Size Dependent Angling Exploitation Rates in pike (*Esox Lucius)* in Northwest Germany

STUDENT PROJECT

by

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Abstract

In this study we addressed the estimation of annual exploitation rate (AER) in five angling clubs in Lower Saxony.1,232 northern pike were captured and tagged. In total, 156 tagged fish, including 59 high reward tag, were returned by the anglers, which gave us a reporting rate of 53± 9%. We encountered two major problems associated with the estimation of the AER relating to the mark and recapture method: (1) the uncertainty associated with the estimation of the reporting rate, tag loss and tagging mortality and, (2) the size dependent vulnerability. Instantaneous total mortality obtained from the annual exploitation rate was 0.44 for 2011, and 0.19 for 2012. The F_{safe} should be 0.15, calculated as 0.75M. Both years were unsustainable exploited and only two angling clubs exploited the fishery at a sustainable AER. We also estimated the selectivity curve with a binomial generalized linear model. As the curve never reaches one, it is suggested that this method was not appropriate to estimate size selectivity

Introduction

Despite the fact that the magnitude of recreational angling participation in developed countries involves 10.52 percent of the population (Arlinghaus et al. 2014 and see Fig. 1), and harvests 17.09 billion fish every year (Cooke and Cowx 2004) the associated fishing mortality (F) to this leisure activity has not been considered until recently (Arlinghaus et al. 2002).

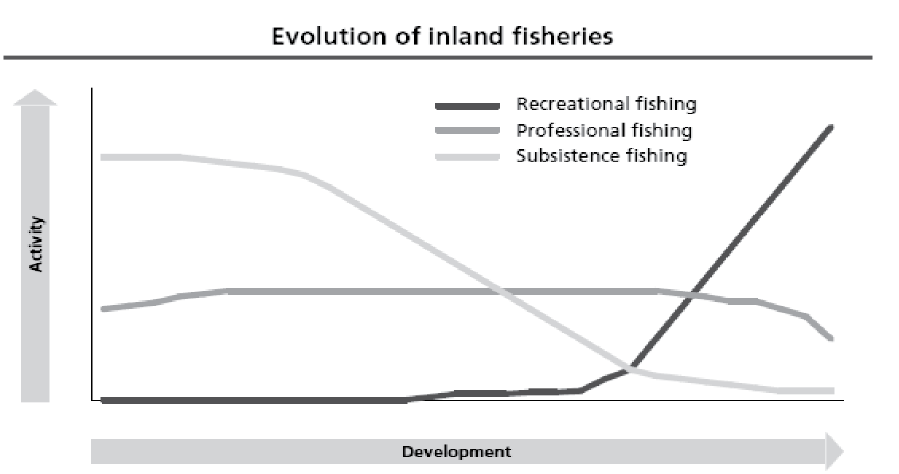

Fig.1.Predicted shifts in the main type of inland fishing in relation to economic development of a society. FAO 2012

In fact, it has been pointed out that the angling activity produces negative impacts on exploited fish and associated ecosystems and may harvest biomass at relatively similar scales as commercial fishing does (Cooke and Cowx 2004). Declining fish stock due to the extraction of biomass, as well as induced selection due to the size-selectivity of the fishing gear or habitat degradation have generated undesirable consequences in many parts of the world (see the review by Lewin et al 2006). Quantifying the fraction of fish that is harvested every year by recreational fisheries is, therefore, a key aspect in understanding the health status of any exploited fish population.

The fraction of fish that is captured every year by commercial or recreational fisheries as described by F is usually incorporated to the stock assessment as the annual exploitation rate (AER) (Beverton and Hold 1957, Allen and Hightower 2010; Meyer and Schill 2014). It is defined as the proportion of a population that is caught, in this case by the angling activity, in one year (FAO glossary). However, the estimation of AER in recreational fisheries is not trivial and usually demands sophisticated social-ecological approaches to estimate the number of fish captured (landings) and the number of fish available (Sutherland 2001; Amstrup 2005; Miranda and Bettoli 2007). Different methodological approaches have been proposed to estimate AER (Allen and Hightower 2010), from those mark-and-recapture (M&R) has been successfully used in recreational fisheries. For example, Crawford and Allen (2006) used this method to estimate AER in bluegills (*Lepomis macrochirus*) and redear sunfish (*L. micropophus*) in Lake Panasoffkee in Florida. Or Pierce and Tomcko (1995) estimated an AER for northern pike (*Esox Lucius*) in seven Minnesota Lakes (U.S.A) combining mark and recapture with creel survey. However, the M&R method is not free of problems and some assumptions and limitations have to be considered.

The basis of M&R relies in tagging a random sample of the populations which are vulnerable to be harvested, the recapture rates made by anglers (Pine et al., 2003; Allen and Hightower 2010) and it implies several assumptions: (1) tagged fish represent the total fish population, (2) tags are not lost, (3) tagging mortality rates for tagged fish are known and (4) fishermen report tag all fish that are caught (Pollock et al. 2001; Pine et al. 2003; Smith et al. 2009). The first two points can be optimized by using different fishing gears to tag a larger fraction of the variability of the population. For example, a combination of angling, electrofishing and netting has been suggested as a potential method to overcome these issues in recreational fisheries (Pollock et al. 1990; Pine et al. 2003). However, the other three assumptions require parallel experiments to estimate how many tagged fish die as consequence of tagging, how many fish lose the tag and how many harvested fish are reported.

Tag loss and tag mortality are usually estimated using double-tagging or with containment experiments (Miranda et al. 2002; Pine et al. 2003; Allen and Hightower 2010). For example Hühn et al. (2014) determined a 12.5± 0.5 % tag lost and tag mortality 9.8 ± 0.7 % in northern pike, *Esox Lucius* (our species case-study, see below) for the first year on a M&R program. In terms of reporting rates, it is usually calculated as the fraction between the number of standard tagged fish reported by fishermen divided by the total number of fish tagged with standard tag and the number of high reward tagged fish reported by fishermen divided by the total number of fish tagged with high reward tags. Unfortunately, the estimation of tag lost , mortality rates and reporting rates are not free of observational errors and and they are usually estimated with uncertainty (see e.g. Hühn et al. (2014), the confident interval for mortality goes from 0 to 26.5%, and for tag loss goes from 0.8 to 24.2%). In this work we provide an analytical solution to estimate AER which explicitly incorporates the uncertainty on the estimation of this three main assumption based on bootstrap resampling.

In addition to the uncertainties associated to the major assumption of the M&R method estimating the AER, there is the associated problem that not all individuals are equally vulnerable regarding their body size. Smaller fish have not the same vulnerability to angling than larger fish, because vulnerability is size dependent (Post et al. 2003)

In fact, size selectivity fishing induces selection and it can influence yield, biomass, and other stock features (Arlinghaus et al. 2009). This is especially relevant for species like northern pike for which it has been demonstrated to have a strong size dependent vulnerability (Paukert et al. 2001, Arlinghaus et al. 2009). Therefore, there is a need to incorporate the size-dependent vulnerability in the number of fish tagged for proper estimation of the AER.

In this work we cope with these two main issues, *i*) uncertainties of tag lost, tag mortality and reporting rate and *ii*) size-dependent vulnerability for the recreational fishery of the northern pike in Lower Saxony, Germany.

Northern pike (*Esox lucius*) (Fig.2) is an important specie for inland fisheries in the northern hemisphere. In Germany this is due to the angler's preference for piscivorous fish (Aas 2008). The final report for The European Commission Directorate-General for Fisheries in 2003, positioned pike as the first species prefered for German fishermen's catch (21%) and ranking in 5th position in preferences for food consumption (8%). Therefore the AER for this species is of key interest for proper stocks assessment and thus the sustainable development of fishery.

