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Tracing possible drivers of synchronously fluctuating species catches in individual logbook data

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Abstract Recreational fisheries statistics can provide valuable information on the dynamics of fish stocks and their exploitation. For some reservoirs in the Czech Republic, there are conspicuous synchronous fluctuations in catches of different species that might be caused by fishing skills and strategies. This study describes a method that could detect signatures of such phenomena in individual logbooks. It classifies anglers by species reported during 1 year and compares the resulting angler groups by group size, fishing effort, catch per unit effort (CPUE) and annual catch. The method is illustrated by data from one reservoir, showing that the number of generalist anglers who caught several species was higher than expected. Generalists also had higher catches and effort but lower CPUE than specialists who caught only one of the species. The results indicate that generalist anglers with a low degree of specialisation and high effort could contribute to long-term correlations in species catches.

KEYWORDS: angler preferences, catch statistics, catch per unit effort, reservoirs, time series correlations.

Introduction

Recreational fishing is an important activity involving a substantial proportion of the population in many countries (Arlinghaus *et al*. 2010). As a consequence of its social, economic and ecological impacts, recreational fishing is regulated and monitored in many countries. Anglers in the Czech Republic are obliged to record daily catches in locally administered logbooks and submit their annual records to the authorities, which extract selected data. Similar procedures exist in other countries (Toivonen *et al*. 1999; Wedekind *et al*. 2001; Smith 2002; Cooke & Cowx 2004). Some authors have questioned the validity and reliability of the resulting statistics, highlighting possible biases (Essig & Holliday 1991; Pollock *et al*. 1994; Bray & Schramm 2001). However, other studies using comparison with direct assessment techniques confirmed that catch

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statistics can be used as independent sources of data (Ebbers 1987; Pivnička *et al.* 2005; Younk & Pereira 2007) and the catch statistics are widely accepted as a measure of the relative abundance of target species and their long-term trends (Green *et al.* 1986; Sztramko *et al.* 1991; Kerr 1996).

Reliable statistics can provide important insights into the dynamics of exploitation as well as natural fluctuations of the stocks. Time series of catches for some Czech stocks show a peculiar phenomenon of more or less regular fluctuations, and some species fluctuate in synchrony (Smutný & Pivnička 2001; Pivnička & Rybář 2001; Fig. 1). This might reflect the true state of harvestable stocks with the variability caused by synchronous fluctuations in stocking, variable environmental drivers, such as fluctuations in overwintering mortality affecting cohort strength, and natural cycles in population dynamics (Pivnička & Rybář 2001). However, data required to test these hypotheses are inadequate for most Czech stocks. The true drivers of these fluctuations, thus, remain unknown.

It is possible that detailed data on individual catches could provide the answers. The fluctuations might be driven by harvesting patterns, i.e. by angler preferences and behaviour. Synchronous fluctuations will arise when a sizeable proportion of anglers catch the given pair of fish species during each year, either because they use a fishing technique or strategy that targets multiple species or because they switch focus to different species over the course of the fishing season. This explanation could be generally applicable and not just limited to Czech reservoirs. Individual-level data are required to test this hypothesis, and this study proposes a method to analyse individual logbook data to assess harvesting patterns, with the aim to highlight possible drivers of the synchronous fluctuations.

Methods

Sources of data

The analyses used one year's data from Slapy Reservoir, a large (13.9 km^2) and remote reservoir south of Prague on the Vltava River (49°49′28″ N; 14°25′58″ E) with numerous camping sites and small hotels, suitable for weekend and summer holiday anglers. The reservoir is administered by one regional office of the Czech Anglers' Union (CAU). Unfortunately, only summary statistics have been routinely collected in the past from the logbooks by the CAU, because the processing of individual logbooks is time-consuming and there has been little interest in the data; the resulting time series of total catches are presented mainly for perspective. Data broken into total catches of members of individual local organisations have only been collected since 2003, and individual logbooks with data on fishing trips (including unsuccessful ones) and fish caught and retained were available only from 2008.

