Graefe & Ditton, 1986), degree of organization (Freudenberg & Arlinghaus, 2008; Gigliotti & Peyton, 1993), species preference (Ross & Loomis, 2001; Spencer & Spangler, 1992), origin of fishers (e.g., resident and non-resident, Hubert & Gipson, 1996), ethnic background (Hunt & Ditton, 2002), consumptive orientation (Aas & Kaltenborn, 1995; Fedler & Ditton, 1986), catch orientation (Arlinghaus, 2006), and fishing motivations (Beardmore, Haider, Hunt, & Arlinghaus, 2011; Magee, Voyer, McIlgorm, & Li, 2018). A key restriction of this largely descriptive research tradition is its limited understanding of angler heterogeneity beyond the grouping variable.

A major step forward in sociopsychological subdiscipline of human dimensions research was the publication of the recreation specialization framework by Bryan (1977). Recreation specialization is a multidimensional concept, conceptualized as entailing at least three subdimensions – behavioural commitment, cognition/skill and an affective component that measures the psychological attachment of an angler to the activity (Scott & Shafer, 2001). Although the research community is still debating how to best operationalize the concept (Scott & Shafer, 2001), the specialization framework has inspired a large number of studies that classified anglers according to their degree of specialization to the activity while examining a range of co-varying characteristics (attitudes, beliefs, acceptance of policy options, harvesting behaviours, setting preferences etc.) in which differently specialized angler groups were supposed to also vary (e.g., Chipman & Helfrich, 1988; Ditton, Loomis, & Choi, 1992; Dorow, Beardmore, Haider, & Arlinghaus, 2010; Fisher, 1997). A key conceptual goal for understanding how differently specialized anglers vary in other cognitions and behaviours was to arrive at fundamental mechanistic understanding of the psychological underpinning of angler heterogeneity rather than merely describing angler heterogeneity phenomenologically in an ad-hoc manner. If specialization would in fact be a key dimension by which angler heterogeneity aligns, it would constitute a much-needed approach forward of practical relevance. For example, researchers and managers could then simply measure degree of specialization (or relevant subdimensions such as psychological or even behavioural commitment) with a set of easily applicable scales and then be able to predict how the current population of anglers most likely varies in other key aspects of managerial relevance (e.g., attitudes to conservation policies, or preferences for site attributes), without directly measuring preferences or attitudes. However, despite decades of research on angler specialization, it is still unclear the degree to which psychological commitment or other subdimensions of specialization is systematically related to key dimensions of relevance for fisheries management, in particular angler preferences and spatial choice behavior (Beardmore, Haider, Hunt, & Arlinghaus, 2013).

Recreation economists have also long acknowledged heterogeneity of outdoor recreationists in terms of explaining variation in preferences, willingness-to-pay and behaviors through choice models (e.g., Jones & Lupi, 2000, Provencher, Bischop, & Richard, 2004; Breffle and Morey 2000; Melstrom, Jayasekera, Boyer, & Jager, 2017, Dabrowska et al. 2017; Curtis, 2018, Deely et al. 2019). Much recreation economics research done so far has been motivated by the desire to improve the welfare estimates generated from either stated or revealed choice models (Haab, Hicks, Schnier, & Whitehead, 2012; Provencher et al., 2004), with perhaps less attention devoted to link economics (i.e., assessment of preferences) and sociopsychological approaches to angler heterogeneity (e.g., angler specialization) (but see Oh & Ditton, 2006; Beardmore et al., 2013). Variation in fishing preferences has been shown to be more fundamentally linked to beliefs and attitudes than to socio-demographic or avidity variables (Arlinghaus & Mehner, 2005; Curtis, 2018). A strong candidate that can explain fishing preferences is the degree of angler specialization in the spirt of Bryan (1977), but research in this area is in its infancy (see Beardmore et al., 2013 for full account).

The conceptual beauty of choice models and a major advantage over sociopsychological approaches to angler behavior is that the resulting statistical descriptors of angler preferences can serve as predictive out-of-sample models suitable for mechanistically modeling effort dynamics – a key aspect of relevance to fisheries resource management (Fenichel, Abbott, & Huang, 2013). Understanding effort dynamics is of paramount importance to fisheries resource managers because it helps them predict the anglers' behavioural reactions to policy interventions, in particular the likely angler mortality induced on stocks or the effort redistribution effect of novel regulations (Johnston et al. 2010, 2018, 2013; Abbott & Fenichel, 2014, Carruthers et al. 2019, Matsumura et al. 2019). In this context, stated and revealed choice models commonly estimated by resource economists (for a review, see Hunt, 2005) can serve as submodels of angler preferences and behaviors in bio-economic model applications, which constitutes a frontier in recreational fishing research (Johnston et al., 2010, 2013, 2015, 2018, Carruthers et al. 2019; Matsumura et al. 2019). They thus have an important advantage over sociopsychological research approaches to angler heterogeneity because the choice models can be straightforwardly linked to fish population models and be used for quantitatively examining the impacts of policy scenarios (Fenichel et al., 2013; Arlinghaus et al., 2017; Johnston, Beardmore, & Arlinghaus, 2015, 2018, Matsumura et al. 2019).

This paper appears in a special issue devoted to one of our key mentors in choice modeling, Dr. Wolfgang Haider, who has been a strong advocate of developing human dimension studies that are of practical relevance to natural resource managers. In the spirit of Wolfgang's legacy, our paper is focused on presenting a set of choice models that can be linked as behavioural submodels to integrative bio-economic models of fish-angler-interactions while accounting for angler heterogeneity (Johnston et al., 2010, 2015, 2018). We do so by explicitly testing whether classical sociopsychological concepts to understand angler heterogeneity, in particular psychological commitment to fishing as a subdimension of specialization, are systematically related to preference heterogeneity in a stated preference survey of recreational anglers from Germany. Many fisheries management activities are directed at selected high profile target species, and hence resource managers are interested in angler heterogeneity in relation to specific target species (Arlinghaus, Beardmore, Riepe, Meyerhoff, & Pagel, 2014). We therefore approach the known context-dependency of angler preferences and motives (Beardmore et al., 2011; Curtis, 2018) by estimating species-specific models of angler choice.

Heterogeneity in preferences of anglers has been captured using four basic approaches in choice modeling studies: 1) pre-clustering anglers into classes (e.g., different degree of specialization) and running independent (often standard conditional logit) choice models, by class (Dorow et al., 2010; Oh & Ditton, 2006); 2) interacting co-variates of relevance (e.g., consumptive orientation, socio-demographics) with attributes in conditional logit choice models to understand the variation in preferences of different anglers along the co-variates' scales (Beardmore et al., 2013; Carlin, Schroeder, & Fulton, 2012); 3) running random parameter logit models, or more general mixed logit models, where a distribution of parameter coefficients is estimated, thereby accounting for preference heterogeneity among and within anglers across contexts (McConnell & Tseng, 1999; Provencher et al., 2004; Haab et al., 2012; Knoche & Lupi, 2016, Dabrowska et al. 2017), or 4) fitting statistical latent class (also known as finite mixture) models that search for classes of anglers that most differ in their parameter estimates (e.g., Boxall & Adamowicz, 2002; Curtis, 2018; Dabrowska et al. 2017; Provencher et al., 2004, 2002). It is an empirical question which of the different modeling approaches or alternative approaches that examine scale heterogeneity among anglers (Breffle and Morey 2000; Melstrom et al., 2017) best describes empirical reality (Povencher et al., 2004; Dabrowska et al. 2017). This paper presents models of species-specific angler heterogeneity using a preference heterogeneity approach with latent class modeling because this approach is judged to best align with our ultimate goal to link the resulting models with fish population models in bio-economic applications (see Johnston et al., 2018 for a recent case).

Most of the published choice modeling studies that address angler heterogeneity have had one important limitation – they were often focused on only one fishery, ecological or social context or target species (e.g., Carlin et al., 2012; Curtis, 2018; Dorow et al., 2010; Oh & Ditton, 2006). In reality, however, an angler population is composed of people targeting a range of species (representing one example of a key contextual factor, Dabrowska et al. 2017) throughout the fishing season and across a given landscape, and the preferences of anglers are likely to be strongly affected by the context of a given species choice (Jones & Lupi, 2000; Curtis, 2018, Curtis & Breen, 2017). If we are to understand the behavior of an entire population of anglers targeting multiple sites and species, studies at the population level for mixed-species fisheries are needed. The challenge is then that a stated preference survey has to offer relevant alternatives to anglers in the choice tasks, e.g., it would be providing little choice information by presenting scenarios of a generally non-considered species A to an angler targeting species B or C. Beardmore et al. (2013) introduced a stated preference choice modeling approach where a one-year diary survey among anglers in one of the 16 German federal states was used to inform a subsequent personalized stated choice experiment to be tailored to the specific species targeted by each of these anglers. A limitation of this and related work, however, is that the levels for biologically important attributes, for example, catch rates, did not encompass extreme-quality conditions near the origin on the attribute scales (e.g., very poor catches), thereby preventing responding anglers from evaluating extremely low catch rates and at the same time preventing researchers to estimate non-linear relationships of attributes of interest (e.g., catch rates) and angler utility. In cases like this, the resulting choice models will not optimally interface with biological models as the reaction of anglers to extremely poor catch expectations is not well estimated.

