Fisheries Research 110 (2011) 136–148

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

The elasticity of fishing effort response and harvest outcomes to altered regulatory policies in eel (*Anguilla anguilla*) recreational angling

Ben Beardmore[a,b,*], Malte Dorow[b,c], Wolfgang Haider[a], Robert Arlinghaus[b,d]

[a] School of Resource and Environmental Management, Simon Fraser University, 8888 University Drive, Burnaby, BC V5A1S6, Canada
[b] Department of Biology and Ecology of Fishes, Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Müggelseedamm 310, 12587 Berlin, Germany
[c] Institute for Fisheries, State Research Center Mecklenburg–Vorpommern for Agriculture and Fishery, Fischerweg 408, 18069 Rostock, Germany
[d] Inland Fisheries Management Laboratory, Department for Crop and Animal Sciences, Faculty of Agriculture and Horticulture, Humboldt-University of Berlin, Philippstrasse 13, Haus 7, 10115 Berlin, Germany

ARTICLE INFO

Article history:
Received 9 June 2010
Received in revised form 23 March 2011
Accepted 28 March 2011

Keywords:
Bag limit
Discrete choice experiment
Effort allocation
Minimum-size limit
Recreational fisheries
Substitution
Temporal closure

ABSTRACT

Understanding how fishing effort responds to management interventions is important for conserving threatened fisheries resources such as the European eel (*Anguilla anguilla*). In this paper, we use a discrete choice survey to predict the allocation of recreational angling days directed at eel versus potential substitute fishing opportunities in northern Germany as a function of eel angling regulations, catch attributes and hypothetical eel fishing costs. We found the allocation model to accurately predict current eel effort allocation patterns. Using the validated statistical model as a forecasting tool, we found eel angling effort to be largely resilient to changes in individual eel angling regulations, including daily bag limits, daily rod limits and fishery closures for up to two weeks each month. An inelastic effort response to the most commonly discussed policy interventions suggests that managers cannot expect to substantially reduce eel fishing effort, and thus mortality exerted by anglers on eel, using moderate management interventions. However, when severe regulations, including a two week closure per month, with remaining days limited to a harvest of 1 eel, 60 cm or larger, per angler using a single rod, would be implemented, angling effort devoted to eel can be expected to be reduced by about 42% relative to current conditions at unaltered expected catches. This would reduce landings of eel by anglers by 73%. This reduction in landings has unknown effects on the future recruitment of eel while at the same time substantially reducing angler welfare. Angler welfare can be largely maintained by increases in minimum-size limits and reductions in daily bag limits, while at the same time reducing eel landings by anglers substantially. Such actions are therefore preferred from an angler welfare perspective.

1. Introduction

Recreational fisheries constitute the dominant use of wild fish stocks in all freshwater and many coastal zones in all industrialized nations (Arlinghaus et al., 2002; Arlinghaus and Cooke, 2009). When fisheries resources become scarce, recreational angling effort, and the mortality it induces on fish populations, may need to be regulated (Post et al., 2002; Lewin et al., 2006). Any form of effective planning of recreational fishing regulations, however, necessitates understanding of anglers' behavioural responses to new regulations because almost inevitably changes in regulations change the attractiveness of a given fishing opportunity to anglers (e.g., Radomski and Goeman, 1996; Johnston et al., 2010; Metcalf et al., 2010). Anglers may respond to a suite of changes in the fishing experience (e.g., type of regulation in place, catch rates, size of fish, crowding) by (i) changing angling frequency, (ii) substituting alternative sites, or (iii) substituting other species to target (e.g., Post et al., 2002; Beard et al., 2003; Ditton and Sutton, 2004). When angler behaviour does not align with regulatory objectives, management policies may fail (Pierce and Tomcko, 1998; Cox et al., 2002; Sullivan, 2003). Therefore, it is important to understand angler behaviour when designing management regulations for a particular fishery or fish species. However, little human dimensions research is available on this topic so far (Radomski et al., 2001; Johnston et al., 2010).

Choosing the right fishing regulation to meet stated management objectives is a hotly disputed topic in recreational fisheries, with contrasting opinions occurring because regulations differ in their biological and social effects (e.g., Radomski et al., 2001; Paukert et al., 2001; Arlinghaus, 2007). For example, daily bag limits may fail to meet management objectives to reduce fishing mortality, because they do not necessarily curtail total angling effort on a given fishery (Radomski et al., 2001). One line of argu-

* Corresponding author at: Center for Limnology, University of Wisconsin, 680 North Park St, Madison, WI 53706, USA. Tel.: +1 608 262 3014.
E-mail address: abeardmore@wisc.edu (B. Beardmore).

0165-7836/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.fishres.2011.03.023

ment advocates more active management of angling effort rather than reliance on traditional output-oriented harvest regulations (e.g., daily bag limits or size-based harvest limits), and stock-enhancement tools (i.e., stocking practices) (Cox and Walters, 2002; Pereira and Hansen, 2003). Managers tasked with the responsibility of limiting recreational fishery harvests are then faced with the issue of predicting the biological effects of regulatory changes. One important component of this context is answering a critical social scientific question: how do changes in angling regulations and catch quality impact angling frequency for a certain fish species in the future? This question may be rephrased in economic terms (Case and Fair, 1999): how elastic is the angling demand (i.e., angling effort) to changes in the fishing environment?

Previous studies examining angling effort responses to altered fishery conditions have reported conflicting findings, with angling effort either decreasing strongly (Beard et al., 2003) or remaining largely unaltered despite changes in the fishing environment (Prayaga et al., 2010). Inelastic angling effort responses to changes in regulations or other attributes of the fishing experience are most likely to occur when few substitute species or locations are available, as in fisheries-sparse landscapes, or for species that have largely unique qualities. One such species is the European eel (*Anguilla anguilla*), which is highly valued by recreational anglers for its consumptive qualities in central and western Europe where no other fish species share similar culinary characteristics (Dorow et al., 2009, 2010). Eel anglers in these regions may therefore be either largely unresponsive to changing eel harvest regulations due to a lack of available substitutes or they may react strongly to additional constraints on harvesting possibilities.

As with eel populations worldwide, the European eel population has declined dramatically. Current recruitment levels have fallen to less than 10% of the average value recorded between 1970 and 1994 (ICES, 2008), and the stakes are particularly high, given that the species comprises a single panmictic population (Dannewitz et al., 2005) and the fishery is of great socio-economic importance throughout Europe (Dorow et al., 2009, 2010). Understanding angler effort responses to altered regulations for eel is thus particularly important for this species (Feunteun, 2002; Dekker, 2008). A range of potential causes for the eel decline affecting both the oceanic and continental stages of this catadromous species have been identified (Feunteun, 2002; Dekker, 2009), Sources of eel mortality in the marine environment include the effect of changing nutrient conditions in the spawning grounds and climate change-induced shifts in the Gulf stream on the survival and transport of the eel larvae to the European continental shelf (Knights, 2003; Friedland et al., 2007). During the continental stage, exploitation of the different life stages by commercial and recreational fishing, pollution, predation by piscivorous birds, habitat loss, parasites, and hydropower use have all been identified as contributors to the decline in the European eel population (Feunteun, 2002; Starkie, 2003; ICES, 2008; Dekker, 2009). Unfortunately, these factors act simultaneously, and their relative contribution to the eel decline is as yet unquantified (Starkie, 2003; Dekker, 2009). In many river catchments, basic information on eel escapement during annual spawning migrations is also inadequate (Bilotta et al., 2011). Uncertainty about the causes of the eel decline thus poses a significant challenge for identifying effective interventions to conserve this species.

Despite the limited availability of information concerning the cause of the eel decline, urgent political and management actions have been initiated to conserve the panmictic eel population throughout Europe. The European eel has been red listed as critically endangered by the International Union for Conservation of Nature (Freyhof and Kottelat, 2008). In 2007, the species was also listed by the Convention on International Trade in Endangered Species of Wild Fauna and Flora to control its international trade, and the European Union (EU) adopted a regulation (EC, 2007), requiring European member states to develop eel management plans at a river basin scale by the end of 2008. States whose management plans are not approved by the EU would face immediate reductions in total eel fishing effort by at least 50% or implementation of other measures to reduce eel harvests by half (EC, 2007). While the effectiveness of such measures from a biological perspective is as uncertain as our understanding of the causes of decline, a 50% reduction in fishing mortality would have significant socio-economic welfare impacts on recreational as well as commercial eel fisheries in central and western Europe (Dekker, 2008; Dorow et al., 2010). Thus, in countries where eel is highly valued for its meat (e.g., Germany), banning recreational eel take altogether (as for example implemented in Norway and Sweden since 2009; ICES, 2010) is not a priority for managers. Instead, policy alternatives that implement less drastic fishing regulations that allow for continued access to the resource while meeting the management goals set by the European Union are emphasized (Dorow et al., 2009, 2010).

Traditional recreational fishing regulations, such as daily bag limits, size-based harvest limits or gear restriction, or even partial temporal closures to eel fishing (EC, 2007), can only be "effective" to the extent they affect fishing-induced mortality (Cox and Walters, 2002; Cox et al., 2002). Fishing-induced mortality may be reduced by directly restricting harvest rates of captured fish (e.g., by increasing a minimum-size limit) and/or by reducing fishing effort, either indirectly as a correlated response to altered harvest regulations or directly. Indirect effort limitations retain angler sovereignty over individual participation levels, relying instead on (dis)incentives (e.g., higher licence fees, gear restrictions). Direct regulation of effort includes such regulations as permit lotteries, or spatial or temporal closures. Certain regulatory policies combine these mechanisms to compound their intended conservation benefits. For example, daily bag limits, in addition to their direct influence on harvest rates, have been found to also reduce effort from consumptively oriented angler populations (Beard et al., 2003; Cox et al., 2002). It is currently unclear how such traditional harvest regulations would affect eel angling effort and harvests. Consequently, the ability of eel management plans using such strategies to meet E.U. targets for recreational eel fisheries also remains obscure. This void provides the impetus for our study to understand likely angling effort responses to altered policies. However, our study stops short of modelling of the impact of regulatory changes on the eel stock given the lack of evidence relating stock size in a given catchment to recruitment along the European coast.