Fig.2: northern pike http://foreverfishingsparky1doug.blogspot.de/p/northernpikeanyone.html

For this reason, management of northern pike can be difficult because fishermen goals can focus on food consumption or on high quality angling (trophy pike). Habitats characteristics should play an important role when choosing the management's scope, because it determines the growth rate (Paukert et al. 2001). Another aspect to keep in mind in northern pike management is the high vulnerability of this specie to angling (Pierce and Tomcko 1995; Paukert et al. 2001; Arlinghaus et al. 2009). Typical regulations include bag limits, minimum and maximum length limit and protected slot length limits.(Paukert et al. 2001)

Materials and methods

Study area

For the objectives of this study, we selected 18 artificial lakes in Lower Saxony, Germany (Table 1). These lakes were small gravel pits and ponds with surface areas smaller than 12 ha. A total of 5 angling clubs is responsible for the fisheries management of these lakes, according to the German fisheries law (Table 1). Different management measures are adopted by each club. For example, a 50 cm minimum length limit was in effect in clubs Bramsche and Stapel and 60 in the others. In all angling clubs, the open angling season goes from the15 th of April until the first of February in the next year.

Table1. Angling clubs and lakes that were included in the study (* natural lakes)

Angling Club	Lakes
SFV "Früh Auf" Bramsche e.V.	Borgstedensee, Darnsee*, Horstsee, Hechtsee
SFV Helmstedt und Umgebung e.V	Buschmühlenteich, Strohmühlenteich, Caroline, Große Mergelgrube, Stiegerteich,
FV Peine-Ilsede und Umgebung e.V	Handorf III, Vöhrum I, Vöhrum II,
VFG Schönewörde und Umgebung e.V.	Großer Weidekampsee, Langer Winkelsee, Kleiner Weidekampsee
ASV "Gut Fang" Stapel e.V	Karpfenteich, Trappsee, Vockfeyer See*

Experimental protocol

Fish tagging.-The first step estimating the AER using the M&R method is tagging a random sample of the population using different fishing gears. A total of 1,232 northern pike (TL>15 cm) were captured and tagged in the 18 study lakes during the 5 sampling events throughout 2011 (March, April, September) and 2012 (March, September) using electrofishing, gillnetting and scientific angling (Table 2). An additional sampling event was conducted in the Vockfeyer See in October 2011 by scientific angling, in Buschmühlenteich,and Karpfenteich in November 2011, via electrofishing. Of these 1232 pikes, 301 were tagged with high reward tags, with a value of 25-.€ in order to estimate the reporting rate (see methods below). The number of tagged fish was different for angling clubs (Table 2). Stapel club had the larger number of tagged fish with 442 and Schönewörde club had the smaller number of tagged fish with 33. Length of tagged fish ranged from 154 to 986 mm (Table 2; Figure 3 and 4).

Gillnetting was conducted using nylon nets. Mesh sizes ranged from 50 to 75 mm. For electrofishing a battery-powered DC electro-fishing unit (Type EFGI 4000, 4 KW, Bretschneider Spezialelektronik, Chemnitz, Germany, 40 cm diameter ring anode) was used to sample pike within the reed and above submerged macrophytes. Scientific angling was conducted with the help of volunteer anglers using non-standardised gear. The number of fish and the distribution of size in each angling club is shown in Fig. 4.

After pikes were caught, they were slightly anaesthetized in 0.4 mL clove oil-ethanol emulsion [(1:9)/L] for better handling and were measured for total length (TL) to the nearest mm and weighed with accuracy of 1 g. Captured pike of more than 150 mm were marked with a passive integrated transponder (PIT) tag measuring 2.15 mm in diameter and 12 mm in length (Oregon RFID, Portland, Oregon, USA) and a T-bar anchor tag (TL < 400 mm TL, FD -68BC FF; TL > 400 mm TL, FD-68B; Floy Tag Inc., Seattle, Washington, USA). PIT tags were implanted with a hypodermic needle in the dorsal musculature on the left side of the nape. The T-bar tags were of grey colouration, individually numbered and anchored in the left side of the anterior base of the dorsal fin, using a Dennison Mark III tagging gun with a 27 mm needle. T-bar tags, i.e. externally visible tags, are necessary for the participation of anglers and calculation of reporting rate. In order to further correct possible bias in the reporting rate by tag loss and tag mortality, an experiment was conducted in an experimental pond to estimate both (see Hühn et al. 2014).

Table 2: Number of northern pike tagged with standard and high value reward tags and their minimum and maximum total lengths by Angling Club and year. See that tagged number represent the final tagged number, i.e. standard tag plus high reward tag

Angling Club	Year	Tagged	Min-max length (mm)	High reward (25€)	Min-max length (mm)
Bramsche	2011	110	154-777	54	186-777
	2012	74	172-931	0	
Helmstedt	2011	293	187-797	95	301-797
	2012	142	379-617	0	
Peine	2011	92	199-935	67	226-935
	2012	46	189-745	0	
Schönewörde	2011	19	229-732	19	229-732
	2012	14	160-687	0	
Stapel	2011	247	166-837	59	222-837
	2012	195	167-986	7	248-495
TOTAL		1232	154-986	301	186-935

Anglers recaptures and estimating tag reporting rate.- The second step estimating the AER, using the M&R method, is to recapture the tagged fish by the recreational anglers. As mentioned in the introduction, a key aspect of this point is the estimation of the fraction of fish captured and reported. The reporting rate (λ) was calculated using the following formula (Pollock et al. 2001):

$$\lambda = \frac{\left(\frac{C_S}{T_S}\right)}{\left(\frac{C_H}{T_H}\right)} \qquad (1)$$

where C_S is the number of standard tag fish reported by anglers, T_S is the number of standard tags released, C_H is the number of high-reward tags returned and T_H is the number of high-reward tags released.

The standard deviation for the reporting rate was calculated as (Meyer and Schill 2014)

$$sd(\lambda) = \sqrt{var(\lambda)} \quad (3) \quad \text{where} \quad var(\lambda) = \lambda^2 * [\frac{1}{C_s} + \left(\frac{\lambda}{C_s}\right) * \left(\frac{T_s}{T_H}\right)^2 * C_H \quad (4)]$$

To avoid bias, the reporting rate of standard tag is corrected with the reporting rate of high reward tags. Therefore high reward tags were anchored in some pikes instead of standard tags (Table 2). It is assumed that fishermen reported all the high-value tags that were caught (Nichols et al. 1991; Pine et al. 2003, Pollock et al. 2001). Angling clubs were informed about the tagging process and encouraged to participate. Fishermen received a diary book (with information about the tagging program) in which they, anonymously, report their catches. In total, more than 5,637 diaries were sent out to the members of the five angling clubs (Year 2011: 2759; Year 2012: 2878). Reward prices were given at the end of the two year survey to ensure participation and only to the first one who noted down the high reward tag id, in order to avoid fishermen from cheating.

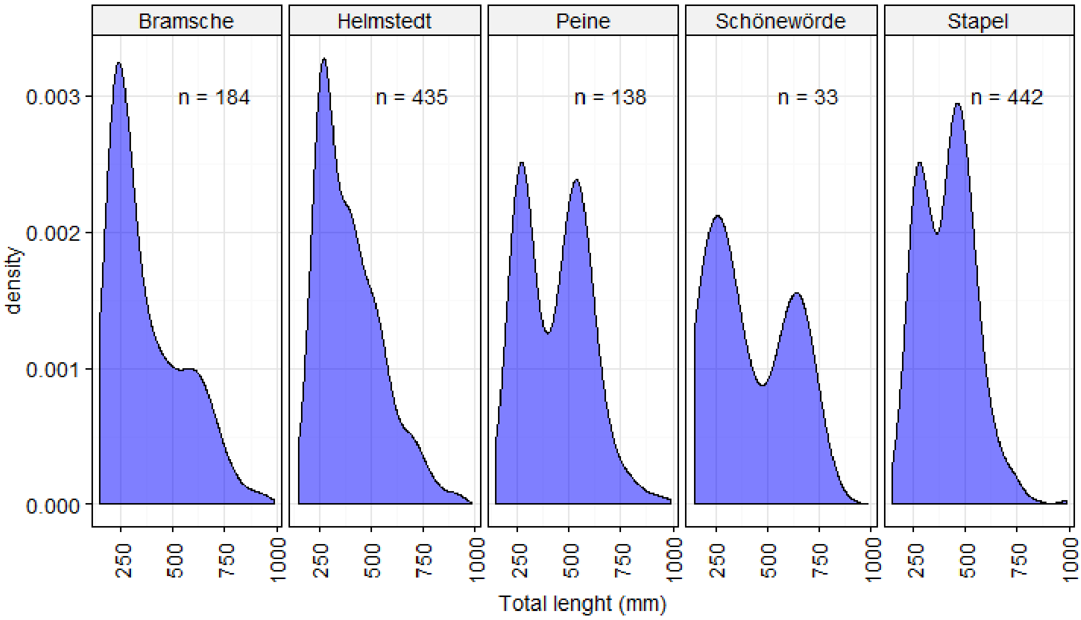

Fig.3. Length distribution of marked northern pike in five Lower Saxony Angling Clubs. (n= fish's total number)