A range of catch (e.g., catch rates, size of fish captured) and non-catch related attributes (e.g., crowding, presence of harvest regulations, cost) affects the utility anglers expect from a fishery and thus their behavior. Acknowledging that different angler types will value different attributes of the fishing experience (e.g., Curtis, 2018; Dorow et al., 2010), it is safe to assume that in many cases the expected catch qualities, in particular size of fish and catch rate, and the cost of fishing will be of relevance to most anglers. Most previous choice models applied to recreational angling estimated linear coefficients for catch attributes (Hunt et al. 2019), but economic theory would strongly support the idea of diminishing marginal returns of angler utility to changes in catch rates (Arlinghaus et al., 2014; Beardmore, Hunt, Haider, Dorow, & Arlinghaus, 2015) or other catch-related attributes (e.g., average size of fish captured). Very few researchers have tested alternate relationships between key drivers of fishing site choice (e.g., catch-related fishing quality or cost) and utility to the common linearity assumption. When these tests were undertaken, a positive, yet diminishing effect of catch rate on fishing site choices was noted (Shaw & Ozog, 1999; Anderson & Lee, 2013; Carter & Liese, 2012; Hindsley, Landry, & Gentner, 2011; Lawrence, 2005, but see Latila & Paulrud, 2006 for an exception). Work on angler satisfaction (revealed data) has shown that angler satisfaction also increases non-linearly with increasing catch rates and sizes of fish, but these relationships were dependent on the degree of angler specialization, thus reflecting variation in basic expectations of different angler types (Beardmore et al., 2015). Similar findings of non-linear increases in angler utility with increasing catch rates were reported by Arlinghaus et al. (2014) using a stated choice experiment, but this work did not address angler heterogeneity and did not formally test alternative models for key determinants of site choice in relation to catch-related fishing attributes (catch rate, size of fish).

We reanalysed the data set published by Arlinghaus et al. (2014) and derived models with species-specific preference heterogeneity and compared the resulting angler groups in several measures related to angler specialization. Our objective was to understand species-specific angler heterogeneity and to examine whether non-linear relationships of catch-related experience qualities and angler utility better explained the choice data relative to the standard of assuming linear relationships. We hypothesized that the population of German anglers would show substantial taste heterogeneity and that the importance of attributes for differently specialized angler types would vary by species (Beardmore et al., 2015, Dabrowska et al. 2017). We also hypothesized that models with non-linear relationships of catch-related attributes of the fishing experience and angler utility would receive greater statistical support than models assuming linear relationships, particularly in relation to catch rates and less so in relation to size of fish (Arlinghaus et al., 2014; Beardmore et al., 2015). Finally, we expected some consistency in preferences across species, as previous research on catch satisfaction has shown that most anglers, independent of degree of specialization, are more satisfied with increasing catch and larger fish in low crowding conditions (Beardmore et al., 2015).

2. Material and methods

Survey: The survey and the questionnaire used for the present study are described in detail elsewhere (Arlinghaus et al., 2014). Only the essentials will be repeated here. Data were collected with a mail survey conducted among angling club members of 17 angling clubs in Lower Saxony, north-western Germany. A discrete choice experiment (DCE, stated preferences) was included in a questionnaire sent in February 2013 to anglers who had previously completed a previous survey assessing basic angler characteristics and attitudes (e.g., catch orientation, Anderson, Ditton, & Hunt, 2007), so that information on the main target species of each respondent was available to allow for a personalized choice experiment. Surveys were mailed to N = 2337 anglers, resulting in 1335 useable returns (a 57.1% response rate) after three contacts, which included an initial mail survey package, a reminder postcard, and a replacement survey package.

Choice experiment: In the discrete choice experiment (DCE), anglers were presented with choice tasks which asked them to allocate 10 potential angling days among a range of fishing alternatives, three of which were embedded within a hypothetical new angling club they could become a novel member (see Fig. 1 for an example of a choice set). The framing of the choice task was that the respondent should imagine relocating housing and considering joining a new angling club for a yearly fee that offered the three fishing experiences in different lakes of 10 ha dimension. The allocation of angling days was used as a relative preference vote rather than as an absolute effort estimate per fishing experience. Attributes of the DCE (Tables 1 and 2) covered nine possible target species, harvest regulations (daily bag limits and minimum-size limits), catch outcomes in terms of catch rates, average size of catch and catch probabilities of trophy fish, stocking frequency (probability of stocking in a given year), catch composition (wild vs. stocked fish in the catch), crowding (number of anglers seen), and a club fee as cost vehicle. Each respondent was given an individualized

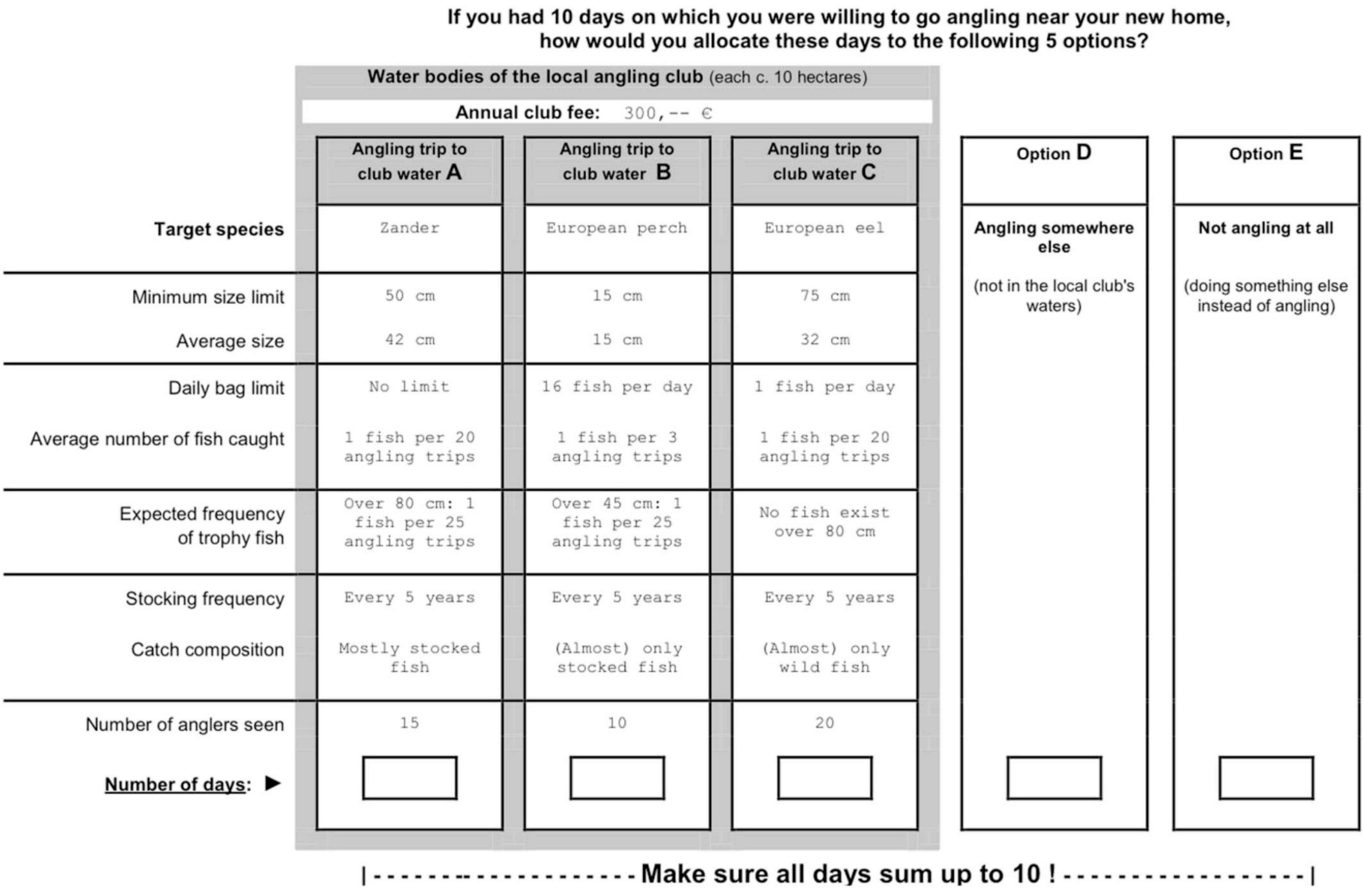

Fig. 1. Example of a choice set presented to respondents (from Arlinghaus et al., 2014).

set of choice tasks featuring a maximum of four fish species of importance to him or her, similar to Beardmore et al. (2013) (for details, see Arlinghaus et al., 2014).