2. Materials and methods

2.1. Study area and data collection

To predict anglers' allocation of effort towards European eel, a mail survey was sent to a random sample of eel anglers residing in the German state of Mecklenburg–Vorpommern (M–V). This region is particularly suitable for our study given the importance of eel to both the commercial and recreational fishing sectors. This species comprises the largest inland commercial fishery in the state, harvesting ~136 t yr^{-1} (Statistisches Amt M–V, 2007). Eel are also highly prized for consumption by recreational fishers, and while harvest data on recreational fisheries is sparse, initial estimates for Mecklenburg–Vorpommern suggest that resident and non-resident anglers harvest as much as 187 t yr^{-1} (Dorow and Arlinghaus, in press). This indicates that the size of the recreational eel fishing sector is substantial.

Anglers were recruited to participate in a twelve-month angling diary program (September 2006 to August 2007) using a combination of random digit telephone calls and random selection

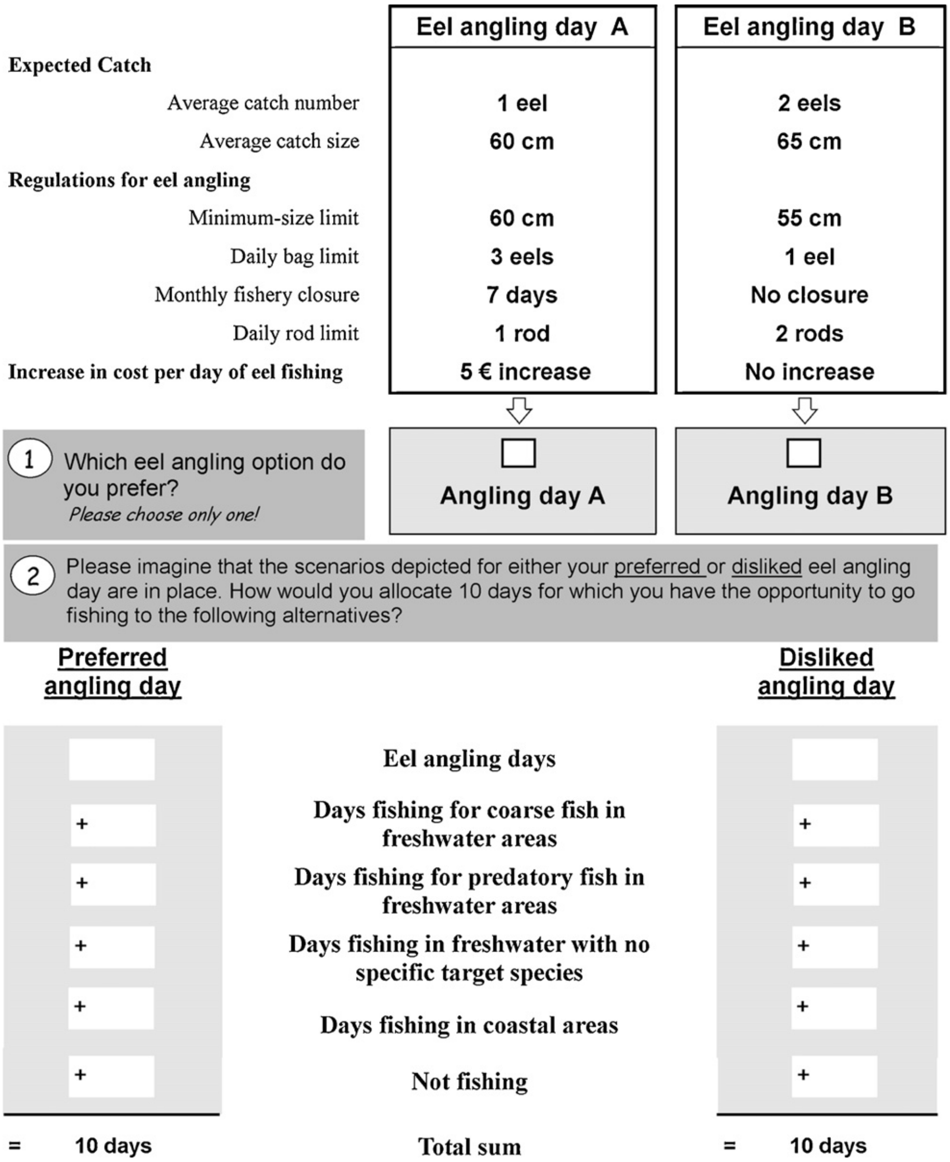

Fig. 1. Example of a choice set used to examine allocation decisions of German eel anglers (translated from German). Only the allocation task (question 2) is analysed in this paper. Note that coarse fish refers to non-predatory and non-salmonid fish of high abundance in the study region. The daily cost reflects increases to the overall costs from any source including licence fees, travel costs, specialized tackle etc.

from a M–V recreational fishing licence database (see Dorow and Arlinghaus, in press, for details). From this sample, eel anglers, defined as those who had targeted or caught eel within 12 months prior to the start of the diary program, were selected for a mail survey. A 14 page questionnaire incorporating a choice-experiment and a series of other questions designed to characterize eel angler types and their opinions about eel management (see Dorow et al., 2010, for details) was mailed in April 2007 to 381 eel anglers, with a telephone reminder following two weeks later. This yielded a final sample of 193 (53%) eel anglers for this study.

2.2. Survey instrument

The main component of the survey comprised a discrete choice experiment that presented respondents with several choice sets consisting of pairs of hypothetical eel angling days (i.e., scenarios, Fig. 1). Each eel scenario was characterized by certain catch expectations (average number and average length of eel in the catch), distinct eel angling regulations supposed to be in effect (daily bag limit, minimum-size limit, daily rod limit, duration of a monthly eel fishery closure) and the hypothetical change in costs associated with angling for eel under those conditions. For the purposes of this study, the cost of fishing was purposely represented in broad terms, to include increased costs associated with permit fees, bait/tackle or travel to more remote angling locations. For each of these attributes three or four levels were identified (Table 1), which were systematically varied in the survey using a fractional factorial experimental design to produce 64 pairs of eel angling scenarios blocked into 16 survey versions (Fig. 1). This design allowed estimation of the main effects, and certain interactions (compare Raktoe et al., 1981). The page prior to this section of the survey presented a sample choice set and provided detailed instructions on how to interpret the scenarios. Anglers were informed to assume that only the displayed criteria and no others differed from the current state of recreational eel fishing in M–V. Respondents were then asked to complete two separate tasks. The first response task, presented in detail elsewhere (Dorow et al., 2010), was to simply select their preferred eel angling scenario from each pair (Fig. 1). The second response task, upon which the present study is focused, required anglers to allocate a total of 10 days available for fishing among six alternative

Table 1
Results of the multinomial logit model testing the effects of catch and regulatory attributes on eel angler fishing effort allocation decisions. Estimated coefficients for each attribute level are called part-worth utilities (PWU).

	Attributes	PWU	s.e.	*z*-Value	*p*-Value
Alternative specific constants (ASC)	Eel	0.340	0.021	16.554	0.000
	Coarse fish	−0.013	0.021	−0.624	0.533
	Predatory fish	0.335	0.019	18.075	0.000
	Undirected freshwater fishing	−0.028	0.021	−1.337	0.181
	Coastal fishing	−0.208	0.023	−9.123	0.000
	Not go fishing	−0.425	0.024	−17.665	0.000
Catch attributes					
Average catch number per day	1 eel	−0.089	0.036	−2.446	0.015
	2 eels	−0.002	0.035	−0.055	0.956
	3 eels	0.099	0.035	2.840	0.005
	4 eels	−0.008	0.036	−0.230	0.818
Average size of eels	50 cm	−0.076	0.036	−2.100	0.036
	55 cm	0.056	0.036	1.549	0.121
	60 cm	−0.017	0.036	−0.475	0.635
	65 cm	0.037	0.035	1.067	0.286
Regulations					
Minimum-size limit	45 cm	−0.046	0.036	−1.265	0.206
	50 cm	−0.032	0.036	−0.907	0.364
	55 cm	0.052	0.035	1.491	0.136
	60 cm	0.026	0.036	0.705	0.481
Daily bag limit	1 eel	−0.132	0.033	−3.975	0.000
	2 eels	0.057	0.027	2.066	0.039
	3 eels	0.076	0.032	2.370	0.018
Daily rod limit	1 rod	−0.059	0.033	−1.794	0.073
	2 rods	0.020	0.028	0.718	0.473
	3 rods	0.039	0.032	1.200	0.230
Monthly eel fisheries closure	0 days	0.065	0.032	2.044	0.041
	7 days	0.080	0.027	2.933	0.003
	14 days	−0.146	0.033	−4.399	0.000
Increase in daily cost of eel fishing	Linear per 2.50€ (Level values: “No increase”, 2.50€, 5€, 10€)	−0.027	0.014	−1.936	0.053
Daily rod limit interactions with ASC					
Coarse fish	1 rod	0.089	0.042	2.108	0.035
	2 rods	−0.051	0.036	−1.397	0.162
	3 rods	−0.039	0.042	−0.916	0.359
Predatory fish	1 rod	0.102	0.038	2.672	0.008
	2 rods	−0.019	0.033	−0.579	0.563
	3 rods	−0.083	0.038	−2.177	0.030
Undirected freshwater fishing	1 rod	0.105	0.043	2.461	0.014
	2 rods	−0.066	0.037	−1.798	0.072
	3 rods	−0.039	0.042	−0.917	0.359
Coastal fishing	1 rod	0.112	0.045	2.488	0.013
	2 rods	−0.036	0.039	−0.924	0.356
	3 rods	−0.076	0.045	−1.683	0.092
Summary statistics	Log likelihood (LL)	BIC (LL)	*n*	R^2(Adj)	R^2
	−2364.5	4744.5	193	0.017	0.001

types of angling opportunities in the region and included the eel fishing scenarios presented. Alternatives thus consisted of one of the two eel scenarios from the first task and five base alternatives: freshwater non-predatory species (hereafter called coarse fish for simplicity), freshwater predatory species, unspecified freshwater targets, coastal fishing, and a non-fishing activity. The allocation task was repeated for both eel scenarios in each pair, thereby ensuring full use of the orthogonal design space, and yielding eight separate allocations per respondent.