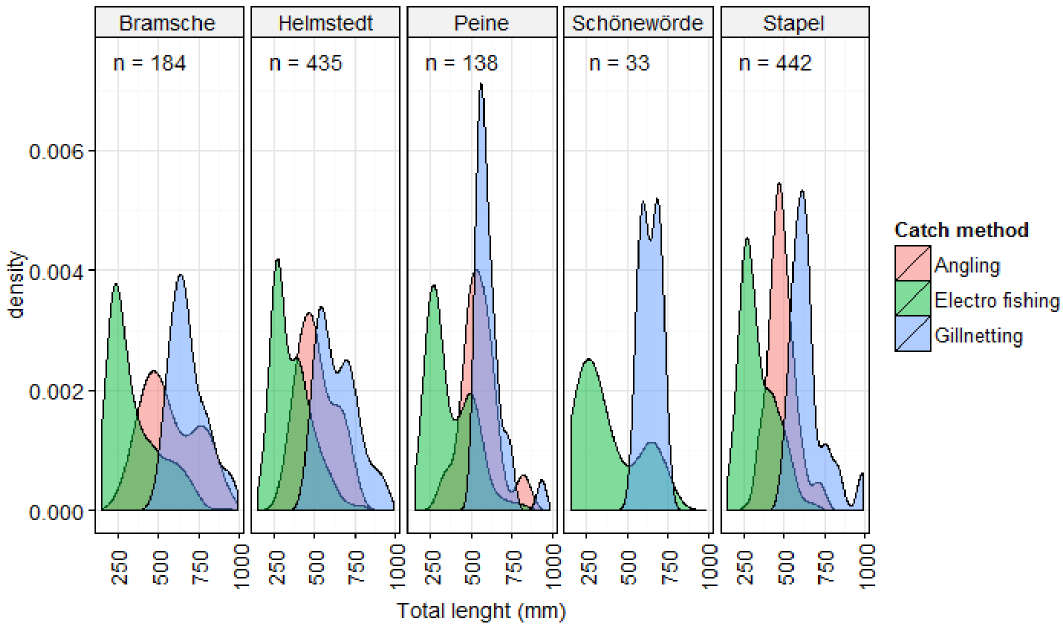

Fig.4. Length distribution of marked northern pike by catch method in five Lower Saxony Angling Clubs. (n= fish's total number)

Estimating annual exploitation rate.- Annual exploitation rate was calculated and adjusted to correct the possible bias due to tag mortality, tag loss and reporting rate, through a parametric bootstrap resampling according to the method provided by Gwinn 2014 (Dan Gwinn on WordPress.com). The basis of this method relies on the explicit incorporation of the uncertainty associated with each variable following the following formulation (5)

$$T_{adjusted} \sim \text{binomial}\ (T_{\text{released}},\ (1\text{-}T_{\text{mort}})(1\text{-}T_{loss}))$$

$$T_{harvest} \sim \text{binomial}\ (T_{adjusted},\ U_{point})$$

$$T_{returned} \sim \text{binomial}\ (T_{harvest},\ R)$$

$$U_{boot} = T_{returned}/R/T_{adjusted}$$

and

$$U_{point} = \frac{T_{returned}/R}{T_{released}(1-T_{mort})(1-T_{loss})} \qquad (6)$$

where $T_{released}$ is the number of fish, T_{mort} is the tag mortality, T_{loss} is the tag loss rate, U is the exploitation rate, R is the reporting rate, and U_{boot} is the value of U for one bootstrap iteration (Dan Gwin on WordPress.com).Tag mortality and tag loss values were obtained from Hühn et al. 2014. We estimated the AER for the two different years and for 2011, tag mortality was 9.8 ± 0.7 % and tag loss 12.5± 0.5 %, while for for 2012 tag mortality was 1.8 ± 0.6 % and tag loss 20± 0.7 %. These values correspond to the estimation of tag loss and mortality after 325 days for 2011 (approximately one year) and after 520 days for 2012 (approximately two years). The AER for 2011 and 2012 (as well as its uncertainty) were calculated using the formula described in equation (5) and (6) and is based on 10,000 iterations.

As mentioned in the introduction, exploitation rate is usually size dependent as the vulnerability of fish increases due to increasing body size (Post et al. 2003; Arlinghaus at al. 2010). As all fish tagged were not vulnerable because of their size, we first estimated the annual exploitation rate for every year by size class (based in 5 cm classes), including the uncertainty of tag loss, tagging mortality and reporting rate. We used these size-dependent AER to correct the number of marked and recaptured fish per size class and year in order to incorporate the vulnerability of fish to angling and thus obtaining a realistic accurate annual exploitation rate. To do that, we standardized the AER considering the maximum AER per size class to be 1 calculating the factor to correct the number of fish tagged and returned. This correction of the number of fish tagged and returned due to their size vulnerability was used to estimate the AER by size class and year.

Annual exploitation rates were estimated for the total population, for angling clubs and for lakes. These latter results may be biased due to the scarcity of the data.

Annual exploitation rates have been calculated using a custom script in R (R Core Team, 2014) and the library ggplot2 of the R-package was used for visualization.

Selectivity.-In addition to exploitation rates, size selectivity was also estimated for every angling club. For the selectivity curve, a binomial generalized linear model with the two years data was applied. The independent variable was the total length of the fish (TL), angling clubs (AC) and their interaction. For the dependent variable (0) represent tagged fish not recaptured and (1) tagged fish recaptured.

$$\text{Logit}(p) = b_0 + b_1(TL) + b_2(\text{AC Helmstedt}) + b_3(\text{AC Peine}) + b_4(\text{AC Schönewörde}) + b_5(\text{AC Stapel}) + b_6(Tl*\text{AC Helmstedt}) + b_7(Tl*\text{AC Peine}) + b_8(Tl*\text{AC Schönewörde}) + b_9(Tl*\text{AC Stapel}) \quad (7)$$

where logit (p) is the logistic probability of a tag being returned and b_i are the parameter to be estimated.