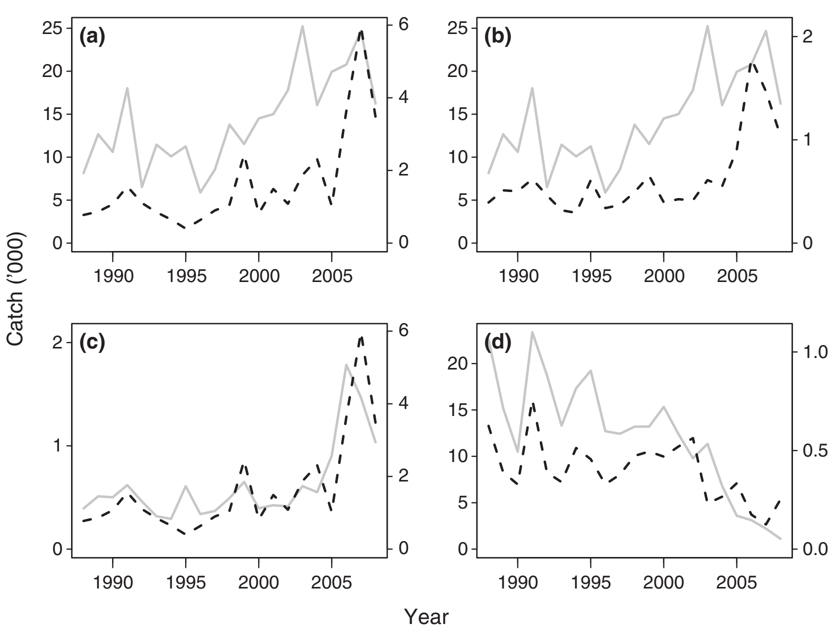

Figure 1. Comparison of selected time series of catches at the Slapy Reservoir: (a) carp (grey solid line, left *y*-axis) and pikeperch (dashed line, right *y*-axis); (b) carp (grey solid line, left *y*-axis) and pike (dashed line, right *y*-axis); (c) pike (grey solid line, left *y*-axis) and pikeperch (dashed line, right *y*-axis); (d) perch (grey solid line, left *y*-axis) and eel (dashed line, right *y*-axis). Catches in thousands of fish.

It was not possible to obtain logbooks of all anglers who visited the reservoir because they would have to be selected manually from all local CAU archives (in total more than 250 000 logbooks, many of which had been discarded by the time this study was initiated). Instead, logbooks were subsampled and restricted to anglers from 11 local CAU organisations that contributed most to the overall harvest at Slapy in 2008. All anglers from these organisations who visited Slapy in 2008 were included in the analyses ($n = 2477$).

Analyses of individual annual catches focussed on four species that were most commonly caught by the anglers included in this study in 2008 (see Results for details): bream, *Abramis brama* (L.), carp, *Cyprinus carpio* L., pike, *Esox lucius* L. and pikeperch, *Sander lucioperca* (L.) abbreviated, respectively, as A, C, E and S in model descriptions, tables and names of triplets of species.

Analysis of individual annual catches

To detect potential biases with which anglers catch a given set of N species of fish, each angler can be classified according to N factors, corresponding to the presence/absence of each of these species in his or her annual catch. Analyses in this study are limited to $N = 2$ and 3, which, respectively, lead to the study of 2×2 and $2 \times 2 \times 2$ contingency tables. For $N = 3$ (i.e. species triplets, e.g. carp, pike and pikeperch), anglers were classified into eight distinct groups: unsuccessful anglers who reported no species, three types of specialists who reported only one species, three types of generalists who reported two species and one type of generalists who reported all three. Analogous classification was used for $N = 2$ (species pairs), in which the anglers were separated into four groups: unsuccessful, two types of specialists and one type of generalists who reported both species. 2×2 contingency tables for each species pair were obtained as marginal tables of the larger $2 \times 2 \times 2$ contingency table by pooling data for the third species. All references to specialist and generalist anglers in this study are relative to the group of fish species being considered at that point; true specialists who reported only one fish species (mostly carp) appeared only in the analysis of contingency tables and in the analysis of catches.