While a choice experiment relies on anglers' statements of behavioural intention rather than observations of actual choice behaviour, a hypothetical survey-based approach was warranted to meet study objectives, because many of the examined eel fishing regulations were not currently in use (Hunt, 2005). The response task was also behaviourally more realistic than traditional single item opinion-type surveys where anglers rate individual regulations or their components independently from each other (Aas et al., 2002).

Our choice experiment is unique in the recreational fisheries literature in the manner it elicits and models effort allocation decisions over multiple hypothetical fishing trips. Typical choice experiments ask respondents to choose their single most preferred option from among the alternatives (Louviere and Timmermans, 1990), whereas we asked respondents to allocate ten choices (i.e., days) among the alternatives provided in each choice set (compare Louviere and Hensher, 1982; Borgers et al., 2007). When dealing with repeated behaviours, as with anglers who hold annual licences, this frequency-based approach offers an important advantage over a conventional choice experiment (Christie et al., 2007), because the allocation task refines measurements of angler preferences. It does so by allowing preferences for marginally less acceptable alternatives (i.e., fishing alternatives that receive some, but not most of an angler's effort) to be included in the analysis. For this reason, frequency-based choice experiments may provide better predictions of actual behaviour than traditional choice experiments (Christie et al., 2007).

2.3. Theoretical grounding and statistical modelling

Analyses of all discrete choice experiments are grounded in random utility theory (McFadden, 1974). This theory states that human decisions are a function of the attributes of the available alternatives, and individuals select options that maximize personal utility, an unobserved (i.e., latent) measure of well-being for an individual

(McFadden, 1974). Most commonly, analysis of choice experiments assumes that error in the utilities follows a Gumbel distribution (Louviere et al., 2000) allowing researchers to fit a multinomial logit (MNL) regression model to observed choices (McFadden, 1974), such as those expressed in our choice survey:

$$Pi = \frac{e^{\alpha_i + \sum_1^j \beta_{ij} x_{ij}}}{\sum_{i=1}^k e^{\alpha_k + \sum_1^k \beta_{ik} x_{ik}}} \quad (1)$$

where the probability of choosing alternative i is equal to the exponent of utility of alternative i, consisting of the sum of the alternative specific intercept value (α_i) and the contributions, termed part worth utilities (PWU), attributed to each of j attributes of that alternative ($\beta_{ij}x_{ij}$, where β_{ij} represents the regression coefficient and $x_{ij,}$ the attribute value) divided by the sum of utilities raised to the exponent for all k alternatives available to that individual.

The analysis of frequency-based choice experiments differs from simple choice tasks only in the treatment of the dependent variable modelled with Eq. (1). Accordingly, rather than treating each choice expressed by the respondent in the survey as a single discrete event, each alternative is assigned a probability of being chosen in proportion to its allocation of units in the task. In our application, the units of allocation are angling days (Fig. 1). Each alternative (e.g., eel, coarse fish, predatory fish, etc.) is then treated as an observation, whose replication weight is equal to the probability of being chosen (Vermunt and Magidson, 2005). Unchosen alternatives have a weight of zero and therefore drop out of the calculation, while every alternative that receives at least one allocated day is retained when fitting the model. In this way, the sum of replication weights for all alternatives in an individual's choice set equals one. To analyse our eel angling choice data, we fitted a MNL using the software Latent Gold Choice 4.5 (Vermunt and Magidson, 2005). Preliminary analyses were conducted with all attributes effects-coded (Louviere et al., 2000) to produce separate, unbiased PWU estimates for each level of an attribute that sum to zero within each attribute and are therefore independent of the model constant. Using this treatment, all main effects as well as the interactions between each attribute and the six alternatives were examined. In the interest of model parsimony, further reductions were made to the number of parameters by treating the cost attribute as a simple linear function and eliminating all insignificant interactions. These reductions resulted in no appreciable loss in model fit, as indicated by the Akaike Information Criterion (AIC).

2.4. Model validation

Before applying the parameterized MNL model as a forecasting tool to predict the impact of changes in eel angling regulations on effort, we first validated it using the model's ability to predict current eel angling effort. To this end, we compared angling effort for eel under current conditions in the study region of M–V estimated from our statistical model with observed eel angling effort using information from a complimentary year-long diary study conducted with the same survey respondents (Dorow and Arlinghaus, in press). Predicting the proportion of effort allocated to eel under the status-quo required specifying attribute levels for eel angling regulations and catch characteristics that reflected current conditions. Specific eel angling regulations in M–V may have differed across the state, as some water bodies were managed by different fishing rights holders (Daedlow et al., in press). In most cases, however, eel regulations across M–V conformed to the minimum standards set by state fisheries legislation, consisting of a minimum-size limit for eel of 45 cm, a daily bag limit of three eels, a maximum of three rods per angler and no closures for eel fishing (M–V, 2005, 2006).

The diary study provided estimates for average eel catches (Dorow and Arlinghaus, in press). In total, 154 survey respondents also returned completed diaries documenting all angling trips taken between September 2006 and August 2007 in M–V. Of these, 38 anglers did not target eel during that period, leaving 116 individuals responsible for 825 individual trips targeting eel. In total, 827 eel were caught resulting in a mean catch rate across anglers based on the number of trips targeting eel of 1.15 eel (±s.e. = 0.13, n = 116 anglers) per targeted eel trip. The mean number of eel caught during an angling trip was calculated as an average of the ratio of summed catches over the total number of trips for each angler. Because the diary did not ask respondents to report average sizes of their eel catch, but rather the size of the largest retained eel (Dorow and Arlinghaus, in press), to estimate the average size of caught eel, the mean size of the largest eel for trips where only one eel was caught was used. Similar to the number of eels caught per trip, the mean size was first calculated for each angler and then averaged across anglers. A total of 186 trips reported catching a single eel, with the mean length caught by each angler being 59.5 cm (±s.e. = 1.16 cm, n = 72 anglers). Their catch attributes were used in the status quo modelling exercise.

The cost attribute in the survey was presented as an increase over the current daily expenses associated with eel angling; therefore respondents were asked to provide an estimate of their total cost per day to go eel fishing excluding licence fees. We added to this estimate the self-reported yearly licence expenses incurred for all angling in M–V divided by the number of angling days for each survey respondent. Accordingly, the current mean cost of an eel angling day was estimated at 17.44€ (±s.e. = 1.40€, n = 127 anglers). This value was taken as the base for calculations of the relative change in cost from the status quo.

The above-mentioned regulations and average eel catch characteristics reflected conditions under which angling days are currently allocated to eel fishing. Accordingly, we defined a status quo as having an average catch of a single 60 cm eel per day, with a daily bag limit of 3 eels, a minimum-size limit of 45 cm, a maximum of three rods per day and no increase in current financial costs for eel fishing. The status quo scenario also included no temporal closure because this management approach had not as yet been implemented in the study region. These attribute levels were imported into the statistical effort allocation model, and the predicted eel fishing effort was compared with the observed angling effort allocation in the study region as derived from self-reported effort allocation in the diary. This procedure was intended to test the predictive validity of using behavioural intention as revealed by the allocation task to predict actual behaviour towards eel angling in the study region.

2.5. Effect of regulations on effort

After validating the statistical model, two sets of scenario analyses to predict eel angling effort to changes in configuration of eel angling attributes were conducted. First, we calculated the elasticity of demand for all significant catch (catch rate and size of eel) and regulation (daily bag limit, daily rod limit, temporal closure, cost) attributes by altering each attribute from its status quo baseline to each level given in the choice experimental design (see Table 1 for attribute levels). The percent change in the attribute level from the status quo (Δx_j) and the associated percent change in predicted angling days allocated to eel (Δy) were then calculated. With this information, elasticities (E) of demand were calculated as the ratio, $E_{x,y} = \Delta x_j / \Delta y$ (Case and Fair, 1999). These calculations were conducted for all attributes significant in the choice model at $p < 0.10$, and this liberal significance value was chosen to model potential angling effort responses that were not statistically significant due to the low sample size of the survey, but that might be managerially relevant. A value of $E_{x,y} < 1$ indicates an inelastic angling demand, whereas values $E_{x,y} > 1$ are considered elastic demand (Case and Fair, 1999). The elasticity analysis was used to examine the magnitude of eel angling effort and its sensitivity or responsiveness to changes in attributes of the eel angling experiences. By removing the unit of analysis and expressing only the relative change within each regulation, effort response to all types of regulations can be directly compared.

2.6. Scenario analysis of effort changes to altered regulatory policies

Additional analysis using the parameterized effort allocation model was conducted to explore the combined effect of changes in multiple eel catch qualities and regulations on eel angling effort. To this end, the status quo was compared to various predetermined policy and management scenarios in the study region for illustrative reasons. These scenarios reflected an increasing degree of regulatory strictness and were designed because narrative interviews with eel managers in the study region indicated that forthcoming regulatory changes would most likely involve multiple eel regulations. Note, however, the scenarios presented in this paper represent only a few potential regulatory combinations, and managers may wish to test other combinations using the results presented below. This analysis was also restricted to attributes significant at $p < 0.10$. First, a set of moderately stronger regulations relative to the current situations composed of a daily bag limit of two eels, a daily rod limit of two eel rods, and a seven-day monthly closure was explored. Second, we examined a scenario comprising highly restrictive regulations composed of daily bag limits of a single eel, and a daily rod limit of one rod combined with a fourteen day monthly closure. Finally, we investigated a potential outcome if the severe regulations mentioned above were to lead to increased stock abundance and improved eel catch expectations that may again attract effort. The goal of all scenario analyses was to help decision-makers understand how eel anglers will likely react to eel management policies and their resulting impacts on catch quality.