And the predicted returned rate (p) is:

$$p = e^{logit(p)} / [1 + e^{logit(p)}] \quad (8)$$

Growth was not considered because it was assumed that the length difference within the size at tagging and size at recapture were similar (Fig 5 and 6)

Size selectivity has been calculated fitting the binomial generalized linear model in R

Results

Fish returned.- Anglers reported, within the 2 years, 156 tagged fished including 59 high reward tag (Table 3). Some fish were released after being caught. This implied that some fish were caught more than one time. Lengths of returned fish ranged from 187 to 806 mm (length measured when tagged)(Fig 6 and 7)

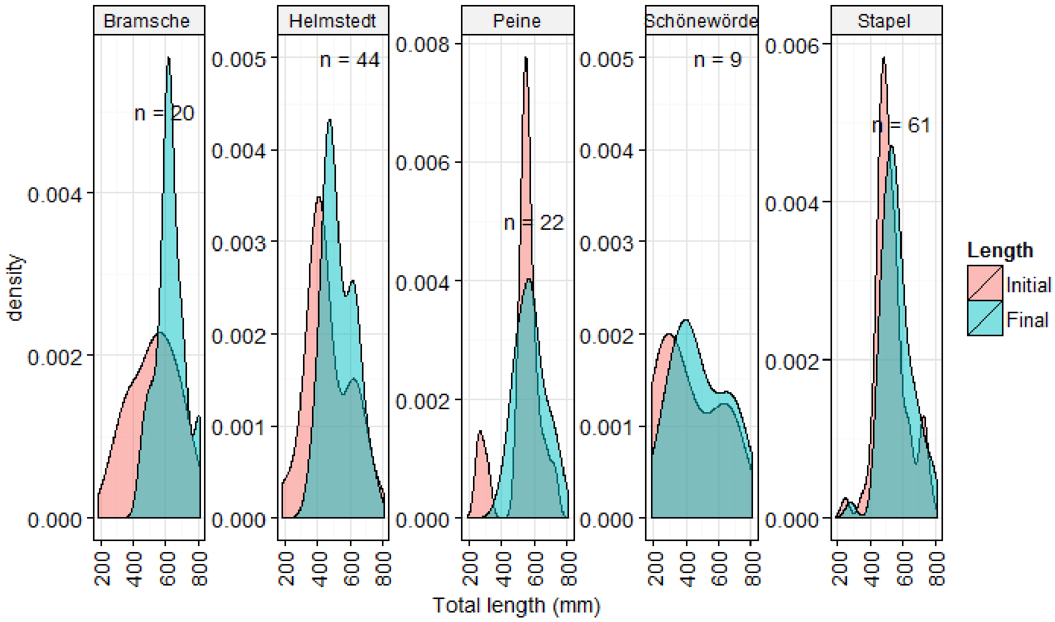

Fig.5: Comparing Initial and Final length of marked and recaptured northern pike in five Lower Saxony Angling Clubs within two years. (n= fish's total number)

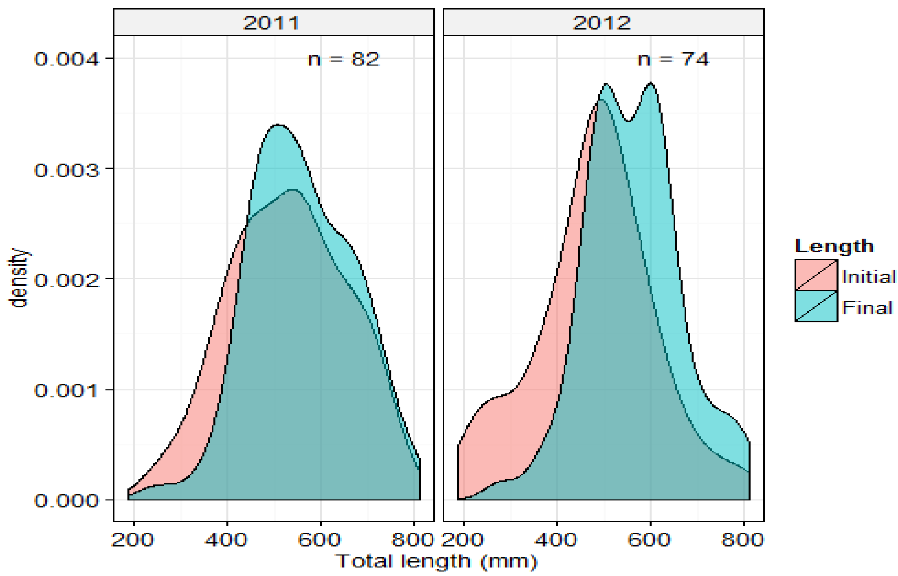

Fig.6: Comparing Initial and Final length of marked and recaptured northern pike in five Lower Saxony Angling Clubs by year.(n= fish's total number)

Table 3: Number of northern pike returned with standard and high value reward tags and their minimum and maximum total lengths by Angling Club and year. Lengths of returned fish are the lengths measured when tagged. See that tagged numbers represent the final returned number, i.e. standard tag plus high reward tag.

Angling Club	Year	Returned	Min-max length (mm)	High reward (25€)	Min-max length (mm)
Bramsche	2011	7	374-714	3	543-700
	2012	13	249-806	6	249-693
Helmstedt	2011	25	330-797	14	330-797
	2012	20	187-646	5	301-646
Peine	2011	15	314-680	10	314-647
	2012	7	252-728	4	252-591
Schönewörde	2011	7	253-676	7	253-676
	2012	2	229-687	0	
Stapel	2011	28	400-732	6	465-719
	2012	32	247-774	4	247-554
TOTAL		156	187-806	59	247-797

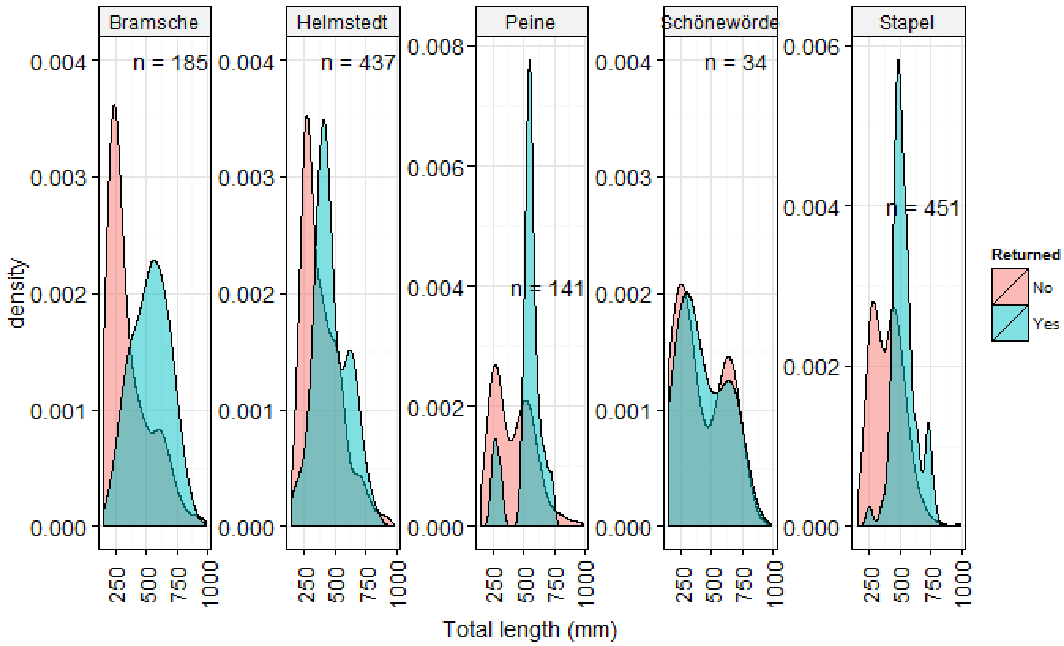

Fig.7. Length distribution of marked and returned or not returned northern pike in five Lower Saxony Angling Clubs within two years. Lengths of returned fish are the lengths measured when tagged. (n= fish's total number)

Reporting rate.- Estimated reporting rate was 53± 9% (C_S=97; T_S=931; C_H=59; T_H=301)

