Appendix I

**Ecological, angler and spatial heterogeneity drive social and ecological outcomes in an integrated landscape model of freshwater recreational fisheries**

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## Estimating a generic utility model for anglers

Most previous revealed or stated preferences models of anglers were directed at a particular target species (e.g., Oh and Ditton, 2006; Dorow et al., 2010). Beardmore et al. (2013) presented a substantial innovation by generating stated choice data from a sample of anglers in northeastern Germany that exploited various fish species, including pike. However, different species differ in catch rates and other units of interest (e.g., size dimension), which complicates the standardized estimation of the relative importance of selected attributes across a range of species for angler choice. Beardmore et al. (2013) found a way of tailoring a stated preference discrete choice experiment to a random sample of anglers for which a previous diary survey indicated target species and variation in catch rates and captured sizes to be expected across species by individual respondents. The very same anglers were then confronted in a second survey with a stated choice experiment tailored to their specific target species, where the variation in levels of attributes describing choice option were made species independent by drawing levels for attributes such as catch rates or fish sizes in a standardized fashion across species, thereby varying levels in a comparable way related to species-specifics means and standard deviations for attributes of interest. Thereby, the model generated species-independent estimates of the so-called part worth utilities of different attributes known to be important to anglers, both catch- and non-catch related. This is the most general representation of angler behaviour published so far and hence was chosen for the present study. These preferences were used to simulate angler behaviour *in silico*.

In the choice experiment described in detail in Beardmore et al. (2013), randomly selected anglers drawn from fishing license holders in the state of Mecklenburg-Vorpommern (M-V) were presented with a set of hypothetical angling experiences composed of several attributes including target fish species, licence cost, distance to the lake, catch number per trip (catch rate), average and maximum size of catch, number of anglers seen a measure of crowding, minimum-length limit, daily bag limit and stock status. Each attribute was systematically varied to allow estimation of preferences for varying attribute levels. For each

choice set, anglers were asked to allocate 10 days among six alternatives: four angling places in the region (i.e., M-V), angling outside the region, and no angling. Besides discrete choice tests, anglers were asked to answer a questionnaire concerning their angling activities during the last twelve months as well as their attitudes towards angling. Random utility theory (McFadden, 1973) assumes that individuals choose one alternative to another to maximize their utility, and the utility of one alternative is a function of its components, i.e., attributes (e.g., expected catch rate) and attribute levels (e.g., different catch rate levels). Based on the observed allocation of days among alternatives, the part-worth utility (PWU, a measure of importance) was estimated for attributes and attribute levels, i.e., the contributions of each attribute and attribute level to the overall utility of the alternative to the angler. The PWU for each attribute was assumed to be a linear function of attribute levels, and estimated the coefficient of the linear function similar to Beardmore et al. (2013). For further details of the choice experiment and its theoretical background, see Beardmore et al. (2013).

## Recreation specialization theory: a framework for understanding angler heterogeneity

Human dimensions researchers have long recognized that the "average angler" does not exist (Shafer, 1969; Aas and Ditton, 1998). In his seminal paper on recreation specialization, Bryan (1977) observed "a continuum of behaviour from the general to the particular, reflected by equipment and skills used in the sport and activity setting preferences" (p. 175) in American trout anglers, concluding that anglers may be grouped into types that share specific values, beliefs, attitudes and behaviours. While conceptualizations of specialization posited that as one gains experience in a recreational activity, one also becomes more emotionally involved or "specialized" (Ditton et al., 1992); however, the notion of clear predictable stages in an angling career being correlated with degree of specialization has been challenged (Scott and Shafer, 2001). That said, specialization is a multidimensional concept (Ditton et al., 1992), with clear correlates related to affective, cognitive and behavioural measures of attachment to the activity (Scott and Shafer, 2001). These measures reflect the degree to which one self-identifies with the activity (Scott and Shafer, 2001), one's dedication to the values and norms of the social world of angling (Buchanan, 1985; Ditton et al., 1992), one's level of expertise (Salz and Loomis, 2005), and one's investment of time, money, and other resources to the activity (Ditton et al., 1992). While these three dimensions form the core of specialization theory, Bryan's (1977) observation also relies on observations of heterogeneous "activity setting" preferences. Preference can be defined as an evaluative judgment in the sense of liking or disliking an object or outcome (Scherer, 2005). Thus, specialized anglers may also be differentiated from one another by their individual preferences for certain fishing

experiences to the exclusion of others. For example, in some fisheries, specialization may be associated with a shift in catch orientation (Graefe, 1980; Fedler and Ditton, 1986; Anderson et al., 2007) from a focus on number of fish towards size of fish; and/or a tendency to release more fish (Bryan, 1977; Salz and Loomis, 2005). In this sense, the concept of specialization may be applied to any segmentation of anglers based on preferences for particular fishing experiences. For example, one may refer to the "fly fisherman" (Bryan, 1977) or "specialized carp angler" (Arlinghaus and Mehner, 2003) as technique or species specialists, or the "trophy angler" (Arterburn et al., 2002) as someone whose behavior is primarily motivated by the outcome of catching a large fish (Fedler and Ditton, 1986, p. 198). While such species-, technique- or outcome- specific preferences may not be fully resolved using the generic model of angler preferences used in this study, specialization still provides a rich conceptual framework for incorporating angler heterogeneity into an examination of social-ecological interactions. Latent class modelling (see main text) applied to the utility data was used to identify classes of anglers and investigated whether the angler types followed specialization levels.