R software (R Development Core Team, 2009) was used to carry out all analyses. Significance level in all tests was set at $\alpha = 0.05$. Hierarchical log-linear models were used to assess the association and interaction patterns in the occurrence of selected fish species in annual catches of individual anglers, implemented as generalised linear models with Poisson family distribution and canonical link function; the symbol assigned to each model lists the highest order interaction term for each variable (Agresti 2002). For example, model (C, E, S) describes mutually independent occurrence of carp, pike and pikeperch in individual annual catches, while model (C, ES) describes joint independence of pike and pikeperch catches on carp. Each model fit was assessed with a deviance-based test described in Faraway (2005) and with a dissimilarity index to evaluate the practical importance of the fit (Agresti 2002, p. 330).

Annual catch data were available for all anglers. Effort data, defined for a given angler as the total number of his/her fishing trips, were available for anglers who caught at least two species. Both types of data were compared across the different angler groups using the Kruskal–Wallis test with Dunn's method for *post hoc* comparisons of pairs (Zar 1999, p. 224); Mann–Whitney U-tests were used for comparison of catches in species pairs. Non-parametric tests were chosen, because both types of data were skewed strongly towards small values (Fig. 2) and goodness-of-fit tests showed they were not consistent with negative binomial or other commonly used distribution types.

Catch per unit effort data (CPUE, defined for a given angler and fish species as the number of the fish caught divided by the total number of his/her fishing trips) were available for anglers with known effort, i.e. those who caught at least two species. All CPUE data except those of carp in the C-E-S triplet were consistent with log-normal distribution (Shapiro–Wilk test of normality on log-transformed data), and log-transformed data for each species were homoscedastic across angler groups (Bartlett's test). Multiplicative error was assumed in the original data. One-way ANOVA was used to compare log-transformed CPUE data of each species across the relevant angler groups. As a result of uneven sizes of the groups, a procedure developed by Herberich *et al.* (2010) was used for *post hoc* comparisons of angler groups and calculation of confidence intervals for pairwise differences between mean values of the transformed data. The pairwise differences were translated back into multiplicative differences in the original CPUE data.

Results

Relation of the analysed data to long-term catch statistics

Catches at Slapy Reservoir between 1988 and 2008 were dominated by carp (mean ± SD = 14227 ± 5458 individual fish per year; 39.6% of all reported fish)

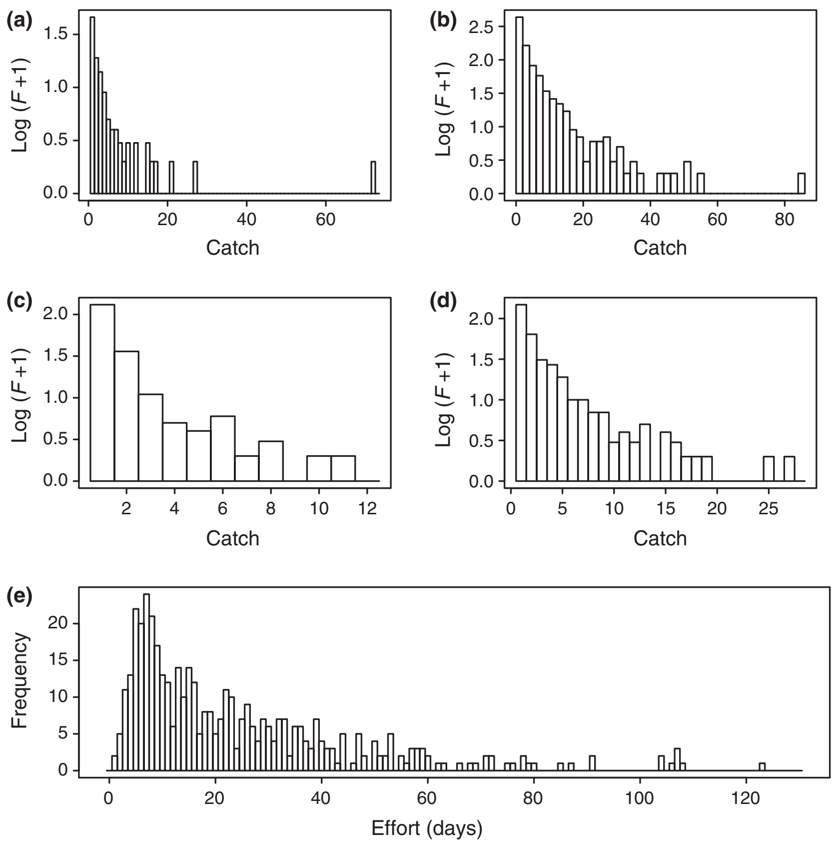

Figure 2. Histograms of individual annual catches and effort at the Slapy Reservoir in 2008. (a) catches of bream; (b) catches of carp; (c) catches of pike; (d) catches of pikeperch; (e) effort. Catch frequencies F in panels A–D transformed to $\log_{10}(F + 1)$ for improved readability. Effort data restricted to anglers who reported at least two species in 2008.