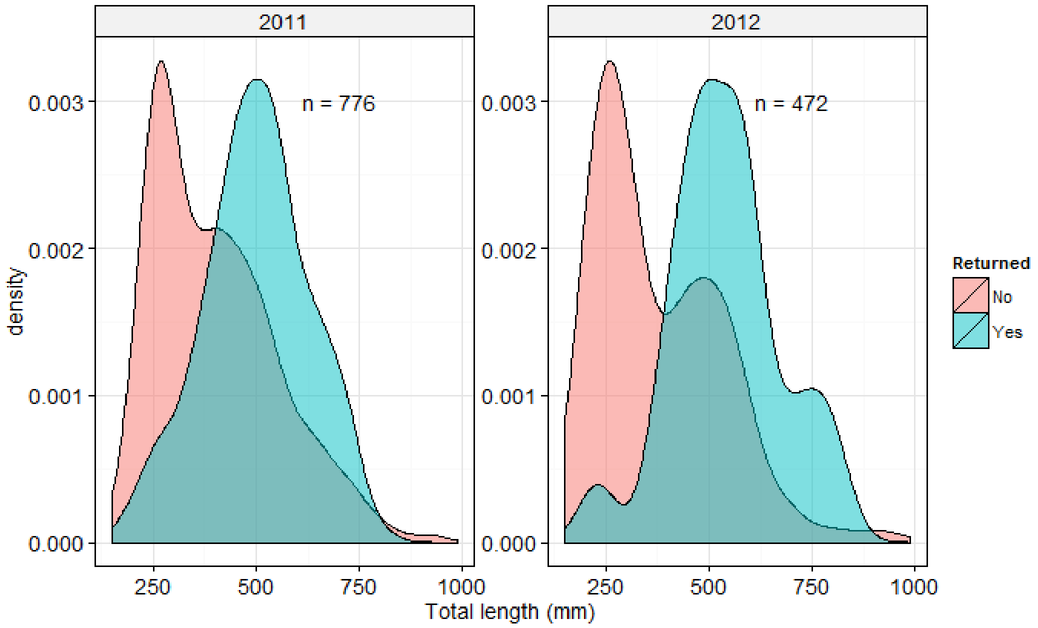

Fig.8. Length distribution of marked and returned or not returned northern pike in five Lower Saxony angling Clubs by year. Lengths of returned fish are the lengths measured when tagged. (n= tagged fish's total number)

Figures 9 and 10 show length distribution of harvested pike.

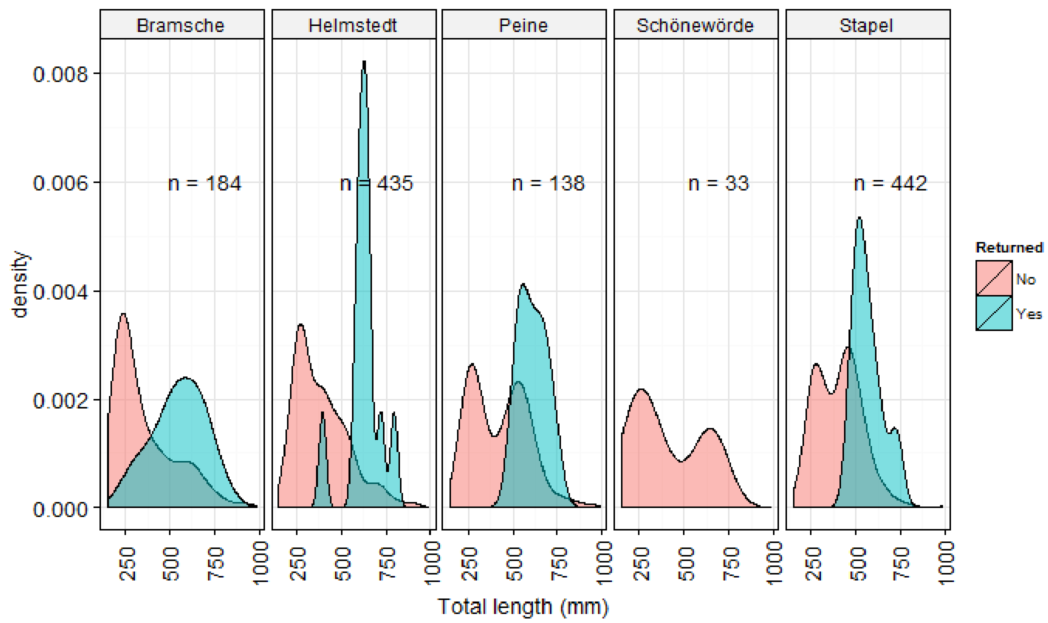

Fig. 9 Length distribution of harvested pike by angling club in five Lower Saxony angling Clubs by year. Lengths of returned fish are the lengths measured when tagged (n= tagged fish's total number)

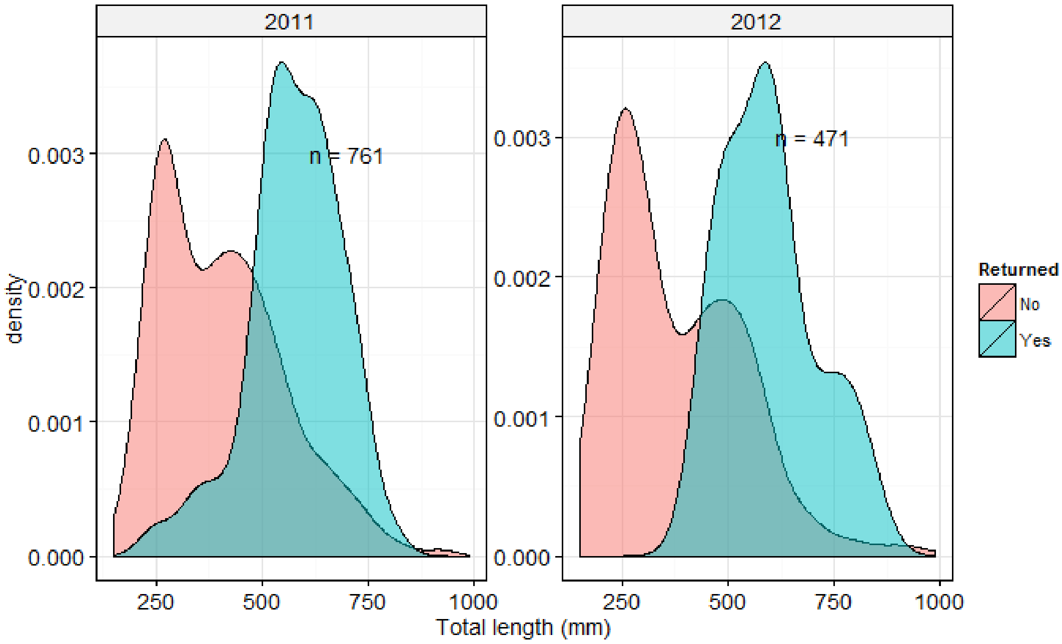

Fig. 10 Length distribution of harvested northern pike by year in five Lower Saxony angling Clubs by year. Lengths of returned fish are the lengths measured when tagged (n= tagged fish's total number)

Exploitation rate.-Exploitation rate was calculated by size class (Table 4 and 5) and plotted (fig.11) for every year and later corrected including the vulnerability of fish to angling. The maximum exploitation rate (60 ± 22.4%) in 2011 occurred in fish which a total length of 700-750 mm. In 2012 the maximum is lower (28.7±11.9 %) at total length of 600-650 mm. In 2011 the trend was to increase exploitation rate with total length until t600-650 mm then decreased slightly to increase again up to the maximum. 2012 showed a smoother increase until the maximum after which it decreases to zero.

Annual exploitation rate (Fig.12) for 2011 was 35.7 ± 8.1 % (95 % CI ± 35.9), after being corrected with vulnerability. In 2012, the annual exploitation rate was 17.6 ± 4.1% (95 % CI ± 17.7), almost half than in 2011.

Exploitation rate differences along the fish total length are a evidence of size-selective angling.