2.7. Effect of regulations on harvest

As the stated management objective for the EU regulation threatened a 50% closure of the fishery is a reduction in fishing mortality rather than effort to achieve a certain prescribed escapement level of silver eels, establishing a relationship between effort levels and eel harvests is insightful for evaluating the potential for success. To this end, we performed a linear regression to predict changes in total eel harvests due to total effort reductions based on the diary data (Dorow and Arlinghaus, in press) for 149 water bodies (i.e., sampling units) where eel were targeted. Additionally, direct effects of certain regulations, namely minimum-size limits and daily bag limits, were also estimated based on the distributions of daily harvest number and size of creel as reported in the diary data. By assuming that every legally harvestable eel in this highly consumptive fishery is retained, these distributions provided a baseline from which to establish harvest reduction associated with more stringent input and output regulations. Assuming that reductions in effort act proportionally on all harvest characteristics (i.e., the distribution of catch numbers and sizes does not differ with varying levels of effort) we then estimated total harvest reductions that accounted for changes in effort plus any direct harvest reduction as a consequence of changes to output regulations. From this analysis, we calculated the effect on harvest, both of individual attributes from within the discrete choice experiment, and also of each scenario described above.

3. Results

3.1. Survey responses and sample description

The survey yielded a response rate of 53%, with $n = 193$ eel anglers returning completed questionnaires. A comparison of respondents and non-respondents, based on information collected at the time of recruitment, ($n = 173$) revealed no significant differences in socio-demographics (age, education, monthly income and household size) or angling specific criteria (angling experience, annual angling frequency, importance of fishing, angling club membership) (see Dorow et al., 2010, for details). Consequently, non-response bias was assumed to be negligible.

Respondents were overwhelmingly male (97.7%), of mean age 42 years (±s.e. = 1.1, $n = 193$). The majority (63.5%) were members of a local angling club. Respondents to our survey had a mean of 22.4 years (±s.e. = 1.4, $n = 193$) of fishing experience with a long history of targeting eel (mean = 18.7 years, ±s.e. = 1.02, $n = 182$). In 2006, they reported fishing for eel an average of 11.8 days (±s.e. = 1.2, $n = 180$). Of these days 89.7% were reported in freshwater systems (61.1% in lakes and ponds and 28.7% in rivers and canals) with the remaining effort occurring in coastal waters and estuaries. The majority of respondents (77.8%) reported using worms as their primary bait for catching eels. Typical bait worms used in the region are of the earthworm family (Lumbricidae).

3.2. Effort allocation model

Model selection was based on maximizing overall fit while including all main effects and significant interactions with the model constants (Table 1). Effort allocation to eel was strongly affected by the alternative specific constants, i.e. the types of fishing opportunities presented as alternatives, irrespective of the level of eel regulations and expected eel catches (Table 1). These constants indicated that all things being equal, respondents allocated a significantly higher proportion of their intended effort to eel relative to other fishing experiences, but they also allocated significant effort to predatory fish in freshwater fisheries. The non-fishing option was the least chosen of all alternatives. Note that model constants were only significant for eel and predatory fish (both positive) and coastal fishing and not fishing (both negative).

The parameter estimates for the eel catch and regulation attributes and their impact on effort allocation followed expected trends (Table 1). Anglers' allocation of effort to eel was significantly and positively influenced by the average number of eel caught ($p < 0.01$) with catch rates of three eels increasing allocations to eel. The average size of eels also had an effect on effort allocation, with anglers avoiding the eel alternative when presented with the smallest average size of captured eel in our scenarios (50 cm in length; $p < 0.05$). Larger average sizes had no significant effect on effort allocation to eel. We cannot extrapolate outside the attribute levels presented in our survey, but it is likely that disutility was also high for fish smaller than 50 cm total length in the catch.

In terms of regulations, eel effort allocation was significantly negatively affected by stringent daily bag limits consisting of one eel per day and a proposed 14-day temporal closure per month ($p < 0.001$), while more relaxed daily bag limits of two or three eel per day and monthly closures up to seven days had a significantly positive effect on eel angling effort. By contrast, effort allocation to eel remained largely unaffected by changes to minimum-size limits (minimum $p = 0.136$). While daily rod limits had only a moderate effect on allocation to eel (minimum p value of 0.07 for a 1 rod limit), this attribute also exhibited significant interactions with the other non-eel fishing alternatives (Table 1). At low rod limits, anglers allocated significantly more effort to all other non-eel fishing activities and avoided eel, while at high rod limits, anglers more strongly

	Current scenario	Eel	Coarse fish	Predatory fish	Undirected freshwater fishing	Coastal fishing	Not go fishing
Average catch number	1 eel	-0.089	-	-	-	-	-
Average catch size	60 cm	-0.017	-	-	-	-	-
Daily bag imit	3 eels	0.076	-	-	-	-	-
Minimum-size limit	45 cm	-0.046	-	-	-	-	-
Monthly fishery closure	0 days	0.065	-	-	-	-	-
Daily rod limit	3 rods	0.039	-0.039	-0.083	-0.039	-0.076	-
Increase in daily cost of eel fishing	0.00 €	0.002	-	-	-	-	-
Constant		0.340	-0.013	0.335	-0.028	-0.208	-0.425
SUM		0.370	-0.052	0.252	-0.067	-0.285	-0.425
EXP		1.448	0.950	1.286	0.935	0.752	0.654
Effort allocation = *EXP/(SUM(EXP))*		24.0%	15.8%	21.3%	15.5%	12.5%	10.8%

Part Worth Utilities

Fig. 2. Sample calculation of angling effort allocation using Eq. (1). For illustrative purposes the predicted allocation of angler days under the status quo is shown. Part-worth utilities represent the model coefficients from Table 1.

avoided fishing in freshwater for other predatory species or in coastal waters and instead targeted eel more frequently. Finally, an increase in financial cost to eel fishing implemented, for example, through a daily eel permit, was associated with the expected significant decline in angler utility indicated by reduced effort allocated to eel as costs increased. These findings jointly highlighted that eel angler effort responses were non-linearly dependent on the type and degree of eel regulatory measures, the eel catch qualities expected and the financial cost for eel fishing.

3.2.1. Model validation

The fully parameterized choice model from Table 1 allowed us to predict the fraction of total effort by the surveyed anglers devoted to eel for various combinations of regulations and eel catch qualities (exemplified in Fig. 2), but it was based on hypothetical responses by anglers in the survey. Under the current conditions for regulations and catch attributes, the model predicted 24% of all days are allocated to eel with the remaining effort divided among the other non-eel fishing alternatives (Fig. 2). By comparison, for survey respondents who reported targeting eel in M–V in their diaries, the mean fraction of angling days devoted to eel was 22.4% (±s.e. = 2.3%, n = 114 anglers) in the angling season of 2006–2007. The point estimate of the predicted eel angling effort allocation fell within the confidence interval (22.4% ± 4.5%), of the true eel allocation behaviour, providing a validity test of the choice model in Table 1. The statistical model could thus be used to forecast eel angling effort as a function of eel angling regulations, catch attributes and costs.

3.3. Effect of regulations on eel angling effort

Elasticity analysis for all significant attributes independent of one another revealed that angling demand for eel was strongly inelastic (i.e., $E_{x,y} < \pm 1$) to changes in individual attribute levels relative to current conditions across all individual regulations tested (Table 2). The sign of the elasticity value indicates the direction of the angling effort responses relative to the change in attribute levels. For example, as costs for eel fishing increased by 2.5€, demand for eel angling decreased by 2.05% relative to the current situation resulting in a negative and highly inelastic value for total elasticity. The highest, yet still inelastic, elasticity values were found for decreases in the average size of eel from 60 to 55 cm, followed by increases in average size to 65 cm, decreasing the supply of eel angling days per month by implementing a 14-day closure, implementation of a daily bag limit of 1 eel and a daily rod limit of 1 rod. All other attributes exhibited elasticity values close to zero. Of similar interest are also the absolute changes to angling effort that may be expected by modifying certain regulations. Effort may be suppressed by approximately 15–17% relative to current levels by implementation of restrictive daily bag limits of 1 eel per day, daily rod limits of 1 eel rod per day or temporal closures of 14 days per month. By contrast, a similar increase in effort (+15%) may be stimulated by increasing the average catch from one to three eel per day. Thus, a combination of regulations and expected catches determine eel angling effort in a non-linear way.

While changing individual attributes exerted comparatively little effort response from eel anglers in the study region (i.e., inelastic effort response), combining regulatory policies into a mix of tools may have a greater effect on eel angling effort. This however was not the case for moderate changes to eel angling regulations compared to current conditions. Indeed, by moderately increasing the stringency of various eel harvest regulations jointly, anglers were predicted to reduce eel angling effort allocation by only 3% relative to current effort levels (Table 3). Thus, moderate changes in daily bag limits, daily rod limits and small temporal closures of 7 days per month can be expected to have a negligible effect on the total effort devoted to eel. By setting significant regulations to their strictest levels, however, managers can expect to achieve reductions in eel angling effort of about 42% relative to the current situation. Under this scenario, anglers are predicted to devote approximately 14% of their total angling days to eel compared to the 22–24% allocated to eel under current conditions (Table 3). Should anglers enjoy improved catch rates, effort is predicted to increase. With the addition of a second eel, eel angling effort can be expected to be 37% less than current, and with 3 eels per day (potentially a result of the conservation benefits stricter regulations), eel angling effort would fall by only 28% relative to the current conditions rather than 42% under the same policies without catch prospect improvements. Effort displaced from eel under this and other scenarios would be distributed among the remaining non-eel alternatives, predominantly to predatory fish in freshwater fisheries (Table 3).