Two types of attributes were incorporated in the DCE: generic attributes that had identical levels across all trip descriptions regardless of the species (e.g. stocking frequency; Table 1) and attributes with species-specific levels taking natural differences between species into account (e.g., in terms of absolute catch rates, Table 2). Regulatory and catch outcome attribute levels encompassed a large range of what could be realistically expected to occur under natural conditions.

We used a D-efficient experimental design, implemented in Ngene 1.1.1 (www.choice-metrics.com) to construct the suite of choice sets for the survey, informed by data from a pretest (see Arlinghaus et al., 2014 for details). After running the design selection algorithm, the most efficient model generated was selected (D-error = 0.029) comprising 120 scenarios blocked into 20 survey versions. Six choice sets were assigned to each respondent in the final DCE, and the order randomized as per Bradley and Daly (1994).

Analysis: Analysis of stated choice experiments is grounded in random utility theory, which states that selection of one alternative i from among k possible alternatives implies that the utility of that alternative is greater than the utility of any other (McFadden, 1974). If the error terms of the utilities are assumed to follow a Gumbel distribution and therefore "the ratio of choice probability for any two alternatives is unaffected by addition or deletion of alternatives" (Carson et al., 1994, p. 354), a multinomial logit (MNL) regression model may be fitted to choice data such as those collected using DCEs (McFadden, 1974):

$$P_{\mathrm{ni}} = \frac{e^{V_{\mathrm{ni}}}}{\sum_{i=1}^{k} e^{V_{\mathrm{ni}}}} \quad (1)$$

where the probability of individual n choosing alternative i is equal to the exponent of that alternative's deterministic utility V divided by the sum of deterministic utilities raised to the exponent for all k alternatives available to that individual. Latent class models build on this foundation by probabilistically assigning each case (i.e., angler) to a given number of maximally different preference classes. Following Swait (1994), we assumed that class membership probabilities and site selection followed conditional logit models:

$$P_{ni} = \frac{e^{\alpha_{nl}+\sum_{c=1}^{C}(\beta_{nlc}*z_{nlc})}}{\sum_{l=1}^{L}\left(e^{\alpha_{nl}+\sum_{c=1}^{C}(\beta_{nlc}*z_{nlc})}\right)} \times \frac{e^{\alpha_{ni}+\sum_{a=1}^{A}(\beta_{nia}*z_{nia})}}{\sum_{i=1}^{J}\left(e^{\alpha_{ni}+\sum_{a=1}^{A}(\beta_{nia}*z_{nia})}\right)} \quad (2)$$

where the probability of individual (n) choosing alternative i from J total alternatives defined by A attributes depends on the product of two logistic functions. The first function estimates the probability that the individual belongs to class l (of L classes), referred in our results as the "Model for Classes". It is a function of a constant (α_{nl}) and parameter coefficients (β_{nlc}) of C angler characteristics (z_{nlc}). The second logistic component of the model estimates the probability that members from a class l will select a given alternative in the choice set (referred to in our results as the "Model for Choices"). This selection is influenced by the class' preferences for attributes defined by an alternative specific constant (α_{ni}) and parameter coefficients (β_{nia}) along with the attributes and level of attributes (z_{nia}, e.g., catch, management regulations).

In our case, no angler characteristics were defined in the model, so that non-response to other questions in the survey that describes angler characteristics would not reduce the effective sample size. Consequently, equation (2) simplified to the following:

$$P_{ni} = \frac{e^{\alpha_{nl}}}{\sum_{l=1}^{L}(e^{\alpha_{nl}})} \times \frac{e^{\alpha_{ni}+\sum_{a=1}^{A}(\beta_{nia}*z_{nia})}}{\sum_{j=1}^{J}\left(e^{\alpha_{ni}+\sum_{a=1}^{A}(\beta_{nia}*z_{nia})}\right)} \quad (3)$$

Table 1
Generic attributes and levels in the choice experiment among anglers in Lower Saxony, Germany. The design levels represent the numeric coding of attribute levels for linear estimates that was used to determine the priors required for generating the efficient experimental design of the choice sets (from Arlinghaus et al., 2014).

Attribute	Design level	Level definition
Club fee	0.4	40 €
	0.6	60 €
	0.9	90 €
	1.2	120 €
	1.5	150 €
	1.8	180 €
	2.1	210 €
	3.0	300 €
Trophy frequency[a]	0	No trophy fish
	0.25	1 trophy in 400 trips
	0.5	1 trophy in 200 trips
	1	1 trophy in 100 trips
	4	1 trophy in 25 trips
	10	1 trophy in 10 trips
Stocking frequency	1	yearly
	0.5	every 2 years
	0.2	every 5 years
	0	no stocking
Catch composition[b]	0	(Almost) Only wild fish
	0.33	Mostly wild fish
	0.66	Mostly stocked fish
	1.0	(Almost) Only stocked fish
Anglers seen	0	No other anglers
	1	2 other anglers
	2	4 other anglers
	4	8 other anglers
	5	10 other anglers
	7.5	15 other anglers
	10	20 other anglers
	12.5	25 other anglers

[a] Trophy size was defined for each species as follows: European carp, *Cyprinus carpio* > 90 cm; Zander, *Sander lucioperca* > 80 cm; Pike, *Esox lucius* > 100 cm; European eel, *Anguilla* > 80 cm; European perch, *Perca fluviatilis* > 45 cm; Tench, *Tinca* > 60 cm; Rainbow trout, *Onchorhynchus mykiss* > 70 cm; Brown trout, *Salmo trutta* > 50 cm; coarse fish: Bream *Abramis brama* > 70 cm as example.

[b] If stocking frequency was "No stocking", then catch composition was constrained to be mostly or entirely wild fish.

In short, we predicted class membership on anglers' attribute preferences, retaining only the intercept values of the first function in equation (3).

The analysis of frequency-based choice experiments as ours differs from other discrete choice tasks in the treatment of the dependent variable (Louviere & Woodworth, 1983). Rather than being asked to select their single most preferred choice, respondents are instead asked to assume they have multiple opportunities (e.g., fishing days) to select from the alternatives (fishing sites) in each choice set (Fig. 1). The frequency-based approach is better suited to capture the dynamic nature of people's actual recreation behavior than to make discrete, one or nothing choices (Christie, Hanley, & Hynes, 2007). Anglers, for example, have been shown to take numerous trips to different sites (e.g., lakes, rivers) over the course of a year (Arlinghaus & Mehner, 2004). Should an individual strongly prefer one option over others, in a frequency-based choice task they are still not prevented from allocating all choices to a single alternative, or else they can distribute leisure days more evenly according to their preferences to various options. Thus, a frequency-based choice task can capture a much richer depth of information on intended behavior by accepting variation in responses by each individual. Analytically, in our frequency-based choice experiment rather than treating each choice expressed by the respondent in the survey as a single discrete event as is typical in discrete choice models, each alternative was weighted in proportion to its allocation of units (here days), with the weights summing to one observation (Louviere & Hensher, 1982; Vermunt; Magidson 2005). In our application, the units of allocation were angling days (Fig. 1), with ten days allocated for each choice set across choice opportunities. After applying these weights, each allocated day represented only one tenth of an observation, and equation (3) was used to produce the part worth utility estimates (i.e., regression coefficients) for each attribute level along with standard errors.

We used the software Latent Gold Choice 5.1 for model fitting (www.statisticalinnovations.com; Vermunt & Magidson, 2005). This software package differs from others (e.g., NLogit, R) that are commonly used for analysis of choice experiments in that one enters the data in three files that are treated as a relational database. The experimental design is contained within two files, with one dedicated to coding the response options (i.e., alternatives) available within the design, and the second file defining how those response options are combined into choice sets. A third file holds the response data and is structured with one row per respondent per response option, in this case, for each respondent, the responses required five rows per choice set (with each response option numbered 1 through 5). The frequency with which each response option is chosen (e.g., if a respondent allocated two out of ten days to a given option, this is coded as 0.2) is used to weight each row to ensure that the number of observations is not inflated. Readers are referred to the software website, www.statisticalinnovations.com, for comprehensive documentation including tutorials in using *Latent Gold Choice* in frequency-based choice tasks.