Table 4. Northern pike exploitation rate (%) adjusted and corrected with vulnerability for length class in 2011 in five Lower Saxony Angling Clubs. (I.C = Confidence Interval, represents the uncertainty)

size	ER	sd	CI r	CI l
0-50	NA	NA	NA	NA
50-100	NA	NA	NA	NA
100-150	NA	NA	NA	NA
150-200	NA	NA	NA	NA
200-250	NA	NA	NA	NA
250-300	NA	NA	NA	NA
300-350	NA	NA	NA	NA
350-400	NA	NA	NA	NA
400-450	NA	NA	NA	NA
450-500	0.0	0.0	0.0	0.0
500-550	0.0	0.0	0.0	0.0
550-600	0.0	0.0	0.0	0.0
600-650	53.9	17.4	54.3	53.6
650-700	29.7	19.6	30.1	29.4
700-750	60.0	22.4	60.5	59.6
750-800	NA	NA	NA	NA
800-850	NA	NA	NA	NA
900-950	NA	NA	NA	NA
950-1000	NA	NA	NA	NA

Table 5. Northern pike exploitation rate (%) adjusted and corrected with vulnerability for length class in 2012 in five Lower Saxony Angling Clubs. (I.C = Confidence Interval, represents the uncertainty)

size	ER	sd	CI r	CI l
0-50	NA	NA	NA	NA
50-100	NA	NA	NA	NA
100-150	NA	NA	NA	NA
150-200	NA	NA	NA	NA
200-250	0.0	0.0	0.0	0.0
250-300	NA	NA	NA	NA
300-350	0.0	0.0	0.0	0.0
350-400	0.0	0.0	0.0	0.0
400-450	0.0	0.0	0.0	0.0
450-500	11.2	11.0	11.5	11.0
500-550	20.4	7.9	20.5	20.2
550-600	17.0	11.6	17.2	16.8
600-650	28.7	11.9	28.9	28.5
650-700	NA	NA	NA	NA
700-750	0.0	0.0	0.0	0.0
750-800	NA	NA	NA	NA
800-850	0.0	0.0	0.0	0.0
900-950	NA	NA	NA	NA
950-1000	NA	NA	NA	NA

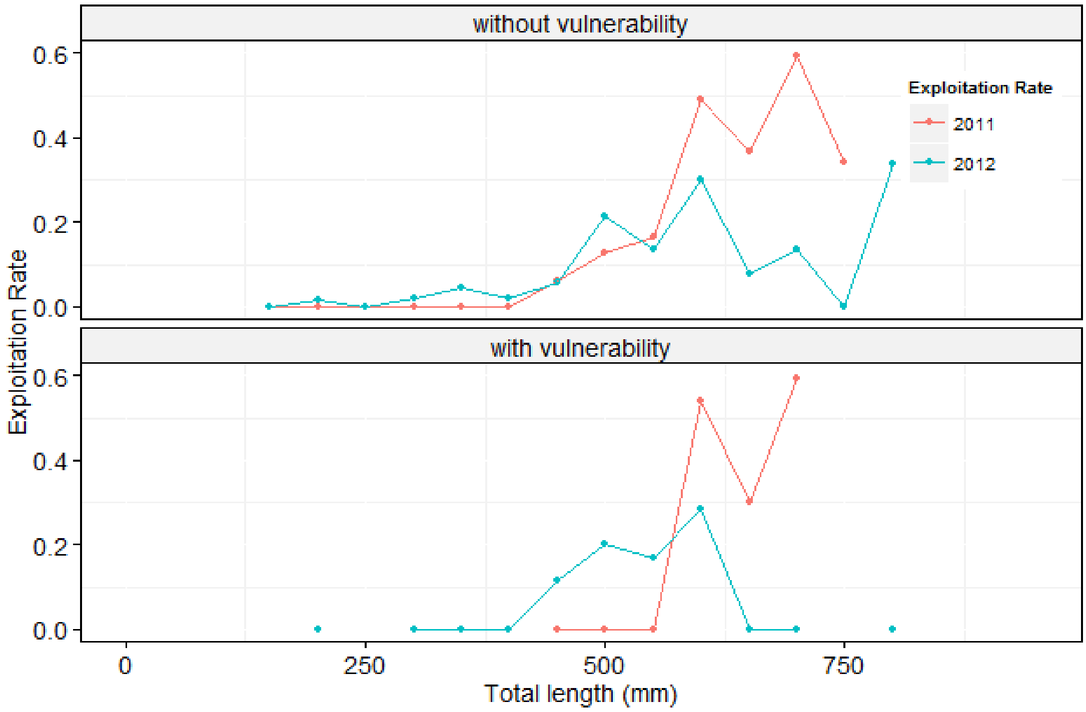

Fig.11. Exploitation rate size dependent adjusted and corrected with vulnerability or not, in 2011 and 2012 for northern pike in Lower Saxony

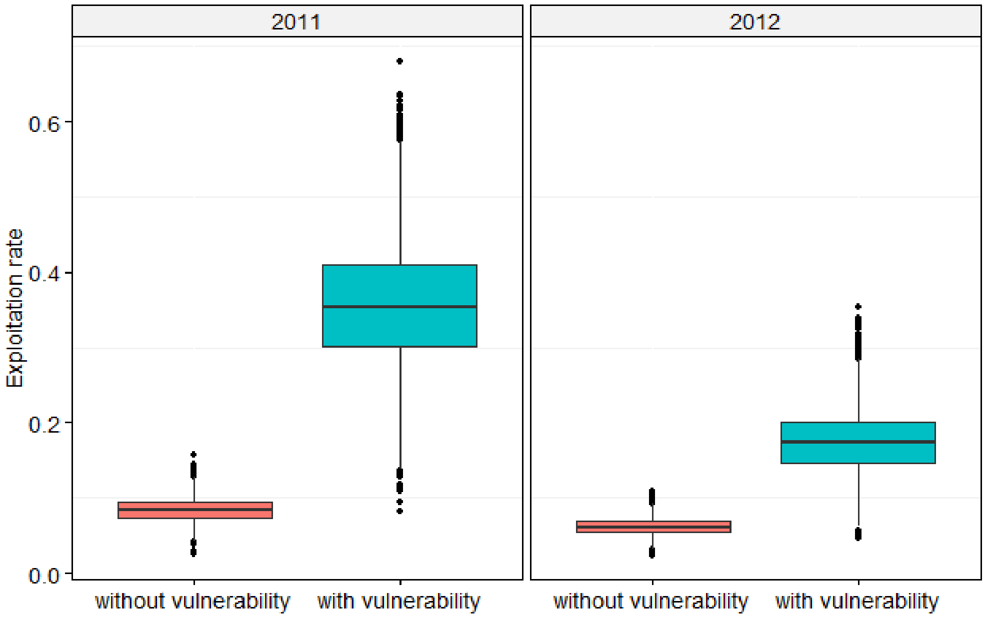

Fig.12 Comparing boxplot exploitation rate adjusted and corrected with vulnerability or not, in 2011 and 2012 for northern pike in Lower Saxony

Exploitation rates for angling clubs are shown in Figure 13 and Table 6. Because the number of data were scarce, the uncertainties were big, as the whiskers show it. Angling clubs with higher exploitation rates were Bramsche and Helmstedet. For the angling club Schönewörde more data are needed but it can be said that the exploitation rate is close to zero.

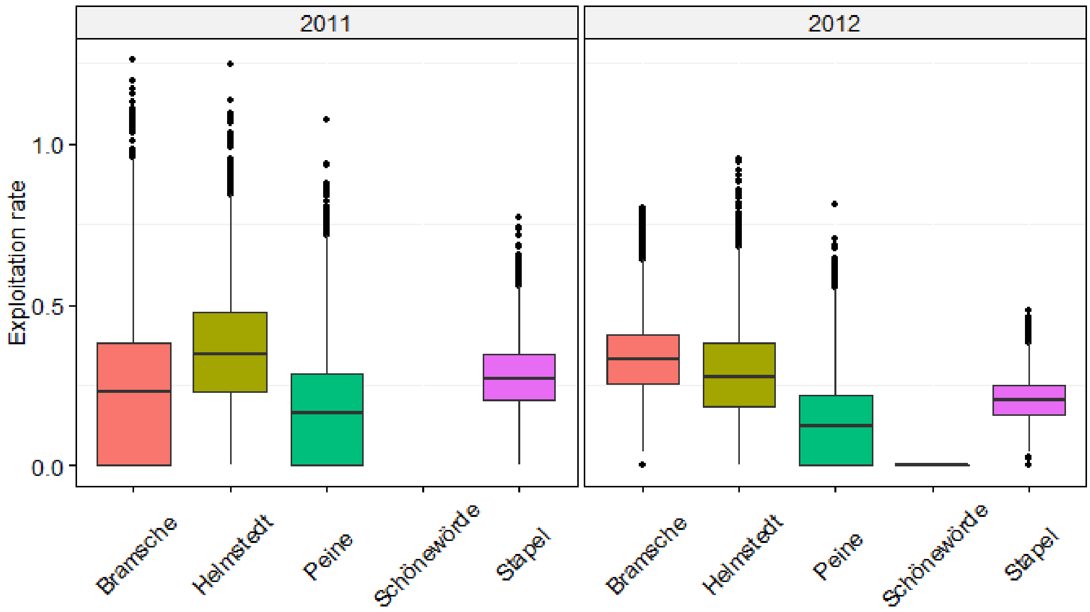

Fig.13 Annual exploiation rate box plot of northern pike in 5 Lower Saxony by angling clubs.