3.4. Effect of regulation changes on eel harvest

To predict the potential reduction in eel harvest as a result of input or output regulatory changes, we first estimated a linear regression of total harvest on total effort for 149 water bodies receiving directed eel angling effort in the study region. This regression revealed a strongly positive relation between total angler days (x) and total harvest (y) ($y = 1.601x - 0.37$, $R^2 = 0.85$, $p < 0.001$). The slope of the regression suggested that 1.6 eel are harvested per angling day on an average water body (Fig. 3). The regression inter-

Table 2
Elasticity of demand (i.e., angling effort allocation) for changing eel catch attributes and regulations compared to the current base scenario (only for significant attributes at $p < 0.1$, see Table 1; an elasticity value <1 indicates an inelastic demand response.

	Change in effort			
	Level	Change in attribute	Eel angling days	Elasticity of demand
Catch attributes				
Average number of eels	1 eel	Base		
per eel angling day	2 eels	100%	6.8%	0.07
	3 eels	200%	15.0%	0.08
	4 eels	300%	6.3%	0.02
Average size of eels caught	65 cm	8%	4.2%	0.50
	60 cm	Base		
	55 cm	−8%	5.6%	−0.67
	50cm	−17%	−4.4%	0.26
Regulations				
Daily bag limit	3 eels	Base		
	2 eels	−33%	−1.5%	0.05
	1 eel	−67%	−15.0%	0.23
Daily rod limit	3 rods	Base		
	2 rods	−33%	−2.7%	0.08
	1 rod	−67%	−17.0%	0.26
Monthly eel fishery closure (assumes 30 fishing days/month)	0 days	Base		
	7 days	−23%	1.1%	−0.05
	14 days	−47%	−15.1%	0.32
Linear increase in daily cost of eel fishing	17.44€	Base		
	+2.50€	+14%	−2.05%	−0.14

Table 3
Change in eel angling effort and harvests for different eel angling scenarios compared to the current scenario. Attribute levels altered from current are indicated in bold.

		Current	Regulatory change only		Influence of change in catch	
	Regulatory change	None	Moderate	Strict	Strict	Strict
	Catch improvement	None	None	None	Moderate	High
Catch conditions	Catch number	1 eel	1 eel	1 eel	**2 eels**	**3 eels**
	Catch size	60 cm	60 cm	60 cm	60 cm	**65 cm**
Regulations	Daily bag limit	**3 eels**	**2 eels**	**1 eel**	**1 eel**	**1 eel**
	Minimum-size limit[a]	45 cm	45 cm	45 cm	45 cm	45 cm
	Closure	0 days	**7 days**	**14 days**	**14 days**	**14 days**
	Rod limit	3 rods	**2 rods**	**1 rod**	**1 rod**	**1 rod**
	Cost increase	0.00€	0.00€	0.00€	0.00€	0.00€
Allocation across alternatives						
	Eel	24.0%	23.3%	14.1%	15.2%	17.3%
	Coarse Fish	15.8%	15.5%	17.6%	17.4%	17.0%
	Predatory Fish	21.4%	22.6%	25.2%	24.9%	24.3%
	Other Freshwater	15.5%	15.0%	17.6%	17.4%	17.0%
	Coastal	12.5%	12.9%	14.8%	14.6%	14.3%
	Not go fishing	10.9%	10.8%	10.7%	10.5%	10.3%
% Change in eel effort (angler days)		(Base)	**−3.0%**	**−41.4%**	**−36.9%**	**−28.1%**
% Change in eel harvest based on effort change		(Base)	−4.0%	−57.0%	−50.0%	−38.0%
% Change in eel harvest as direct effect of daily bag limit		(Base)[b]	−13.0%	−38.0%	−38.0%	−38.0%
% Total change in harvest		(Base)	**−17.0%**	**−73.0%**	**−69.0%**	**−62.0%**

[a] The minimum-size limit had no significant effect on effort (see Table 1), and was therefore held constant.
[b] Harvests may be reduced by 9% if current regulations (daily bag limits and minimum-size limits) are met with 100% compliance.

cept was found to be insignificant ($\beta = -0.37$; s.e. = 0.33; $t = -1.11$; $p = 0.28$), while the slope of the regression of harvest on effort was highly significant (ß = 1.601; s.e. = 0.056; $t = 28.36$; $p < 0.001$).

Using the current distribution of daily eel harvests (Fig. 4) and the size distribution of eel harvest by anglers (Fig. 5), the potential savings of eel landing by anglers in response to changes to traditional harvest regulations and other tools was estimated. Under conditions of full compliance with regulations, a daily bag limit of two eels, alone, may directly reduce eel harvests by anglers by 13% (Fig. 4). When the landings reduction effect stemming from reductions and daily bag limits and associated effort reductions are combined, eel take under this regulation could be reduced by as much as 15% (Fig. 4). A more stringent daily bag limit of only a single eel could reduce overall eel harvests by as much as 51%.

Similar reductions in harvest may also be achieved using minimum-size limits (Fig. 5). An increase in minimum-size limit to 50 cm would decrease harvests by up to 12%, while size limits of 55 cm and 60 cm could reduce harvests by 36% and 55% respectively. As our model found minimum-size limits within the range tested to have insignificant effects on effort, only direct effects on harvest are reported.

Combining various regulatory tools into more comprehensive management scenarios, the potential reduction in total eel harvest ranged from the moderate scenario of 17–73% harvest reduction (Table 3) relative to the current case of about 187 metric tonnes of eel harvest in the study region (Dorow and Arlinghaus, in press). Note that the combinations of regulations and catch qualities examined in Table 3 represent only a few conceivable options for eel management. Other scenarios of specific interest may also be examined using parameters in Table 1 as exemplified in Fig. 2.[1]

[1] See Supplementary material for interactive exploration of alternative scenarios.

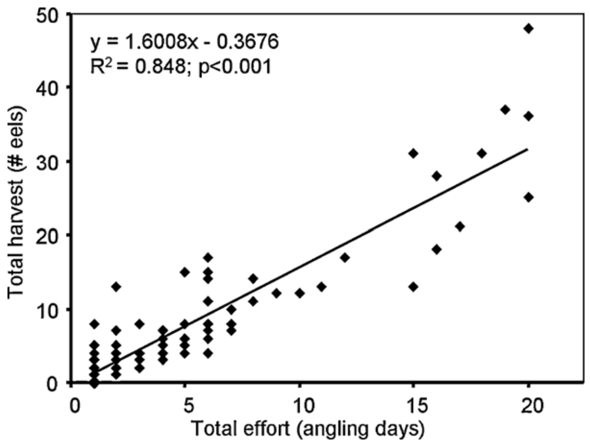

Fig. 3. Linear regression of total eel harvest on water body-specific total directed eel effort across 149 water bodies in Mecklenburg–Vorpommern, Germany.

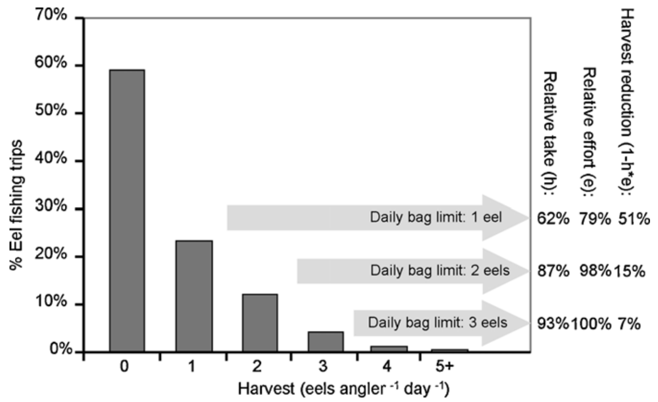

Fig. 4. Distribution of daily eel catch characteristics and predicted harvest reduction associated with increasingly stringent daily bag limits. Direct effects on harvest, indirect effects though associated changes in fishing effort, and their combined effects on overall harvest are presented.

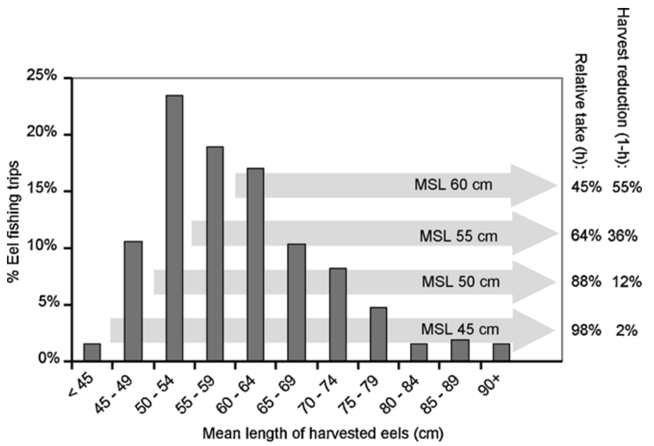

Fig. 5. Distribution of eel sizes per successful trips and predicted harvest reduction associated with increasingly stringent minimum-size limits (MSL). Effort was not found to significantly change across the range of levels examined; hence it was not assumed to affect harvest.