We were specifically interested in testing linear vs. non-linear relationships of angler utility and a set of generic attributes related to catch, cost and regulations (e.g., harvest regulations and stocking) as well as species-specific attributes of the fishing experience because a recent review of the choice literature in recreational fisheries has identified this question as an outstanding research gap (Hunt et al. 2019). Before formally testing the statistical support of models with linear or non-linear coefficients, we choose to conduct preliminary analysis with all attributes effects-coded and thus treated as categorical variables, so that the coefficients estimated for each level of an attribute sum up to zero (Bech & Gyrd-Hansen, 2005). This was done to visually examine patterns of coefficients by attribute level. These patterns were then used to inform an inital selection of possible continuous functional forms that describe the relationship of an attribute across levels and angler utility, to in turn formally use statistics to test for statistical support for a given attribute-specific functional form. Species-independent attributes (i.e, model intercepts and species ranks) retained in the final model were kept as categorical variables, while club fee as our cost attribute was treated as linear throughout the formal model selection process as the initial exploration supported treating the cost attribute as linear. The formal model selection process then focused on the identification of a best-fitting number of latent classes to optimally account for angler heterogeneity as well to examine support for use of linear or non-linear functions to describe species-specific attributes related to both management attributes (harvest regulations, bag limits and stocking) and catch aspects of each fishing alternative in relation to catch numbers, size of fish and probability of catching trophy fish. We tested both quadratic and logarithmic functional forms to examine support for either the presence of non-linear relationships that exhibited either maxima or minima (quadratic) or asymptotic relationships of an attribute and angler utility.

The form model selection used the information theoretic approach based on AIC model weights (Akaike, 1974; Burnham & Anderson, 1998). Model selection was undertaken using a two step process. First, we selected for the optimal number of latent classes among identically specified models. Second, we explicitly set out to test whether the data were best described by linear or non-linear utility functions, by testing both linear and non-linear coefficients for the catch-based and management-related fishing attributes. Thereby, we systematically tested

Table 2

Species-specific attributes and levels used in the choice experiment. While the values differed according to each species, each level followed the same rules established by the generic specification given by the design level (Table 1). In the final model, species-specific attributes were based on real world measures in terms of unit (cm for minimum length limit and average size, and number of fish for daily bag limits and average number caught) (from Arlinghaus et al., 2014). The number of respondents who saw each species an option in their choice experiment is indicated in the top row.

Attribute	Design level	Generic specification	European eel	Common carp	Coarse fish	Pike	Rainbow trout	Perch	Brown trout	Zander	Tench
Number of anglers (N)			629	604	325	757	333	230	351	612	145
Minimum-length limit	0	No MSL	0 cm	0 cm	0 cm	0 cm	0 cm	0 cm	0 cm	0 cm	0 cm
	1	Current MSL	35 cm	35 cm	15 cm	40 cm	25 cm	15 cm	25 cm	35 cm	25 cm
	1.4	40% larger	50 cm	50 cm	20 cm	55 cm	35 cm	20 cm	35 cm	50 cm	35 cm
	1.8	80% larger	65 cm	65 cm	30 cm	70 cm	45 cm	30 cm	45 cm	65 cm	45 cm
	2.2	120% larger	75 cm	75 cm	35 cm	90 cm	55 cm	35 cm	55 cm	75 cm	55 cm
Average size	0.65	35% smaller	32 cm	36 cm	15 cm	37 cm	24 cm	15 cm	24 cm	33 cm	24 cm
	0.825	17.5% smaller	41 cm	46 cm	19 cm	47 cm	30 cm	19 cm	30 cm	42 cm	30 cm
	1	Current mean size	50 cm	56 cm	23 cm	57 cm	37 cm	23 cm	37 cm	51 cm	37 cm
	1.175	17.5% larger	59 cm	64 cm	27 cm	67 cm	43 cm	27 cm	43 cm	60 cm	43 cm
	1.35	35% larger	68 cm	74 cm	31 cm	77 cm	50 cm	31 cm	50 cm	69 cm	50 cm
Daily bag limit	10	No limit	No limit	No limit	No limit	No limit	No limit	No limit	No limit	No limit	No limit
	1	1 fish	1 fish	1 fish	4 fish	1 fish	1 fish	4 fish	1 fish	1 fish	1 fish
	2	2 fish	2 fish	2 fish	8 fish	2 fish	2 fish	8 fish	2 fish	2 fish	2 fish
	4	4 fish	4 fish	4 fish	16 fish	4 fish	4 fish	16 fish	4 fish	4 fish	4 fish
Average number of fish caught	0.05	5%	1 per 20 days	1 per 20 days	1 per 3 days	1 per 20 days	1 per 20 days	1 per 6 days	1 per 20 days	1 per 20 days	1 per 20 days
	0.1	10%	1 per 10 days	1 per 10 days	1 per day	1 per 10 days	1 per 10 days	1 per 3 days	1 per 10 days	1 per 10 days	1 per 10 days
	0.2	20%	1 per 5 days	1 per 5 days	3 per day	1 per 5 days	1 per 5 days	1 per day	1 per 5 days	1 per 5 days	1 per 5 days
	0.5	50%	1 per 2 days	1 per 2 days	5 per day	1 per 2 days	1 per 2 days	3 per day	1 per 2 days	1 per 2 days	1 per 2 days
	1	100%	1 per day	1 per day	10 per day	1 per day	1 per day	6 per day	1 per day	1 per day	1 per day
	2	200%	2 per day	2 per day	20 per day	2 per day	2 per day	12 per day	2 per day	2 per day	2 per day
	5	500%	5 per day	5 per day	40 per day	5 per day	5 per day	24 per day	5 per day	5 per day	5 per day
	10	1000%	10 per day	10 per day	80 per day	10 per day	10 per day	48 per day	10 per day	10 per day	10 per day

whether our initial "eye-balling" of suitable functional forms for selected attributes was statistically supported or not. We only interpreted significant regression coefficients for each angler type (class) at a p-value of <0.05.

Three specific treatments in our analysis are worth noting. First, while the initial design was developed using priors from a parsimonious and species-independent model, to facilitate interpretation and offer greater relevance to fisheries ecologists, a species-specific approach was taken in the final analysis. For attributes that shared a common setoff level across species, the linear coding specified in the design was used (Tables 1 and 2), but for species-specific levels, real world measurements were used (Table 2). Thus, minimum-length limits and average sizes were measured in centimetres relative to the lowest chosen level, which served as the base. In the case of minimum-length limits, the lowest level was 0 cm, representing no limit, while for average size the value of the lowest level (e.g., 37 cm for pike, Table 2) was subtracted from each level for that species, thereby defining the basis of comparison. Daily bag limits and average catches were simply expressed in numbers of fish per day. Second, rather than including main effects and then including species interactions for all but one reference species, effects for each species were treated separately. This simplified interpretation of the model by providing single parameter estimates for each species-specific attribute, at the cost of being able to statistically compare species. Moreover, due to the species-specific values for some catch outcomes (Table 2), some numeric values were perfectly confounded with a particular species. Given the choice of our approach, this did not affect the species-specific parameter estimates. Finally, two species and one species group, Eurasian perch *Perca fluviatilis*, tench *Tinca* and coarse fish (small-bodied non-salmonid fishes of the cyprinid family), were grouped together rather than being treated separately. This was done because perch and coarse cyprinid fish are abundant in most water bodies, and differ from other species by offering very high catch rates. Consequently, their catch outcomes were not comparable to the rest of the species. Tench was included into the "other" category due to low sample size. All other species tested (pike, *Esox lucius,* zander, *Sander lucioperca,* brown trout, *Salmo trutta,* European eel, *Anguilla,* rainbow trout, *Oncorhynchus mykiss*) were kept separately and use to estimate species-specific parameters.

After selecting our final model, we retrospectively compared key characteristics of anglers among the latent classes. This was done to further our understanding as to the differences among latent classes formed by preference assessments. Using four items of the catch orientation scale (Anderson et al., 2007) and seven items of the centrality of angling to the lifestyle of a respondent scale (Kim, Scott, & Crompton, 1997), we examined differences among latent classes in key dimensions of recreation specialization (Bryan, 1977). Both scales were answered on a five-point agreement-disagreement scale. We additionally measured and then compared a few other indicators of angler commitment (e.g., avidity, years of membership in a fishing club), satisfaction (with the past angling year, on a ten point scale) and demographics (e.g., age). This was done exploratorily to further our understanding as to how the three angler classes differed in key dimensions regularly reported in recreational fisheries papers. Mean scores of individual items were compared among classes using standard ANOVAs and F-statistics as well as post-hoc tests (Tukey for homogenous variances, Dunnett T-3 for heterogeneous variances) using the SPSS software and were interpreted in terms of differences in specialization among the three latent classes.

3. Results

3.1. Model selection

The AIC weights revealed that a three-class model was by far the best supported model despite including a total of 188 parameters (Table 3). Therefore, we subsequently explored species-specific angler heterogeneity assuming three different angler types (Table 6).

Table 3
Model selection of the optimum number of angler types identified through a latent class choice model.

Model	AIC	Number of parameters	AIC weight
1-Class	24134.53	62	0%
2-Class	23660.06	125	0%
3-Class	**23500.92**	**188**	**100%**
4-Class	23597.13	251	0%
5-Class	23692.23	314	0%
6-Class	23813.44	377	0%
7-Class	23899.43	440	0%

When examining whether a linear or non-linear (quadratic or logarithmic) relationship of catch-qualities best described the choice data, model ranking based on AIC weights suggested that out of 14 different specifications for the utility function a model that relied on linear specifications for most attributes (all management attributes, composition of catch, crowding, trophy fish capture probability) except for catch rate (number of fish captured) and average size of the catch, both described by $\log_{10}$ functions, was most supported (Table 4).