One challenge associated with latent class analysis is that the probabilistic nature of the class assignment does not necessarily provide a clear picture of the archetypal member of each class (Beardmore et al., 2013). Examining the angler types identified by latent class analysis through the lens of recreation specialization, however, provided some insights that aided in this regard. For ease of understanding, Table S1 presents a qualitative rating of the relative PWU values among the four angler types for attributes included in the choice experiment, along with other indicators of specialization taken from the surveys, interviews and diaries completed by study participants (for details, see Dorow and Arlinghaus, 2011; Beardmore et al., 2013).

Type 1 anglers were the least likely to choose choice alternatives other than fishing in the study region. They were the least averse to paying high license fees, as well as the most accepting of high travel distances to get to fishing destinations within the region. They were the most tolerant of fishing in sight of other anglers, and strict regulations. This group also derived the least utility from the number of fish harvested. The commitment to fishing under less than ideal conditions demonstrated by this group was consistent with their tendency to score highly on a centrality to lifestyle index (measuring the degree to which fishing is a core aspect of their identity and lifestyle, data not shown here), their self-assessment of their fishing skill level, and their financial and travel investments into fishing in the region. These anglers therefore were considered to be highly specialized, fitting the label of "Committed

anglers".

Type 2 anglers and Type 3 anglers represented incremental decreases in specialization, with each of these types more likely to opt out of fishing the last. Of note is the apparently increasing importance of catch outcomes among these groups, indicating that perceptions of high fishing quality are necessary to overcome the propensity to pursue non-fishing activities. Type 2 and Type 3 anglers were therefore considered to exhibit moderate and low specialization levels, respectively, fitting the labels of active and casual anglers.

While the first three angler types represent a specialization continuum from committed to casual in their preferences and commitment to angling in the study region, Type 4 anglers presented a different breed. In their choice responses, Type 4 anglers demonstrated a strong preference for fishing outside the region, showed a medium aversion to license costs and travel within the region. They derived higher utility from larger fish. They considered themselves to be more skilled on average than did the other groups, but were similar to Type 2 in their centrality to lifestyle. On average they tended to travel farthest to fish, while paying less than other anglers for their regional licenses. On the other hand, they had the highest average investment in fishing equipment. On the whole, Type 4 anglers appeared less invested in fishing freshwaters in Mecklenburg-Vorpommern; however, their commitment to fishing extended beyond the borders of the state with substantial investments in time and money to pursue their fishing activities. Consequently, one should consider these anglers as highly specialized (similar to Type 1 anglers) but with a greater emphasis on fishing elsewhere than in the study region.

## Calibration of the mechanistic angler model

The original choice model presented the levels of some attributes (in particular catch rates, the size of fish captured and the angler numbers seen while fishing) in a standardized and personalized fashion to remove scale and units issues different among species (Beardmore et al., 2013). This was done by varying the levels of the mentioned attributes around a species specific distribution in units of SD so that choice sets presented to respondents for species A and species B varied in the same fashion along species-specific characteristics (e.g., the same SD change in length of fish captured when a pike scenario was evaluated compared to a perch scenario, for example). To find means and SDs for the attributes Fish number, Maximum size, and Angler seen in the simulated virtual landscape and allow the calibration of Beardmore et al.'s (2013) model, initial simulations were run assuming that anglers are distributed across the lakes to achieve the maximum sustainable yield (MSY) of any one population. The

resulting distribution of the three attribute levels at equilibrium across lakes were used to define the expected variation in the virtual landscape at optimal conditions and to compute means and SDs so that variation in catch rate, size and crowding all exerted effect on utility, and hence on lake choice.