4. Discussion

Our case study of eel anglers in northern Germany highlights the importance of understanding recreational fisher behaviour when planning for biological outcomes associated with regulatory changes, which is especially critical in the case of threatened populations. Regulations may either repel or attract fishing effort. Using a novel frequency-based choice experiment to predict angling effort responses to altered regulations, we found that eel angling effort response was inelastic to changes in catch and regulation attributes of the eel fishing experience. Thus, eel fishery managers across Europe should not necessarily expect proportional changes in recreational eel angling effort and subsequent harvest savings in line with changes to any individual input regulation. Instead, our model suggests that substantial changes to eel angling mortality are only likely once multiple regulations become highly restrictive and/or direct output control measures are implemented. Under such conditions, landings savings up of to 73% relative to current levels are conceivable. Whether this has any positive impact on the panmictic eel stock, however, is biologically unknown.

Respondents to our survey preferred all five fishing alternatives presented in our choice experiment over the non-fishing alternative, reflecting respondents' avidity for recreational fishing in general (Dorow et al., 2010). Of the fishing alternatives, freshwater options were preferred over coastal fishing, which may reflect higher travel costs for eel anglers living in inland communities. As may be expected for the angler subpopulation constituting our sample, the most preferred alternative was fishing for eel, with pronounced effort also occurring for other predatory fishes (e.g., pike (*Esox lucius*), perch (*Perca fluviatilis*), and pikeperch (*Sander lucioperca*). These results confirm previous findings from German fisheries that anglers prefer predatory over non-predatory fish species (Arlinghaus and Mehner, 2004; Arlinghaus et al., 2008) and target eel primarily in freshwater (Dorow and Arlinghaus, in press).

Most of the attributes that we examined exerted significant, yet small individual effects on the number of days allocated to eel angling. The effect of catch qualities on eel angling effort allocation was apparent in both the number of eel caught and also their size. However, an increase of expected size beyond 55 cm was not associated with a significant increasing allocation in favour of eel, and once catch rates exceeded three eel per day, respondents actually decreased their rate of allocation to eel. These findings may be perceived as counterintuitive in light of other recreational fishing studies where larger sizes and higher catch rates were found to increase utility to anglers (e.g. Aas et al., 2000; Laitila and Paulrud, 2006; Oh et al., 2007), but they support the consumptive character of recreational eel fisheries in Germany and agree with existing harvest regulations for several reasons. First, size may exert little influence on effort allocation because aspects of trophy fishing are of low importance to eel anglers, possibly because smaller eels are judged to have a higher culinary value (Dorow et al., 2010). Second, as a recreational meat fishery, higher catch rates of eel are only important to anglers to the extent that catches may be retained. Daily bag limits in our study region as well as in our study never exceeded three eels per day; therefore, a fourth eel may not provide additional benefit to anglers.

Angler intentions to fish for eel were also significantly affected by changes in eel regulations, yet these angling effort responses were not commensurate with the relative change in the underlying regulatory attributes. Significant attribute levels were found for daily bag limits, daily rod limits and temporal closures, but not for minimum-size limits. The latter finding was unexpected given previous findings that showed strong preferences of eel anglers for intermediate minimum-size limits in the study region of 50–55 cm. This preference for increasing the minimum-size limit over the status quo may reflect a perceived obligation to contribute to eel conservation, without the associated hardship imposed by more burdensome regulations such as temporal closures (Dorow et al., 2010). Our study, however, indicates that such preferences do not influence the amount of time allocated to eel fishing. Nevertheless, minimum-size limits may contribute substantially to conservation efforts through their direct effect on fishing induced mortality

(Dorow et al., 2010). We found that increasing minimum-size limits to 55 cm may reduce harvest levels by 36%, representing 67 fewer tonnes harvested by anglers in the study region (assuming a current harvest level of 187 t yr^{-1}, Dorow and Arlinghaus, in press).

In contrast, we found that stricter daily bag limits of two or one eel per day (relative to three eel per day as currently the case) did reduce total eel angling effort. Similar effects of harvest control measures have also been described in another highly consumptive recreational fishery – walleye (*Sander vitreus)* in Wisconsin (U.S.A.) (Beard et al., 2003). Changes to angling effort through implementation of lower daily bag limits can be explained by their effect on reducing potential eel harvests, a primary benefit of this particular angling experience; however, angler perceptions of their ability to harvest eel also strongly contribute to this effect. The effect of perceived harvest constraints on angling effort dynamics is particularly clear when comparing the effect of minimum-size-limits and daily bag limits on harvest savings in our results. Both regulations act directly on harvests by anglers by constraining the sizes or numbers of eel that people can take home from each trip. Our findings suggest, however, that given current catch quality and regulatory levels, stricter minimum-size limits have greater potential to directly limit harvests than daily bag limits. Fifty five percent (103 t yr^{-1}) of harvested eel fall below the current mean size of 60 cm, while only 38% of harvested eel are in excess of the current average catch of one eel per day. Consequently, increasing minimum-size limits to 60 cm would directly reduce harvests more than decreasing daily bag limits to a single eel. Daily bag limits, however, compound their effects on harvest by also significantly reducing angling effort, whereas minimum-size limits apparently do not. As a result, predicted harvest reductions for a daily bag limit of one eel (51%, 94 t yr^{-1}) are similar in overall magnitude to increasing the minimum-size limit 60 cm. These results support previous findings that daily bag limits are ineffective when they do not constrain angling harvests but they affect angler expectations and behaviour (Radomski et al., 2001; Cox et al., 2002; Beard et al., 2003). Thus, when appropriately set, output controls such as daily bag limits can be very effective at limiting recreational harvests due, in part, to their impacts on angling effort.

Allocation of angling days to eel was not only influenced by output control measures (e.g., daily bag limit), but was also significantly influenced by restrictive input (i.e., effort) control measures, namely the implementation of a 1 rod per angler daily limit and a 14-day/month temporal closure. Regarding daily rod limits, the complimentary diary study showed many anglers in the study region devote only a fraction of their rods to eel, preferring instead to target multiple species simultaneously (Dorow and Arlinghaus, unpublished data). A limit of two rods does not constrain eel anglers because there is little opportunity cost to directing one rod towards catching an eel while using the other rod to pursue other fishing prospects. Only at a limit of one rod are anglers forced to select a single target species. Hence, significant effects of daily rod limits on eel angling effort and displacement to other fisheries, mainly predatory fish in freshwaters, occurred only once this severe rod limit was implemented. The challenge that managers face when implementing any form of rod limits for eel, however, is enforcement, because eel anglers typically apply generic baits used also for other species. As a result, to be effective daily rod limits may require implementation across all angling activities, not just eel fishing, which will have high social costs (Dorow et al., 2010).

Effort allocated to eel was predicted to decline by 15% relative to current levels when a temporal closure of 14 days per month was implemented in the survey. This represented an inelastic effort response. Indeed, limiting the amount of time that can be devoted to fishing is among the most drastic measures to control effort. It is therefore disliked by eel anglers (Dorow et al., 2010) and thus not unexpectedly negatively affected eel angling effort in the present study. However, this response was still relatively small given that a 14-day closure represents 47% of the current number of open fishing days. Unlike commercial fishing, recreational fishing, by definition, takes place during discretionary, leisure time. Moreover, few anglers spend their entire leisure time fishing. As a result, anglers may accommodate temporary closures by concentrating their eel angling during times when the fishery is open. This argument is supported by previous findings that a closure of 7 days per month has been found to be acceptable to anglers in the study region (Dorow et al., 2009) and did not significantly reduce the proportion of effort directed to eel (this study). Only when fishery closures span a time period sufficient to limit one's ability to reschedule angling activities can they be expected to markedly affect the effort. Our study, however, made no separation between weekdays and weekends when examining the impact of temporal closures. Because angling activities are often concentrated during the weekend (Hunt et al., 2007), eel fishery closures throughout a month may actually have a greater effect on eel angling effort than predicted by our survey if they are selectively timed to occur during peak fishing periods. One should note, however, that the predicted reduction of effort was only 15% at a temporal closure of 14 days per month, with similar reductions also found for a daily bag limit of 1 eel per day. Previous findings, however, have shown that the welfare loss to anglers is considerably larger from a 14-day temporal closure than from a daily bag limit of 1 eel per day (Dorow et al., 2010). Managers are well advised to consider the differential social impacts of imposing new and therefore unfamiliar forms of effort regulation such as temporal closures over modifying existing measures, such as daily bag limits and minimum-size limits, and consider trade-offs between the potential biological effects of regulations versus their social costs. Otherwise, intensive conflict and loss of stewardship behaviour, such as stocking and habitat management, by anglers is to be expected, which may contribute to further decline of eel stocks.

While individual regulations alone did not strongly affect eel angling effort, we also examined the joint effects of implementing multiple tools simultaneously. In doing so, we found that moderate regulatory changes (2 eels day^{-1}, 7 day closure, 2 rod maximum) altered the allocation of eel angling effort by only 3%. A possible explanation may relate to media coverage of the eel decline to which anglers in Germany have been exposed. This result corroborates previous findings that moderate additional regulation for the purpose of conserving eel stocks is quite acceptable to anglers (Dorow et al., 2009). From our diary data, it appears that such regulations do not substantially restrict harvests (a 4% decrease relative to current) and thus provide little incentive to substitute another activity. In conclusion, moderate eel fishing restrictions do not appear to pose a barrier to fishing participation and will therefore only contribute to meeting management goals to the extent they directly constrain harvests.

Angling effort changes were more pronounced once regulations become very strict (daily bag limit of 1 eel, 14-day monthly closure, maximum of 1 rod), which supports previous findings by Dorow et al. (2010) showing that severe restrictions have strong welfare consequences for the eel anglers in northern Germany. The 41% effort reduction associated with our strict regulation scenario is less than might be expected *a priori* given the draconian regulations that included only half the allowable days per month, severe daily bag and size-based harvest limits (1 eel day^{-1}), and a maximum of one allowable rod. This reluctance to abandon eel fishing or reallocate effort more strongly to other fish species can be explained by the surveyed anglers' strong commitment to the eel fishery and the lack of substitutes for eel (Dorow et al., 2010). Thus, only with the implementation of a set of highly restrictive regulations in addition to a temporal closure of 14 days per month (EC, 2007) can a 50% reduction of effort be expected. This will then reduce annual harvests by as much as 137 tonnes relative to the present (73% less than current).