Table 6. Annual exploitation rate of pike in 5 Lower Saxony angling clubs

Angling club	Year	mean	sd	Clr	Cll
Bramsche	2011	23.8	22.9	24.3	23.4
	2012	33.7	11.6	33.9	33.5
Helmesdet	2011	35.8	18.8	36.2	35.5
	2012	28.7	15.5	29.0	28.4
Peine	2011	17.0	16.4	17.3	16.7
	2012	12.5	12.3	12.8	12.3
Schönewörde	2011	NA	NA	NA	NA
	2012	0	0	0	0
Stapel	2011	27.3	10.4	27.5	27.1
	2012	20.6	6.5	20.7	20.5

Selectivity.- As shown in the figure 11,the probability to capture an individual pike was size selective. The recapture rate varied across the different total length. At 400 mm, the returning rate increased considerably compared with smaller sizes, increasing gradually until the peak in 700 mm where circa 40% of the fish with this size were recaptured (Fig. 14).

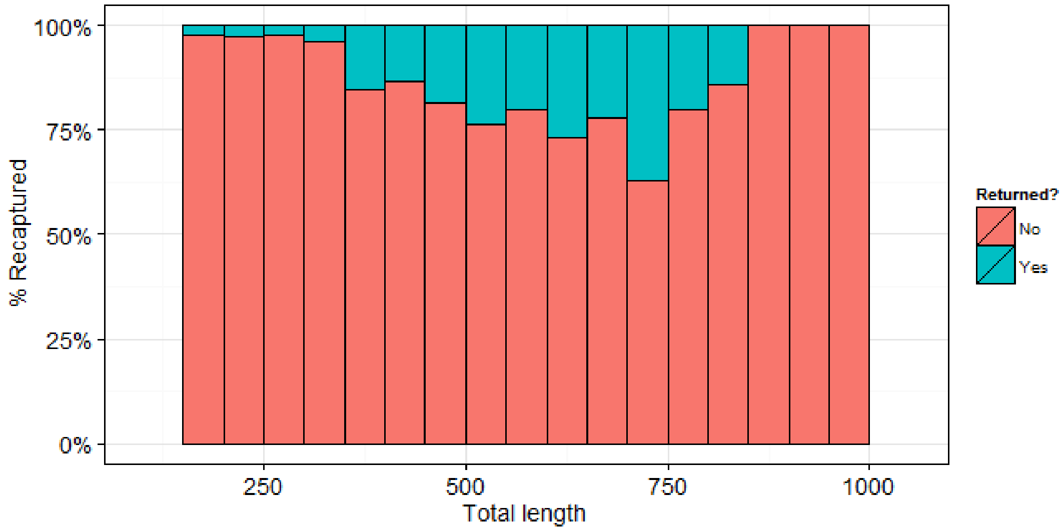

Fig.14 Bar charts showing the relation between size and returned rate in five Lower Saxony Angling Club within two years

The logistic regression model (table 7) showed that the probability of catch (vulnerability) was significantly affected by the total length of individual (Table 7) Neither the effect of angling club nor the effect of the interaction between total length of fish and angling clubs were significant and were removed from the full model.

The predicted selectivity curve is shown in Figure 13 and it describes a logistic regression with a L_{50}, i.e. the probability that half of the fish are caught, at 878-887 mm total length. Figure 16 shows the predicted curves by angling club.

Table 7. Binomial logistic regression model of logit (p) for northern pike in five Lower Saxony Angling Club during 2011 and 2012

Parameter	Estimate	z values	Pr(>|z|)
a	-3.9915851	-14.247	<0.001
Length	0.0045331	8.248	<0.001

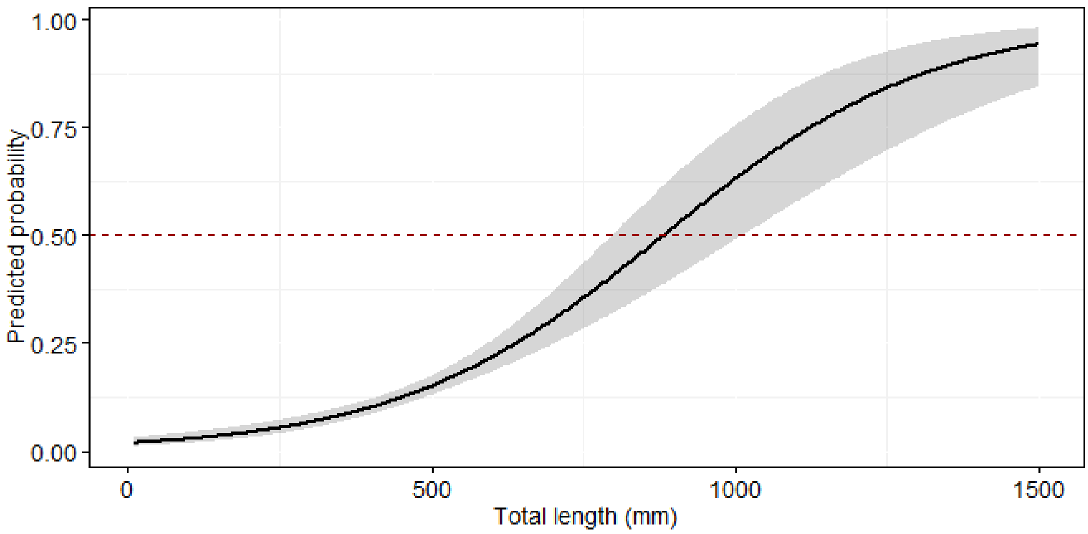

Fig.15 Predicted selectivity curve for total length of northern pike in five Lower Saxony angling club during the years 2011 and 2012. Red line correspond to the L50

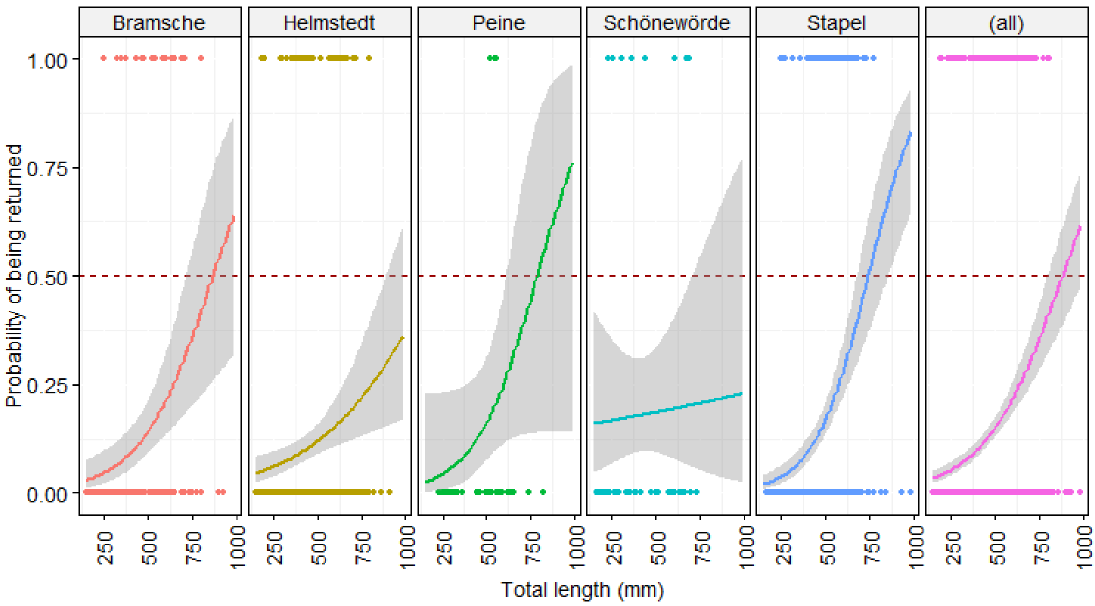

Fig.16 Predicted selectivity curve for total length of northern pike by angling club during the years 2011 and 2012 in Lower Saxony, Germany. Red line correspond to the L50