Within these treatments, one attribute worth noting is that of catch composition. While it was described ordinally (almost entirely stocked fish, mostly stocked fish, mostly wild fish, almost entirely wild fish) to respondents in the survey, we settled on a model that specified catch composition as a single linear parameter (coded 0%, 33%, 66%, 100%). This choice improved model selection by reducing the number of degrees of freedom taken up by an attribute that remained insignificant for all species (Table 6). Indeed, removing it entirely from the model would likely lead to further improvements; however, as catch composition was included in our experimental design, it represented an explicit hypothesis that was tested in our choice experiment; albeit one whose result was negative. The attribute "catch composition" was thus left in the model, despite its lack of contribution to model fit.

3.2. Relationship of latent classes and angler specialization

Following model estimation, respondents were sorted according to their most (modal) probable latent class, and the resultant groups were compared. Class-1 anglers encompassed the largest segment (63.5%; s.e. = 1.1%, modal frequency = 879), followed by class-2 anglers (23.7%; s.e. = 1.0%, modal frequency = 288) and class-3 anglers (12.8%; s.e. = 0.7; modal frequency = 168). The three angler groups did not differ in age and history of club membership (Table 5). The three types, however, significantly differed from one another on characteristics related to catch orientation and specialization as well as satisfaction and measure of behavioural commitment (e.g., avidity). Class-1 and class-3 anglers exhibited the strongest centrality to fishing as a lifestyle and hence showed the largest commitment as the psychological subdimension of specialization, followed by class-2 anglers (Table 5). When examining class differences in the four subdimensions of catch orientation (catch something, catch large numbers of fish, catch large fishes, keep fish as harvest), all three angler classes expressed a statistically similar attitude towards the importance of numbers of fish captured and the size of fish that are captured (Table 5). However, class-2 anglers exhibited a significantly greater retention orientation compared to the other two anglers groups, and class-3 anglers revealed the least harvest-oriented (Table 5). Moreover, class 3 anglers showed the lowest degree of satisfaction and behavioural avidity (Table 5). Combined with the fact that class-2 anglers had a more pronounced preference for not fishing compared to the other two anglers groups in the utility model (Table 6), these findings supported the classification of class-2 anglers as least committed anglers among the three latent classes.

In terms of the choice preferences, class-1 anglers had the least

Table 4
Model selection to test whether a 3-class choice model was best described using linear or non-linear estimates for catch-related angling qualities. Note: Use of + indicates a second variable used to define an attribute in a linear quadratic function ($y = ax^2 + bx + C$). Use of the word "and" indicates an attribute was not specified by a linear term, but only by a $\log_{10}$ function ($y = \log_{10}[x]$). AIC weight represents the relative statistical support for a given model.

	AIC	Number of parameters	AIC weight
Categorical	24624.00	857	0%
Linear (all species-specific attributes) + categorical catch composition	23585.66	230	0%
Linear (all species-specific attributes)	23520.86	188	0%
Linear (all species-specific attributes) + quadratic (all species-specific attributes)	23773.85	356	0%
Linear (all species-specific attributes) + quadratic (all catch outcomes only)	23640.06	272	0%
Linear (all species-specific attributes) + quadratic (all management only)	23654.38	272	0%
Linear (all species-specific attributes) + quadratic (harvest regulations only)	23582.41	230	0%
Linear (all species-specific attributes) + quadratic (stocking regulations only)	23592.92	230	0%
Log_{10} (all species-specific attributes)	23772.90	356	0%
Linear (all management attributes) and $\log_{10}$ (all trip outcomes)	23540.26	188	0%
Linear (all management attributes, crowding) and $\log_{10}$ (all catch outcomes)	23510.97	188	0%
Linear (all management attributes, crowding, trophy catch probability) and $\log_{10}$ (average size and catch number)	**23500.92**	**188**	**68%**
Linear (all management attributes, crowding, trophy catch probability, catch number) and $\log_{10}$ (average size)	23517.79	188	0%
Linear (all management attributes, crowding, trophy catch probability, average size) and $\log_{10}$ (catch number)	23502.46	188	32%

aversion towards club fees, while class-3 anglers had a strong aversion towards it. Anglers of class 3 also preferred to fish elsewhere than in new angling club waters, indicating that these anglers were avid, but have limited interest to pay to enter yet another fishing club. Class-3 anglers also had the largest centrality to lifestyle index and the strongest aversion against "not fishing" of all angler types, indicating their strong attachment to angling (Table 6). Thus, anglers in class-3 were characterized as the most committed and specialized anglers in our sample, but with little interest in joining a new angling club (which was the context of the choice experiment). Class-1 anglers were in turn classified as moderately committed and specialized in between class-2 and class-3 anglers. Based on these findings, we will refer to the three angler classes in terms of level of commitment in the remainder of this paper: class 3 = most committed anglers, class 1 = moderately committed anglers, and class 2 = least committed anglers following the specialization framework. Overall, the data showed that preference heterogeneity estimated statistically based on a latent class framework was systematically related to angler specialization.

3.3. Preference heterogeneity for species-specific attributes of the fishing experience

The most committed class-3 anglers revealed 10 significant coefficients in the choice model compared to the other two angler groups (Table 6). However, none of the species-specific coefficients related to harvest regulations (minimum-length limit, daily bag limit), stocking (stocking frequency) or the composition of the catch in relation to whether the fish were natural or stocked were significant at $p < 0.05$. Although the signs of the coefficients for crowding were always negative, the crowding coefficient was only statistically significant when committed anglers targeted common carp. The greatest number of significant coefficients for class-3 anglers were revealed for size-related attributes, while none of the catch-rate coefficients were significant (Table 6). However, highly committed anglers targeting a range of species significantly benefited from large average sizes. This was the case when targeting eel, pike, zander and the "other fish" category, which involved small-bodied cyprinid coarse fish, tench and perch. Note that the increase in average sizes of these species non-linearly increased utility, indicating diminishing marginal returns of utility for an increase in average catch size. Additionally, the trophy catch probability of pike was linearly related to angler utility in the most committed angler class, but was not significant for the other species.

The intermediately committed class-1 anglers revealed the greatest amount of significant coefficients in the latent class model, in total 22 coefficients, suggesting these anglers have a more pronounced preference structure compared to the other two anglers groups (Table 6). As was the case in the most committed class-3 anglers, there were no significant coefficients in the harvest regulations, stocking frequency and composition of the catch for any of the target species. Similarly, the sign of the crowding attribute was consistently negative across all species, and it was significant in the case of targeting brown trout, carp, pike, zander and "other". The intermediately committed anglers also expressed utility gains in relation to catch-related angling qualities across a range of species, and both catch rate and size of fish played a role, depending on the species. Specifically, the utility of class-1 anglers non-linearly increased with an increase in catch numbers (i.e., catch rates) when targeting eel, zander and "other". Similarly, the utility increased non-linearly with diminishing marginal returns for increases in average size of the fish in the catch when targeting carp, eel, pike, rainbow trout, zander and "other". Finally, intermediately committed anglers received linear increases in utility for an increasing trophy catch probability when targeting carp and zander.

The least committed, more casual class-2 anglers showed the weakest expression of preferences for fishing attributes, overall only 5 coefficients in the choice model were significant (Table 6). Again, none of the significant coefficients were revealed for harvest regulation and stocking-related attributes. The same was true for catch rate (numbers of fish captured). Significant coefficients were revealed for one size-related aspect of the fishing experiences in one species in terms of diminishing marginal utility for average size of eel. Moreover, more crowded experiences were significantly negatively evaluated in targeted pike, although again all signs of the crowding coefficients were negative as in the other two angler types.

4. Discussion

4.1. Angler heterogeneity in preferences in systematically related to angler specialization

We found a choice model with preference heterogeneity for three latent classes to best describe the data. We also found taste heterogeneity to be systematically related to indicators of specialization. The three angler types not only differed in centrality to lifestyle (which is a well-accepted construct to differentiate anglers that differ in psychological attachment to the activity; Scott & Shafer, 2001; Beardmore et al., 2013), but also in their harvest orientation (which is systematically related to specialization, Bryan, 1977; Allen & Miranda, 1996; Oh & Ditton, 2006; Arlinghaus, 2007). In agreement with the specialization framework (Bryan, 1977), the least specialized anglers in class 2 (24% of total sample) were also the most harvest-oriented when judged by the retention subdimension of the catch orientation construct. It is well accepted in the literature that more specialized anglers

Table 5
Mean scores of selected angler characteristics related to angler specialization and consumptive orientation among three angler types, determined by the most probable latent class assignment for each respondent. Catch orientation and centrality to lifestyle statements use an agreement scale ranging from (1) strongly disagree to (5) strongly agree. Satisfaction also used a ten-point scale where 1 = very dissatisfied and 10 = very satisfied. Differences among angler classes were tested using an ANOVA (F-statistics) and post-hoc-tests, where similar letters indicated non-significant differences in mean scores (p > 0.05). Note that the sum of samples sizes is smaller than total sample size due to item non-response.