Another finding of our study is that effort reductions stemming from regulatory restriction may be partly compensated by increased eel abundance and its corresponding effect on catch rates. Considering the potential for successful conservation efforts to attract anglers back to the fishery with improvements in catch quality (this study; Cox and Walters, 2002), long term eel fishing effort may be higher than predicted in our scenarios if the eel stocks recover. This effect is well documented in the fisheries literature, known as the "paradox of enhancement" (Johnson and Staggs, 1992) or the "success breeds failure pathology" (Cox and Walters, 2002). The implication for the conservation of eel stocks is that without constraining total effort and harvest, conservation efforts may not be as effective as initial results indicate.

Ultimately, any recommendations inferred from our study are dependent on the conditions and mortality sources (e.g., loss at hydropower turbines, predation by fish-eating birds, commercial fishing) in each catchment and should not be uncritically applied at a local scale. Therefore, our scenarios should not be seen as quantitative predictions for individual catchments, but as an exercise to highlight the complex interplay of angler behaviour in response to regulatory policies that may create unexpected results from a management perspective. In particular, our predictions for eel effort responses and associated harvest reductions should be applied with caution as there are large gaps in our understanding of the biology of *Anguilla anguilla* and the dynamics of eel fishing in each catchment. Data needs specific to recreational fishing include information regarding size-related recapture rates. As all eel captured in freshwater have not yet spawned, the conservation benefits of output controls are dependent on probabilities of recapture prior to migration. Therefore, minimum-size limit regulations may concentrate fishing mortality on larger eels, but the overall fishing mortality may not be appreciably affected in contrast to what we assumed in our scenarios. Second, better information regarding the interaction of size and number based harvest controls is needed. If stricter daily bag limits are imposed, anglers may be tempted to retain only the largest specimens (with the lowest probability of recapture), continually releasing smaller (but still legally harvestable) fish to maximize harvestable biomass. Moreover, for many catchments there are no empirical studies to determine the catchability of eel using angling gear, although our regression of total effort on total harvest across water bodies suggest a proportionality of effort to landings. However, without quantifying catchability in a recreational setting and the stock–recruitment relationship, it is impossible to estimate the contribution of any changes in harvest in a single catchment to the overall pan-European population.

From a methodological perspective, our study illustrates the usefulness of stated preference surveys to forecast human responses to changes in recreational fishery management. While this type of forecasting necessitates the use of hypothetical scenarios, our predictions are validated by the congruence between our model results and eel angling effort allocation currently observed in the study region. Our study presents a method by which managers can assess the potential for proposed conservation measures to affect consumptive recreational users, and ultimately succeed in meeting biological outcomes. While application of specific findings beyond our study area and across other threatened fish species is strongly discouraged, our results provide unique insights into the possibilities of angler behaviour affecting the outcome of any well-intended biological regulations. Thus, our study underscores the need to account for the human dimensions of recreational fishing in biological planning.

5. Conclusions and implications

The broad geographic range for this species requires concerted conservation efforts across Europe, and commercial and recreational fisheries management are mandated requirements of the European Union's eel regulation directive (EC, 2007). However, very little is known about the contribution to the decline in eel abundance made by commercial and recreational fisheries relative to other sources of eel mortality. To identify regulatory actions that are capable of achieving stated management goals of increased escapement of eel from European catchments (EC, 2007), it is crucial to anticipate stakeholder responses (Dorow et al., 2009, 2010). This is particularly evident given the need for voluntary compliance with regulations, a characteristic of all freshwater recreational fisheries, where regulatory enforcement is limited by a large population of independent agents (i.e., anglers) dispersed across complex fishery landscapes (Gigliotti and Taylor, 1990; Pierce and Tomcko, 1998; Walker et al., 2007). Our study showed that the effort responses of eel anglers are likely to be inelastic to individual changes in regulatory policies. Strong reductions in eel angling effort, and associated reductions in eel landings, are only likely if regulatory policies become very restrictive. Should such policies be implemented, managers then face the difficult task of trading off uncertain conservation benefits associated with reducing recreational harvests by up to 73% against substantial welfare losses associated with such policies of up to several million € per year (Dorow et al., 2010).

Our case study provides several additional insights of relevance to both eel conservation and also recreational fisheries more generally. First, reducing angling effort and corresponding harvest levels may, depending on the fishery, necessitate implementing severe input and output regulations jointly. Should the EU or national eel managers intend to implement temporal closures of 14 days month^{-1}, our study shows that additional regulation (i.e., restrictive harvest limits) will be necessary to reduce fishery mortality by 50%, but these angling regulations will come at a cost of considerable welfare losses for anglers (Dorow et al., 2010). The consumptive orientation of eel fishing coupled with the anglers' determination to continue eel fishing constitutes the key management challenge that results in an inelastic effort response. Overcoming this challenge will most likely require that managers scientists establish the extent to which recreational fishing contributes to the decline of the European eel population. The continuing and alarming decline of the European eel (ICES, 2010) raises concerns that the targets set by the EU (EC, 2007) may be inadequate to effect conservation success. This is however for managers to decide and is not the task of a researcher. Giving current management goals, we recommend focusing on increases in minimum-size limits and decreases in bag limits first, because such tools may reduce recreational harvests considerably without causing major welfare losses to anglers. Otherwise, opposition and conflict between managers and anglers is a likely outcome, especially if recreational angling is perceived to have been selectively targeted by decision-makers, excluding other sectors that have been identified to induce mortality on eel (Dorow et al., 2009). Should more conservative management targets for recreational eel harvests be implemented, our model provides a useful tool to allow managers to develop more restrictive regulatory options that are likely to achieve the desired biological outcome. For recreational fisheries research and management more broadly, our study thus emphasizes the need to better understand how management actions influence angler behaviour in a non-linear, complex way. Neglecting human behavioural responses in crafting conservation-oriented regulations may otherwise lead to misguided management and result in some unexpected dilemmas (Sullivan, 2003). Future application of similar allocation-based choice experiments will enhance *a priori* understanding of angler effort dynamics in the context of regulatory and ecological change.

Acknowledgements

The project was funded by the European FIFG (Financial Instrument for Fisheries Guidance, 2000–2006, 75%) and the State of M–V (25%). Funding was also provided by the Adaptfish-Project through a grant within the Pact for Innovation and Research by the Leibniz-Community (www.adaptfish.igb-berlin.de) to R.A. Additional funding to R.A. was granted by the German Ministry of Education and Research within the project Besatzfisch (www.besatz-fisch.de) in the Program for Social-Ecological Research (Grant no. 01UU0907). Additional funding for B.B. came from a Canada Graduate Scholarship from the Social Sciences and Humanities Research Council of Canada. We thank the anglers participating in this survey and those providing helpful insights during the pre-tests, and Don Anderson for his assistance with the experimental design. We would also thank USUMA GmbH (Berlin, Germany) for execution of the field work and reviewers for insightful recommendations that helped improve our paper.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.fishres.2011.03.023.

References

Aas, Ø., Haider, W., Hunt, L., 2000. Angler responses to potential harvest regulations in a Norwegian sport fishery: a conjoint-based choice modeling approach. N. Am. J. Fish. Manage. 20, 940–950.

Aas, Ø., Thailing, C.E., Ditton, R.B., 2002. Controversy over catch-and-release recreational fishing in Europe. In: Pitcher, T.J., Hollingworth, C.E. (Eds.), Recreational Fisheries: Ecological, Economic and Social Evaluation. Blackwell Science, Oxford, pp. 95–106.

Arlinghaus, R., 2007. Voluntary catch-and-release can generate conflict within the recreational angling community: a qualitative case study of specialised carp, *Cyprinus carpio*, angling in Germany. Fish. Manage. Ecol. 14, 161–171.

Arlinghaus, R., Bork, M., Fladung, E., 2008. Understanding the heterogeneity of recreational anglers across an urban–rural gradient in a metropolitan area (Berlin, Germany), with implications for fisheries management. Fish. Res. 92, 53–62.

Arlinghaus, R., Cooke, S.J., 2009. Recreational fisheries: socioeconomic importance conservation issues and management challenges. In: Dickson, B., Hutton, J., Adams, W.A. (Eds.), Recreational Hunting, Conservation and Rural Livelihoods: Science and Practice. Blackwell Science, Oxford, pp. 39–58.

Arlinghaus, R., Mehner, T., 2004. A management-orientated comparative analysis of urban and rural anglers living in a metropolis (Berlin, Germany). Environ. Manage. 33, 331–344.

Arlinghaus, R., Mehner, T., Cowx, I.G., 2002. Reconciling traditional inland fisheries management and sustainability in industrialized countries, with emphasis on Europe. Fish Fish. 3, 261–316.

Beard jr., T.D., Cox, S.P., Carpenter, S.R., 2003. Impacts of daily bag limit reductions on angler effort in Wisconsin walleye lakes. N. Am. J. Fish. Manage. 23, 1283–1293.

Bilotta, G.S., Sibley, P., Hateley, J., Don, A., 2011. The decline of the European eel *Anguilla anguilla*: quantifying and managing escapement to support conservation. J. Fish Biol. 78, 23–38.

Borgers, A., Timmermans, H., van der Waerden, P., 2007. Spatially differentiated utility functions for urban greenspace: a test based on conjoint choice experiments. In: Woodside, A.G. (Ed.), Advances in Culture, Tourism and Hospitality Research, 1. Elsevier JAI Press, Oxford, pp. 221–234.

Case, K., Fair, R., 1999. Principles of Economics, fifth ed. Prentice-Hall, New Jersey.

Christie, M., Hanley, N., Hynes, S., 2007. Valuing enhancements to forest recreation using choice experiment and contingent behaviour methods. J. Forest Econ. 13, 75–102.