For application of the choice model to the simulated landscape, the originally estimated linear PWU function for the utility effect of catch rates (fish numbers, Table S1) was modified. This was done because during preliminary simulations using the original functions given by Beardmore et al. (2013), anglers also visited lakes where catch rates are zero. This unreasonable outcome arouse from the fact that the original stated preference choice experiment did not include extremely low catch levels by design. Moreover, the extreme nonlinearities of the PWU function for fish catch reported in subsequent work by Arlinghaus et al. (2014) (i.e., infinitely low utility of zero catch and marginal diminishing returns as catch rates close some threshold level of one to two fish per day) could not be approximated by the original linear function fitted through five catch levels in the experiment by Beardmore et al. (2013). To avoid systematically overestimating the number of anglers at lakes present at even extremely low catch rates, logarithmic functions were re-fitted as

$$PWU(x) = \log_{\gamma_1}(x + \gamma_2) + \gamma_3$$

through the PWU values predicted by the original functions at five levels of expected catch rates ($x$), that is, $\mu - 2.63\sigma$, $\mu - 0.5\sigma$, $\mu$, $\mu + 1.0\sigma$, and $\mu + 3.76\sigma$, where $\mu$ and $\sigma$ represent the mean and SD for catch rates at MSY, respectively. The first and last values correspond to actual catch rates that are zero and the maximum number of catch rates per angler possible in the region, respectively. Note that catch rate was standardized before calculating PWU, so the mean of the standardized catch rate is zero and the absolutely zero value for catch rate is negative on the standardized curve (Fig. S1). The PWU at the point of actual zero catch rate was determined to achieve a low probability of fishing of 6.3% when PWUs of all other attributes are zero. The probability value (6.3%) was chosen corresponding with angler diary data from anglers in M-V; it corresponds to the average percentage of trips taken by anglers who had average daily catch rates of zero. The modified functions are shown in Fig. S1, and the values of parameters $\gamma_1$, $\gamma_2$, and $\gamma_3$ are reported in Table S1. The functional form agreed with the diminishing marginal return of utility of catch rate expected from economic theory and reported for German anglers elsewhere (Arlinghaus et al. 2014). In Fig. S1 you can also see variation in angler types in how utility of catch rate changes with increasing catch.

Regulation-related attributes in Beardmore et al. (2013) were also modified. The

original attributes "Minimum-size limit" and "Daily bag limit" were combined into a single attribute "Regulations", and was estimated parameter values of the new PWU function.

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Table S1. Relative utility values across angler types and indicator variables associated with for classification by recreation specialization assessed from the choice model (see main text) and a qualitative assessment of differences among anglers in additional variables (cognitive and affective as well as behaviour) taken from the survey data (for details see Beardmore et al., 2013).

| | **Type 1** | **Type 2** | **Type 3** | **Type 4** |
|---|---|---|---|---|
| **Attribute** | | | | |
| Propensity to Fish | High (in region) | Medium | Low | High (Elsewhere) |
| Cost aversion | Very Low | Low | High | Medium |
| Travel aversion | Low | High | Very High | Medium |
| Utility from fish harvested | Low | Medium | High | Medium |
| Utility from max. size | Medium | Medium | Medium | High |
| Congestion aversion | Very Low | Medium | Low | Medium |
| Overfishing aversion | High | High | Medium | High |
| Regulation aversion | Low | Medium | High | Medium |
| **Cognitive and Affective commitment** | | | | |
| Centrality to lifestyle (affective) | High | Medium | Low | Medium |
| Self-rated angling skill (cognitive) | Medium-High | Medium | Low | High |
| **Behavioral commitment** | | | | |
| Average travel distance | High | Medium | Low | Very high |
| License expenditures in MV | High | High | Medium | Low |
| Average trips targeting pike (per year) | 4.3 | 4.3 | 3.6 | 3.3 |
| Equipment value (Euro) | 1520 | 1120 | 913 | 1834 |
| **Specialization label** | **Committed (in region)** | **Active** | **Casual** | **Committed (elsewhere)** |

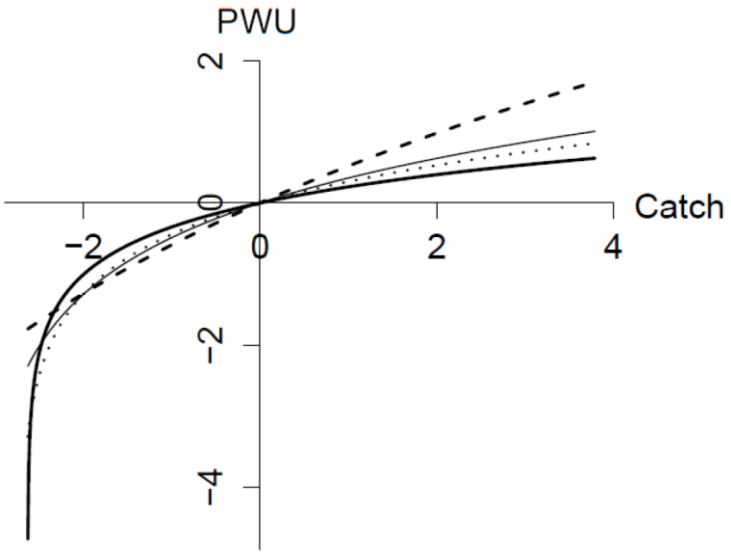


Fig. S1. Modified part worth utility (PWU) functions for standardized catch rate. The smallest value of the standardized catch rate corresponds to zero catch. Thick, dotted, dashed and thin lines correspond to the type 1, 2, 3, and 4 angler classes (Table S1), respectively.