		Angler Type	N	Mean	Std. Error	F	p-value
Catch orientation	I go fishing to catch fish to eat.	Class 1[ab]	828	3.64	0.04	3.207	0.041
		Class 2[a]	283	3.75	0.07		
		Class 3[b]	145	3.42	0.12		
	The bigger the fish caught, the better the fishing day.	Class 1	824	3.29	0.04	0.801	0.449
		Class 2	282	3.27	0.07		
		Class 3	145	3.41	0.11		
	The greater the number of fish I catch, the happier I am.	Class 1	823	3.02	0.04	2.954	0.052
		Class 2	282	2.83	0.06		
		Class 3	146	3.02	0.09		
	I release most of the fish I catch.	Class 1[ab]	818	3.25	0.04	4.552	0.011
		Class 2[a]	282	3.01	0.08		
		Class 3[b]	144	3.31	0.11		
Centrality of fishing to lifestyle	Were I to stop fishing, I could lose a great many of my friends.	Class 1[ab]	839	2.13	0.04	6.979	0.001
		Class 2[a]	284	1.90	0.06		
		Class 3[b]	145	2.30	0.10		
	If I couldn't go fishing, I don't know what I would do instead.	Class 1[a]	835	2.05	0.04	12.819	< 0.001
		Class 2[b]	283	1.71	0.05		
		Class 3[a]	146	2.16	0.09		
	Due to my passion for angling, I have almost no time for other hobbies	Class 1[a]	832	2.16	0.04	23.224	< 0.001
		Class 2[b]	283	1.71	0.05		
		Class 3[a]	143	2.31	0.10		
	I came to know the majority of my friends through fishing.	Class 1[ab]	836	2.16	0.04	4.962	0.007
		Class 2[a]	284	1.95	0.06		
		Class 3[b]	146	2.23	0.09		
	I'd rather go fishing instead of doing something else.	Class 1[a]	832	2.82	0.04	24.712	< 0.001
		Class 2[b]	280	2.30	0.07		
		Class 3[a]	146	3.02	0.10		
	Other hobbies don't interest me as much as fishing.	Class 1[a]	837	2.84	0.05	28.609	< 0.001
		Class 2[b]	284	2.26	0.07		
		Class 3[a]	146	3.06	0.10		
	I find that a large part of my life revolves around angling.	Class 1[a]	837	2.55	0.04	21.525	< 0.001
		Class 2[b]	284	2.05	0.06		
		Class 3[a]	146	2.69	0.11		
Satisfaction	Angling year satisfaction 2012	Class 1[a]	845	5.22	0.07	7.819	< 0.001
		Class 2[a]	256	4.84	0.13		
		Class 3[b]	153	5.68	0.17		
	Catch satisfaction 2012	Class 1[b]	846	4.83	0.08	7.852	< 0.001
		Class 2[a]	259	4.34	0.14		
		Class 3[b]	153	5.17	0.17		
Behavioural commitment	Number of days fished in 2012	Class 1[a]	872	26.95	1.15	24.450	< 0.001
		Class 2[b]	281	12.90	1.21		
		Class 3[a]	157	29.51	2.31		
	Number of years of membership in fishing club	Class 1	787	19.87	0.482	0.678	0.508
		Class 2	268	20.57	0.799		
		Class 3	135	18.94	1.167		
Age	Age	Class 1	836	49.22	0.52	1.369	0.255
		Class 2	279	50.75	0.82		
		Class 3	147	48.70	1.18		

are more prone to voluntary catch-and-release angling (e.g., Bryan, 1977), although there are exceptions in some species that are culinarily prized (Wilde & Ditton, 1991, Dorow et al. 2000). The fact that the latent class models based on choice data (i.e., preferences) correlated with the angler's centrality-to-lifestyle and the related construct "retention orientation" – both dimensions were not part of the latent class modeling - is encouraging and shows that the sociopsychological construct of specialization has classificatory power for explaining preferences of anglers towards catch and non-catch dimensions of fishing (Beardmore et al., 2013).

Although there is still large uncertainty about how to operationalize specialization in anglers (Scott & Shafer, 2001), centrality-to-lifestyle has been identified as a robust specialization indicator for explaining variation in preferences in stated preference models with German anglers (Beardmore et al., 2013). Our work supports this conclusion in a latent class modeling framework. The fact that angler specialization relates to preferences helps develop a joint framework on which the mechanistic basis of angler preferences and behavior can be explained and linked to bio-economic models of angler-fish interactions (Johnston et al., 2010, 2018). Although the correlation of centrality to lifestyle and preferences is firmly established in the present and related work (e.g., Beardmore et al., 2013; Dorow et al., 2010), centrality to lifestyle is only one subdimension of psychological involvement of anglers with their hobby (Kyle et al., 2007). Future work may study alternative means for measuring the psychological attachment of anglers to fishing, and we suggest to test the predictive power of the modified involvement scale (Kyle et al., 2007) in future choice modeling applications because it was found that other involvement subdimension than centrality are better predictors of preferences for management measures in anglers (Schroeder et al., 2018).

4.2. Diminishing returns of catch-related angling qualities to angler utility

Fisheries managers are often interested in angler heterogeneity

Table 6
Results of a 3-class latent class preference model for fishing intentions of German anglers. Bold coefficients are statistically significant at $p < 0.05$. Wald statistics and associated p-values indicate the statistical significance of the attribute to the overall model. MSL = minimum-length limit, s.e. = standard error.