Cox, S.P., Walters, C.J., 2002. Maintaining quality in recreational fisheries: how success breeds failure in the management of open-access fisheries. In: Pitcher, T.J., Hollingworth, C. (Eds.), Recreational Fisheries: Ecological, Economic, and Social Evaluation. Blackwell Science, Oxford, UK, pp. 107–119.

Cox, S.P., Beard jr., T.D., Walters, C., 2002. Harvest control in open-access sport fisheries: hot rod or asleep at the reel? Bull. Mar. Sci. 70, 749–761.

Daedlow, K., Beard jr., T.D., Arlinghaus, R. A., in press. Property rights-based view on management of inland recreational fisheries: contrasting common and public fishing right regimes in Germany and the U.S.A. In: Beard jr., T.D., Arlinghaus, R., Sutton, S.G. (Eds.), Proceedings from the 5th World Recreational Fisheries Conference. American Fisheries Society.

Dannewitz, J., Maes, G.E., Johansson, L., Wickström, H., Volckaert, F.A.M., Jarvi, T., 2005. Panmixia in the European eel: a matter of time. Proc. Roy. Soc. B 272, 1129–1137.

Dekker, W., 2008. Coming to grips with the eel stock slip-sliding away. In: Schechter, M.G., Leonard, N.J. (Eds.), International Governance of Fisheries Ecosystems: Learning from the Past, Finding Solutions for the Future. American Fishery Society, Bethesda, Maryland, pp. 335–355.

Dekker, W., 2009. A conceptual management framework for the restoration of the declining European eel stock. In: Casselman, J.M., Cairns, D.K. (Eds.), Eels at the Edge: Science, Status and Conservation Concern American Fisheries Society, Symposium 58. Bethesda, Maryland.

Ditton, R.B., Sutton, S.G., 2004. Substitutability in recreational fishing. Hum. Dimens. Wildl. 9, 87–102.

Dorow, M., Arlinghaus, R. (in press) A telephone-diary-mail approach to estimate catch, harvest and effort and complementary human dimensions information about recreational fisheries for large geographic scales, and some descriptive landings findings for northern Germany, in Beard jr., T.D., Arlinghaus, R., Sutton, S.G. (Eds.), Proceedings from the 5th World Recreational Fisheries Conference. American Fisheries Society.

Dorow, M., Beardmore, B., Haider, W., Arlinghaus, R., 2009. Using a novel survey technique to predict fisheries stakeholders' support for European eel (*Anguilla anguilla* L.) conservation programs. Biol. Conserv. 142, 2973–2982.

Dorow, M., Beardmore, B., Haider, W., Arlinghaus, R., 2010. Winners and losers of conservation policies for European eel, *Anguilla anguilla*: an economic welfare analysis for differently specialised anglers. Fish. Manage Ecol. 17, 106–125.

EC (European Commission), 2007. Council regulation (EC) No. 1100/2007 of 18 September 819 2007 establishing measures for the recovery of the stock of European eel. Off. J. Eur. Union, 248, 17–23.

Feunteun, E., 2002. Management and restoration of European eel population (*Anguilla anguilla*): an impossible bargain. Ecol. Eng. 18, 575–591.

Freyhof, J., Kottelat, M., 2008. *Anguilla anguilla*, in: IUCN (Ed.), 2008 IUCN Red List of Threatened Species. Available from: http://www.iucnredlist.org (last accessed 20.05.2010).

Friedland, K.D., Miller, M.J., Knights, B., 2007. Oceanic changes in the Sargasso Sea and declines in recruitment of the European eel. ICES J. Mar. Sci. 64, 519–530.

Gigliotti, L.M., Taylor, W.W., 1990. The effect of illegal harvest on recreational fisheries. N. Am. J. Fish. Manage. 10, 106–110.

Hunt, L.M., 2005. Choice models and recreational fishing site choice: insights and future opportunities. Hum. Dimens. Wildl. 10, 153–172.

Hunt, L.M., Boots, B.N., Boxall, P.C., 2007. Predicting fishing participation and site choice while accounting for spatial substitution, trip timing, and trip context. N. Am. J. Fish. Manage. 27, 832–847.

ICES (International Council for the Exploration of the Sea), 2008. Report of the joint EIFAC/ICES Working Group on eels (WGEEL), 3–9 September 2008, Leuven Belgium. Rep. No. ICES CM 2008/ACOM: 15.

ICES (International Council for the Exploration of the Sea), 2010. Report of the joint EIFAC/ICES Working Group on eels (WGEEL), 9–14 September 2010, Hamburg Germany. Rep. No. ICES CM 2010/ACOM: 18.

Johnson, B.M., Staggs, M.D., 1992. The fishery. In: Kitchell, J.F. (Ed.), Food Web Management: A Case-study of Lake Mendota. Springer Verlag, NewYork, pp. 353–375.

Johnston, F.D., Arlinghaus, R., Dieckmann, U., 2010. Diversity and complexity of angler behaviour drive socially optimal input and output regulations in a bioeconomic recreational fisheries model. Can. J. Fish. Aquat. Sci. 67, 1507–1531.

Knights, B., 2003. A review of the possible impacts of long-term oceanic and climate changes and fishing mortality on recruitment of anguillid eels of the northern hemisphere. Sci. Total Environ. 310, 237–244.

Lewin, W.C., Arlinghaus, R., Mehner, T., 2006. Documented and potential biological impacts of recreational fishing: Insights for management and conservation. Rev. Fish. Sci. 14, 305–367.

Louviere, J.J., Hensher, D.A., 1982. Design and analysis of simulated choice or allocation experiments in travel choice modeling. Transp. Res. Rec. 890, 11–17.

Louviere, J.J., Hensher, D.A., Swait, J.D., 2000. Stated Choice Methods – Analysis and Application. Cambridge University Press, Oxford.

Louviere, J., Timmermans, H., 1990. Stated preference and choice models applied to recreation research: a review. Leis. Sci. 12, 9–32.

McFadden, D., 1974. Conditional logit analysis of qualitative choice behaviour. In: Zarembka, P. (Ed.), Frontiers in Econometrics. Academic Press, New York, pp. 105–142.

Metcalf, S.J., Moyle, K., Gaughan, D.J., 2010. Qualitative analysis of recreational fisher response and the ecosystem impacts of management strategies in a data-limited situation. Fish Res. 106, 289–297.

M–V (Mecklenburg–Vorpommern), 2005. Verordnung zur Ausübung der Fischerei in den Binnengewässern (Binnenfischereiverordnung – BiFVO M–V) FAOLEX Id: LEX-FAOC074990. Available from: http://faolex.fao.org/docs/texts/ger74990.doc (last accessed 20.05.2010).

M–V (Mecklenburg–Vorpommern), 2006. Verordnung zur Ausübung der Fischerei in den Küstengewässern (Küstenfischereiverordnung – KüFVO M–V) FAOLEX Id: LEX-FAOC075146. Available from: http://faolex.fao.org/docs/texts/ger75146.doc (last accessed 20.05.2010).

Oh, C.O., Ditton, R.B., Riechers, R., 2007. Understanding anglers' preferences for fishing tournament characteristics and policies. Environ. Manage. 40, 123–133.

Paukert, C., Klammer, J., Pierce, R., Simonson, T., 2001. An overview of northern pike regulations in North America. Fisheries 26 (6), 6–13.

Laitila, T., Paulrud, A., 2006. A multi-attribute extension of discrete-choice contingent valuation for valuation of angling site characteristics. J. Leis. Res. 38, 133–142.

Pereira, D.L., Hansen, M.J., 2003. A perspective on challenges to recreational fisheries management: summary of the symposium on active management of recreational fisheries. N. Am. J. Fish. Manage. 23, 1276–1282.

Pierce, R.B., Tomcko, C.M., 1998. Angler noncompliance with slot length limits for northern pike in five small Minnesota lakes. N. Am. J. Fish. Manage. 18, 720–724.

Post, J.R., Sullivan, M., Cox, S., Lester, N.P., Walters, C., Parkinson, E.A., Paul, A.J., Jackson, L., Shuter, B.J., 2002. Canada's recreational fisheries: the invisible collapse? Fisheries 27 (1), 6–17.

Prayaga, P., Rolfe, J., Stoeckl, N., 2010. The value of recreational fishing in the Great Barrier Reef Australia: a pooled revealed and contingent behavior model. Mar. Policy 34, 244–251.

Radomski, P.J., Goeman, T.J., 1996. Decision making and modeling in freshwater sport-fisheries management. Fisheries 21 (12), 14–21.

Radomski, P.J., Grant, G.C., Jacobson, P.C., Cook, M.F., 2001. Visions for recreational fishing regulations. Fisheries 26 (5), 7–18.

Raktoe, B.L., Hedayat, A., Federer, W.T., 1981. Factorial Designs. John Wiley and Sons, New York.

Sullivan, M.G., 2003. Active management of walleye fisheries in Alberta: dilemmas of managing recovering fisheries. N. Am. J. Fish. Manage. 23, 1343–1358.

Starkie, A., 2003. Management issues relating to the European eel *Anguilla anguilla*. Fish. Manage. Ecol. 10, 361–364.

Statistisches Amt M–V (Mecklenburg–Vorpommern). 2007. Statistisches Jahrbuch 2007. Statistisches Amt Mecklenburg–Vorpommern (State statistical office Mecklenburg–Vorpommern), Schwerin.

Vermunt, J.K., Magidson, J., 2005. Technical Guide for Latent GOLD Choice 4.0: Basic and Advanced. Statistical Innovations Inc., Belmont, MA.

Walker, J.R., Foote, L., Sullivan, M.G., 2007. Effectiveness of enforcement to deter illegal angling harvest of northern pike in Alberta. N. Am. J. Fish. Manage. 27, 1369–1377.