Conclusion

In this study we estimated the total annual exploitation rate for two given years (2011 and 2012) for 18 lakes in Lower Saxony, incorporating uncertainties and size-dependent vulnerability. We have treated with two of the major difficulties estimating AER using one of the most common methods applied to recreational fishery: the uncertainties associated with tag loss, tagging mortality and reporting rate; and the size-dependent vulnerability of exploited species. AER is a key aspect for stock assessment (Hilborn 2003; Allen and Hightower 2010) and therefore the estimates and associated uncertainties can be useful to inform anglers associations and managers for sustainable development of the fishery of the northern pike in Lower Saxony.

The AER were different across the two years studied here. For 2011, the annual exploitation rate corrected with vulnerability was 35.7 ± 8.1 %, while for 2012, the annual exploitation rate was 17.6 ± 4.1%. Between years, differences in the AER of the same fishery are expected and have been observed in other fisheries. For example, Crawford and Allen (2006) found similar results for bluegills (*Lepomis macrochirus*) and redear sunfish (*L.microlophus*) and the AER varied over years. In our case study, the reason to explain the lower exploitation rate in 2012 could be that the fishing effort for this year was also smaller, 68.8 anglers-hours/ha against 80.9 anglers-hours/ha for 2011. This highlights the importance of establishing long-term monitoring programms to accurately asses the inter-annual variability in the AER.

These estimates of the AER allow us to interpret the results as F and therefore evaluate the health status of the exploitation of the northern pike in Lower Saxony. Assuming that natural mortality (M) was 0.2 (Pauly 1980) and transforming the exploitation rate into instantaneous total mortality (F) (F= Ln (1-AER)), it was possible to say wether the exploitation rates were sustainable. According to Lester et al. (2014) and Zhou et al. (2012), fishing mortality shouldn't be higher than natural mortality. Furthermore, Lester et al (2014) proposed that the instantaneous total mortality to be safe (F_{safe}) considering the uncertainties associated to the estimation of F should be around 0.75M. For 2011, the instantaneous total mortality was 0.44, that made the exploitation rate unsustainable. F_{safe} should be 0.15. Population with high exploitation can suffer from a decrease in the numbers of adults and truncation of age and length distribution (Miranda et al 2002). For 2012, F was 0.19, still higher than the $F_{safe.}$ Exploitation rates must be reduced in order to prevent the over exploitation of angling pike in this 18 lakes.

We found some differences in the AER across angling clubs although the estimations were highly overlapped. For example, AER for the angling club Peine was 17 % in 2011 while in the angling club Bramsche was 23.8 % but the boxplots showed that in both of them the AER could vary from 0 to 40 % (Figure 13). Differences in AER have been observed in other studies and usually are associated with different fishing efforts (Pierce et al. 1995)

If we consider the AER estimated for the different angling club for sustainable exploitation, only the angling club Schönewörde and Peine in 2012 were sustainable (Table 8). Remaining angling clubs were unsustainable as is shown in table 8, considering that F_{safe} should be 0.15.

Table 8. Instantaneous total mortality

Angling club	Year	F
Bramsche	2011	0.27
	2012	0.41
Helmesdet	2011	0.44
	2012	0.34
Peine	2011	0.19
	2012	0.13
Schönewörde	2011	NA
	2012	0.00
Stapel	2011	0.32
	2012	0.23

In this study we coped with two major problems associated with the estimation of the AER with the M&R method: (1) the uncertainty associated to the estimation to the reporting rate, tag loss and tagging mortality and, (2) the size dependent vulnerability. It has been mentioned by different authors (Allen and Hightower 2010, Miranda et al. 2002) that the reposting rate may be the more difficult part in using M&R methods, because it is difficult to know how fishermen will respond, if they will report all tagged fish that they catch or just some of them. In this study we obtained a RR of 53± 9%

Miranda et al. 2002 proposed, in order to correct the estimation of reporting rate, to use simultaneously to the tagged fish a postcard program. The reporting rate of the postcard is used to adjust the reporting rate of tagged fish.

However, Nichols et al. 1991 said that to be sure that fishermen report all high reward tag, the values of those must be at least 100.- $.

In this study, high-reward tags were used to have an accurate reporting rate, but the value of those was 25.- €. According to the mentioned above, our reporting rate could be overestimated, leading us to an underestimation of the exploitation rate.

Besides the uncertainty associated with the estimation of the reporting rate, tag loss and tag mortality, are also estimated with error. In this work, we used the data previously published in our species case study, *Esox Lucius,* by Hühn et al. (2014). We see how these estimations can widely vary across the different measures. For example, mortality at 325 days post-tagging varies in pike from 9.1% to 10.5%, although the average value is 9.8%. Or the tag loss can be highly variable as a given fish can lose the tag from 0 to 520 days. For example for 195 days tag loss is 6% while for 520 days it is 20%. However, both, the uncertainty associated with the reporting rate and tag loss and mortality were included in our approach through parametric bootstrapping, providing a more realistic value of the AER.

The second major problem that we coped with here that estimating AER using M&R is the sized dependent vulnerability. Size-dependent mortality is common in recreational fisheries (Lewin et al. 2006) and usually larger fish are more vulnerable than smaller sizes. Here we estimated the size-selectivity estimating the AER per size fraction. The results showed a exploitation rate clearly size dependent, where large/medium fish have the maximum exploitation rate. In 2011, the maximum exploitation rate (60 ± 22.4%) occur at 700-750 mm . However few fish with this size were tagged (e.g. in 2011 only 20 fish were tagged which length range 700-750 mm).

Exploitation rates are higher than the ones obtained by Pierce and Tomcko (1995) in seven lakes in Minnesota. Their ER range from 4-22 % and our from 13-44%. But both results show size dependent exploitation rates with maximums within larger sizes. Our approach allowed us to determine the AER corrected by size selectivity or size dependent vulnerability which provides a more realistic estimate of the exploitation rate.

The usefulness of our AER corrected for size vulnerability was evidenced when we estimated size selectivity using a conventional binomial regression against fish size. The resulting selectivity curve (Fig. 15) agrees with the results of exploitation rates, i.e. size is a significant predictor of vulnerability. However, the predicted curve never reaches 1 which makes it arguable if this method is correct to estimate size selectivity or the probability of being captured by a lure. The scarcity of data at large fish sizes could be the reason for the inadequacy of this method. Fortunately, the annual exploitation rate per size classes, corrected for vulnerability, give us information about the size selectivity. We saw how the population for fish smaller than 400 mm is almost fully unexploited (Fig. 11) and for bigger size, the exploitation rate increases until it reaches the maximum at a medium size of 700 mm. We can not fully extract a robust conclusion for the AER of larger sizes (up to 1000 mm) as the sample size is very limited. However, there is a tendency to decrease compared to those medium sizes. This is very important as it suggests that large fish (usually big females) are less vulnerable than expected in linear relationship between size and vulnerability. It is known how large and old females can contribute more to the resilience of the exploited populations (Gwinn et al. 2013) and therefore the bell shaped size-selectivity observed here suggests a benefit for those large females. However, we have to be cautious about results as the sample size is very limited and there is a need for further experiments about this topic. We hope that all the information presented here can contribute to the sustainable development of the fishery of pike in Germany

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