Model for Choices									
		Attributes	Class1	s.e.	Class2	s.e.	Class3	s.e.	Wald
Brook Trout	Intercept	Fish club waters	**1.460**	**0.087**	**0.828**	**0.160**	**1.881**	**0.258**	**681.199**
		Fish elsewhere	**−0.426**	**0.057**	**−0.915**	**0.095**	**0.345**	**0.167**	
		Not fish	**−1.034**	**0.071**	0.087	0.094	**−2.226**	**0.247**	
	Species Rank	most preferred	**0.093**	**0.034**	−0.007	0.079	−0.023	0.116	**25.257**
		second most preferred	0.063	0.035	0.077	0.075	0.167	0.105	
		third most preferred	−0.014	0.034	0.016	0.081	−0.102	0.121	
		fourth most preferred	**−0.142**	**0.036**	−0.086	0.081	−0.042	0.117	
	Club Fee	Linear	**−0.378**	**0.052**	**−0.962**	**0.095**	**−1.502**	**0.164**	**248.646**
	MSL	Linear	−0.171	0.384	−0.503	0.862	−0.836	1.298	1.003
	Bag Limit	Linear	−0.006	0.020	−0.009	0.045	0.067	0.065	1.161
	Stocking Frequency	Linear	0.038	0.180	0.132	0.446	0.622	0.668	1.045
	Catch Composition	Linear	0.001	0.184	−0.119	0.424	−0.011	0.682	0.080
	Crowding	Linear	**−0.045**	**0.018**	−0.062	0.045	−0.081	0.074	**9.599**
	Trophy Chance	Linear	0.013	0.021	0.021	0.048	−0.024	0.076	0.668
	Average Size	Log	0.533	0.481	0.620	1.155	2.319	1.818	3.298
	Number Caught	Log	0.165	0.102	0.303	0.224	0.490	0.373	6.592
Carp	MSL	Linear	−0.048	0.175	−0.312	0.409	−0.504	0.557	1.578
	Bag Limit	Linear	0.004	0.013	0.002	0.032	0.011	0.041	0.187
	Stocking Frequency	Linear	0.020	0.120	0.123	0.286	0.095	0.400	0.287
	Catch Composition	Linear	0.027	0.118	0.053	0.275	−0.010	0.392	0.093
	Crowding	Linear	**−0.034**	**0.012**	−0.055	0.031	**−0.085**	**0.042**	**15.882**
	Trophy Chance	Linear	**0.035**	**0.014**	0.020	0.032	0.067	0.041	**10.120**
	Average Size	Log	**1.514**	**0.419**	1.359	1.028	1.622	1.404	**16.831**
	Number Caught	Log	0.080	0.066	0.164	0.158	0.321	0.230	4.797
Eel	MSL	Linear	−0.229	0.173	−0.334	0.377	−0.291	0.513	3.021
	Bag Limit	Linear	0.013	0.013	0.016	0.029	0.047	0.038	2.937
	Stocking Frequency	Linear	0.060	0.117	0.107	0.265	−0.168	0.375	0.622
	Catch Composition	Linear	0.118	0.121	0.059	0.286	0.109	0.382	1.105
	Crowding	Linear	−0.023	0.012	−0.049	0.029	−0.063	0.040	**9.503**
	Trophy Chance	Linear	0.014	0.014	0.043	0.030	0.029	0.041	3.835
	Average Size	Log	**1.177**	**0.369**	**2.101**	**0.878**	**3.017**	**1.287**	**22.365**
	Number Caught	Log	**0.187**	**0.067**	0.137	0.158	0.172	0.207	**9.649**
Other	MSL	Linear	−0.237	0.323	0.372	0.749	0.079	1.100	0.758
	Bag Limit	Linear	0.000	0.002	−0.002	0.005	−0.005	0.007	0.696
	Stocking Frequency	Linear	0.024	0.126	−0.026	0.309	0.058	0.457	0.058
	Catch Composition	Linear	0.031	0.121	0.046	0.284	0.190	0.410	0.320
	Crowding	Linear	**−0.031**	**0.012**	−0.054	0.031	−0.062	0.045	**12.251**
	Trophy Chance	Linear	0.017	0.014	0.023	0.033	0.054	0.043	3.862
	Average Size	Log	**0.905**	**0.250**	1.141	0.602	**2.040**	**0.899**	**23.039**
	Number Caught	Log	**0.126**	**0.060**	0.040	0.141	0.295	0.204	6.949
Pike	MSL	Linear	−0.128	0.144	0.033	0.312	0.109	0.448	0.846
	Bag Limit	Linear	−0.004	0.013	−0.041	0.028	0.010	0.041	2.354
	Stocking Frequency	Linear	0.111	0.114	0.251	0.260	−0.083	0.404	1.973
	Catch Composition	Linear	0.055	0.113	0.057	0.249	−0.277	0.359	0.867
	Crowding	Linear	**−0.038**	**0.012**	**−0.060**	**0.027**	−0.061	0.040	**18.609**
	Trophy Chance	Linear	0.025	0.013	0.010	0.030	**0.091**	**0.038**	**9.507**
	Average Size	Log	**1.469**	**0.399**	1.753	0.940	**3.397**	**1.414**	**23.994**
	Number Caught	Log	0.095	0.064	0.123	0.143	0.103	0.204	3.359
Rainbow trout	MSL	Linear	−0.012	0.413	0.045	0.858	0.084	1.283	0.008
	Bag Limit	Linear	0.019	0.021	0.013	0.042	0.031	0.068	1.209
	Stocking Frequency	Linear	0.160	0.190	0.303	0.408	0.142	0.610	1.352
	Catch Composition	Linear	0.099	0.193	−0.060	0.430	0.494	0.606	0.965
	Crowding	Linear	−0.026	0.020	−0.032	0.040	−0.067	0.071	3.431
	Trophy Chance	Linear	0.013	0.022	0.033	0.046	−0.023	0.077	0.943
	Average Size	Log	**1.363**	**0.517**	1.524	1.134	1.410	1.702	**9.818**
	Number Caught	Log	0.135	0.106	0.201	0.218	0.167	0.354	2.887
Zander	MSL	Linear	0.157	0.180	−0.148	0.367	0.628	0.553	2.287
	Bag Limit	Linear	0.004	0.013	−0.006	0.029	−0.010	0.045	0.156
	Stocking Frequency	Linear	0.115	0.120	0.169	0.267	0.040	0.404	1.393
	Catch Composition	Linear	0.121	0.120	0.310	0.264	0.283	0.364	3.192
	Crowding	Linear	**−0.030**	**0.012**	−0.028	0.027	−0.058	0.042	**9.984**
	Trophy Chance	Linear	**0.049**	**0.013**	0.017	0.029	0.020	0.042	**14.022**
	Average Size	Log	**1.629**	**0.386**	1.449	0.893	**2.851**	**1.321**	**26.129**
	Number Caught	Log	**0.162**	**0.067**	0.103	0.152	0.325	0.210	**9.241**
Model for Classes			Class1	s.e.	Class2	s.e.	Class3	s.e.	Wald
		Intercept (α_{nl})	**0.863**	**0.067**	−0.124	0.083	**−0.739**	**0.101**	164.805

because variation in preferences for salient fishery attributes affects decisions to fish and reactions to management interventions (Johnston et al., 2010; Massey, Newbold, & Gentner, 2006; Fenichel et al., 2013; Lee, Steinback, & Wallmo, 2017, Carruthers et al. 2019, Matsumura et al. 2019). When integrated models of fish-angler interactions are constructed, it is decisive whether the modeler assumes angler utility increases linearly or non-linearly at diminishing marginal returns with catch metrics (e.g., catch rate) (Camp et al., 2013; Johnston et al., 2018). We confronted our latent class model in an information theoretic approach to assumptions about linear and non-linear relationships of utility with catch attributes related to both catch rates and size. The best supported model suggested that catch rates and average size of fish non-linearly related to angler utility in a three class latent class model, indicating diminishing marginal utility returns to improved catch outcomes. By contrast, the trophy fish catch probability was found to linearily relate to catch prospects of exceptionally large fishes. Although the species-specific coefficients were not always significant for the examined catch attributes and also varied in importance among species and angler classes, the catch-related attributes belonged to the group of attributes that was most consistently significant, particularly in the more committed angler types. This finding suggests that catch matters consistently and importantly across different angler types. However, we also found that catch rate was never significant for the utility of the most committed class-3 anglers, while size of fish was more important in selected fish species. By contrast, the moderately committed class-1 anglers benefit from both catch rate and size of fish, indicating that increasing commitment increases the relevance of size of fish in the catch and decreases the importance of high catch rates.

The fact that diminishing marginal returns were revealed for several species-specific catch rate and average size attributes, but not for trophy catch probability, can be explained based on economic theory and the rarity effect of a good on demand. Catch rate and average size of a fish are regular fishing experience components, while the probability of catching a trophy fish is a rare event. Consequently, the utility gain from increasing units of catch rates or incremental changes in the average size of the catch should decline, while no such ceiling in utility gain is to be expected for anglers catching rare trophies. Our choice data agree with this assumption and they also agree with a previous satisfaction study using diaries that also revealed diminishing marginal returns in angler satisfaction for catch rate, but not for trophy catch, across a wide range of freshwater species in Germany (Beardmore et al., 2015). Importantly, Beardmore et al. (2015) also revealed variation in satisfaction expressed by anglers of different specialization degree. Similarly, in our work, the species-specific coefficients for the catch-related attributes were not consistently significant across species for a particular angler group, and in agreement with other choice models from Germany (Dorow et al., 2010) and Irish fisheries (Curtis, 2018) they also varied in strength and significance across angler types and species. Therefore, although we believe that diminishing marginal returns of utility for increasing catch rate and linear or even accelerating increases in utility with trophy fish catch should be the norm in recreational fisheries, important angler heterogeneity and species-specific effects precludes us from overgeneralizing across species and angler types.

4.3. Catch preferences and aversion to crowding

Our study shows that despite relevant variation in preferences, there were also some experience attributes where anglers of all three types showed consistent preferences in terms of direction and shape of the utility functions across most species or species groups we examined. However, again, caution is raised in generalizing as the preference coefficients for catch attributes were not always and not consistently significant. However, across all freshwater fish species, at least one of the three angler groups consistently received positive utility from either high catch rates and from the catch of larger fishes and disutility from crowding. There was also a consistently negative sign of the crowding attribute, although it was not always significant, and the three angler types also showed significant preferences for both the intercept (importance of fishing vs. not fishing) and costs (expressed as club fees). The overwhelming importance of cost, catch-related fishing quality (depending on species and angler type either catch related or size related or both) and to a lesser degree crowding is a consistent finding in the fishing preference and angler satisfaction literature (e.g., Beardmore et al., 2015; Curtis, 2018; Dabrowska et al. 2017; Dorow et al., 2010). However, there are selected fisheries where crowding does not produce negative utility, e.g., when engaging in fishing competitions for small-bodied cyprinid so-called coarse fish (Beardmore et al., 2015, Deely et al. 2019). The existence of angler heterogeneity in preferences where some angler desire solitude and other company likely contributed to the fact that the crowding attribute was less often significant across target species than the catch-related attributes. Importantly, however, it was the two more committed angler types that expressed more pronounced, nuanced (and more often significant) preferences in relation to both catch-related angling qualities and crowding compared to the least committed casual angler. This is understandable given the dedication of the more committed angler types to fishing, which is then expressed in more pronounced preferences. The data, however, also strongly reject the idea that more committed anglers are less catch-oriented, confirming earlier motivation research (Ditton et al., 1992). In fact, our data indicate that more committed anglers are more catch oriented than casual anglers, with the highest committed anglers focusing particularly on size of fish and not on catch rate – a finding also reported in motivation research that accounted for contextual conditions (such as species choice, Beardmore et al., 2011) similar to our approach. Hence, if catch conditions deteriorate, based on our work and related studies in similar species or species groups (e.g., Deely et al. 2019; Curtis, 2018) and other choice models from the German fishing culture (Beardmore et al., 2013; Dorow et al., 2010), we predict that in particular the more committed (and hence specialized) anglers will feel utility loss and in response either move to alternative fisheries or become political advocates to change regulations, with the most committed anglers responding strongest to declines in size of fish and the catch prospects of trophies. By contrast, based on the much less pronounced preference structure, we would expect mild or no reaction by casual anglers to declining catch prospects. The lack of significant utility coefficients in this angler group may also stem from the fact the sample size was lower than in the moderately committed angler group (*sensu* Curtis, 2018).

It is interesting that all anglers preferred on average larger fishes based on the sign of the coefficients, but the preferences for a high probability of catching trophies (i.e., exceptionally large fishes) was much less consistent, less often significant within angler groups and across species and generally more variable across species and angler types. The most committed class-3 anglers were an exception to this rule. The same was reported from Irish pike and trout anglers (Curtis, 2018), where some angler types received utility from size of fishes and others not. In our study, in a selected set of large-bodied species (e.g., common carp, pike, zander), the more specialized anglers received significant utility of trophy catch, which agreed with qualitative insights from specialization theory (Allen & Miranda, 1996; Bryan, 1977), other choice experiments (Dabrowska et al. 2017) and models (Johnston et al., 2010). Importantly and perhaps surprisingly, there were species-specific cases where the more specialized anglers did not receive relatively more utility from a high probability of catching a trophy (e.g., trout species, “other”), while the difference in utility gained from trophies relative to less specialized anglers was strongly pronounced in species such as carp, zander and pike. Consistent with our work, German tourist anglers in Denmark were classified into three latent classes in a stated preference survey, and only one of the three placed a high premium on trophy fish (“trophy anglers”), while two other segments cared about other catch aspects (“catch oriented”) or were predominantly about the setting aspects of the experience ("nature oriented"; Bonnichsen, Lensen, & Olsen, 2016). Thus, although all anglers seem to prefer to catch on average large fish, this preference does not carry over to a consistent preference for exceptional, rare trophy fish, which seems to be most strongly expressed in the most specialized anglers when targeting selected species. This finding supports the practical experience that a discourse around trophy fish is often related to specific species, e.g., pike and common carp in Germany (Arlinghaus, 2007), and less so towards other species, such as eel, trout or tench.

4.4. Harvest regulations, stocking and preference for wild fish as opposed to stocked fishes

We did not detect a single significant coefficient in relation to preferences for harvest regulations, stocking frequency and the presence of wild as opposed to stocked fishes in any of the three angler types. This finding either indicates that there are no systematic and consistent preferences towards these management tools or catch outcomes or that preferences towards these tools maybe captured by preferences for catch attributes (Arlinghaus et al., 2014). For example, after accounting for catch attributes there was very little intrinsic preference for stocking in this study, similar to earlier reports that did not account for angler heterogeneity (Arlinghaus et al., 2014). Therefore, strong pro-stocking attitudes found in opinion surveys in Germany (e.g., Arlinghaus & Mehner, 2005) are likely driven by the functional belief that stocking is needed to maintain catch rates, but such preferences do not express an intrinsic preference for stocking per se (in contrast to assumptions of Camp, Lorenzen, Ahrens, Barbieri, & Leber, 2013, see Arlinghaus et al., 2014 for a detailed discussion). It is very likely, however, that smaller subgroups of anglers exist in the German population that carry a preference for wild over hatchery fish. In particular in salmonids, highly specialized anglers have repeatedly been documented to exert a preference for wild over stocked fishes (e.g., Andersen & Lee 2013 Bryan, 1977; Olaussen & Liu, 2011). These anglers are often dedicated fly fishers that are able to discriminate stocked from wild fishes. Fly fishers are rare in the north-western German fishing environment (due to the lack of suitable river systems hosting abundant wild trout stocks) and they were likely so rare that their typically well expressed preferences for wild fishes did not emerge as a separate latent class in our study. Our results and related work by Arlinghaus et al. (2014) should thus not be misread to suggest that German anglers in general do not care about wild fish in their catch. One reason for the lack of preferences in our study is that it is virtually impossible to discriminate wild and hatchery fish in a range of species other than stocked salmonids (where fin erosion can be identified visually), and it is also standard practice to stock small water bodies regularly and annually with fish (Teisi et al., 1996). Therefore, anglers may actually believe that most of their catch is hatchery-based in north-western Germany, which may have contributed to preventing the development of a pro-wild-fish preference.

The lack of significant coefficients for both minimum-length limits and daily bag limits in our work is more difficult to explain. A wealth of previous work has shown that selected angler groups have very pronounced preferences for harvest and other fish stock management tools (e.g., Curtis, 2018; Dabrowska et al. 2017; Dorow et al., 2010), and repeatedly revealed data have shown that consumptive anglers strongly react to constrained harvesting opportunities (e.g., Beard, Rasmussen, Cox, & Carpenter, 2003; Johnston, Arlinghaus, Stelfox, & Post, 2011). Reasons for the lack of significant coefficients in our work either relate to the fact that other attributes with more consistent preferences (e.g., catch or cost) were dominating the latent class model building or that the use of too many attributes in the choice task prevented the anglers from paying careful attention to the catch-retention trade-off introduced through the harvest regulations. Earlier single-species choice models in selected species also presented in our choice model, such as eel in Germany, showed that differently specialized angler groups strongly differ in preferences towards harvest regulations (Dorow et al., 2010) – a finding not recovered in our work, e.g. for eel. One possible reason is simply insufficient sample size coupled with substantial within class heterogeneity in preferences for harvesting regulations. For example, it has previously been found that highly specialized trout anglers cluster in subgroups that are either strongly harvest oriented or not interested in harvest at all (Hutt & Bettoli, 2007). Such heterogeneity would in turn prevent preferences to turn out significant. Although we used a large sample size, probably even larger samples are needed to fully capture heterogeneity in harvest regulations that is mostly likely present in smaller subgroups than those recovered in our choice model. It is highly unlikely that all anglers in north-western Germany are indifferent towards harvest regulations, but the more committed angler types may indeed be because they engage in voluntary catch-and-release to a great extend (Arlinghaus, 2007) and thus do not receive disutility from constrained harvesting.

4.5. Methodological limitations

"All models are wrong, but some are useful" (Box, 1976) is a common aphorism among statisticians. We confined our search for angler heterogeneity to a latent class approach, but we do not claim this is the best model to identify preference heterogeneity. For example, Dabrowska et al. (2017) showed that random parameter logit models outperform latent class models when explaining both inter and intra angler heterogeneity in preferences. It is an empirical question to understand which model type is best able to capture angler heterogeneity. We choose to focus on the latent class approach for convenience because the resulting models can be readily interfaced with fish population models. Further work is needed to account for contextual factors in understanding angler heterogeneity because it is very likely that a range of contexts (e.g., whether multiple day trips or single day trips are chosen) affect the preferences of anglers (Dabrowska et al. 2017). Our study provides, in a single choice experiment, a high-level examination of angler preferences across a diverse fishery landscape. Practitioners who focus rests on a single species fishery may thus find our model less useful than one specific to their focus. As an example, substantial heterogeneity likely exists in preference regulations for pike, but we did not have enough pike/pike comparisons to adequately capture it. This limitation is evident in the selection of a three class model, whose parameters differed only on general aspects related to fishing participation. Given that each respondent was provided only species options that they were known to pursue, we could not capture information about an important subset of species for each angler, namely those that they dislike. A final limitation relates to the fact that we only tested $\log_{10}$ functional forms in our models on linear vs. non-linear relations, and other functional forms may perform equally well or better. Further work is thus warranted to improve our understanding of angler heterogeneity and how different angler types trade-off attributes they desire and those they dislike. There is certainly also room for testing alternative choice model to a utility maximization approach, e.g. random regret or satisficing models should be tested in the future.

5. Conclusions

Our research revealed the presence of substantial angler heterogeneity and that preferences for a range of fishing attributes were systematically related to angler specialization. We also showed that catch rates and average sizes of fish showed diminishing marginal returns to angler utility, while trophy catch prospects did not. Finally, we showed that cost, catch-related qualities and crowing revealed more consistent and more often significant coefficients compared to harvest regulations and stocking attributes in our sample, but the details differed strongly by angler type and target species preventing generalizations. Managers can use the information presented in this paper to understand how different anglers will likely react to changes in a fishery induced by natural, fishing or regulatory factors. In particular, based on our work the more specialized angler types are likely to be most strongly affected by reductions in average size and trophy size of fish, particularly in large-bodied species such as carp, pike and zander. However, the degree of utility loss will depend on the benchmark against which a change in catch prospects is judged, corresponding with our finding of diminishing marginal utility loss in relation to catch rates and sizes of fish. Finally, the details on how anglers will respond to changes in a fishery are a function of the angler type and the target species, preventing clear-cut generalizations and demanding an angler-type and species-specific focus in management (Beardmore et al., 2015).

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