and perch, *Perca fluviatilis* L. (12265 ± 6140 fish; 34.1%), followed by roach, *Rutilus rutilus* (L.) (4311 ± 2604 fish; 12.0%), bream (2506 ± 1372 fish; 7.0%), pikeperch (1618 ± 1303 fish; 4.5%), pike (626 ± 373 fish; 1.7%) and eel, *Anguilla anguilla* (L.) (400 ± 149 fish; 1.1%). Eight of 21 pairwise correlations of these seven most frequently reported species in the 1988–2008 time series were significant ($n = 21$, ANOVA analysis of dependence of annual catch of one species on annual catch of another species, Bonferroni adjusted $P < 0.05$). Four pairs fluctuated in synchrony, having a positive correlation (Fig. 1): carp–pikeperch ($r = 0.64$), carp–pike ($r = 0.65$), pike–pikeperch ($r = 0.83$) and eel–perch ($r = 0.79$).

The proportion of catches by anglers from the 11 selected local CAU organisations relative to total catches was quite stable, ranging between 28 and 37% of the total annual catch at Slapy Reservoir during 2003–2008 (bream, mean ± SD = 28.3 ± 2.0%; carp 32.3 ± 1.7%; eel 33.9 ± 5.5%; perch 29.6 ± 5.5%; pike 36.8 ± 2.7%; pikeperch 34.3 ± 2.0%; roach 31.3 ± 2.3%). In 2008, these anglers caught 4559 carp (reported by 879 anglers), 1087 pikeperch (335 anglers), 463 bream (108 anglers) and 335 pike (192 anglers) (Fig. 2). Their catches of eel, perch, roach and other fish were low (not shown).

Catches by specialist and generalist anglers in 2008

Only about half of the anglers included in the analyses were successful in 2008: 1360 anglers (55%) reported no catches, 681 (27%) caught a single species and 436 (18%) caught at least two species. Analysis of the three-way contingency table describing the presence/absence of carp, pike and pikeperch in the annual catch of individual anglers revealed that the log-linear model (*CE*, *CS*, *SE*) of homogeneous associations provides the closest fit of the data, i.e. all three pairs of fish species are conditionally dependent, and their interactions are significant (Table 1). The dissimilarity index of model (*ES*, *CS*) of conditional independence of carp and pike presence in the individual annual catches was smaller than 0.03, suggesting another reasonable fit. All six remaining models did not fit the data, including all

Table 1. Classification of anglers based on the presence of a given triplet of fish species in their annual catch. Each three-way contingency table is collapsed into one row; abbreviations of angler groups indicate reported species

		Angler groups											
Triplet	Data/Model	Zero	C	E	S	C-E	C-S	E-S	C–E–S	G^2	d.f.	*P*	DI
C-E-S	O	1421	631	48	98	42	135	31	71				
	(*CE*, *CS*, *ES*)	1407.3	632.5	49.5	99.5	40.5	133.5	29.5	72.5	0.26	1	0.61	0.002
	(*ES*, *CS*)	1407.3	644.7	61.7	89.7	28.3	143.3	39.3	62.7	13.7	2	0.001	0.018
	(*CE*, *ES*)	1364.1	687.9	37.0	154.9	53.0	78.1	42.0	60.0	75.7	2	$< 10^{-16}$	0.055
	(*CE*, *CS*)	1396.4	586.5	72.7	122.6	86.5	179.5	6.4	26.5	158.75	2	$< 10^{-16}$	0.056
	(*C*, *ES*)	1323.8	728.2	58.1	150.3	31.9	82.7	65.8	36.2	122.8	3	$< 10^{-16}$	0.078
	(*E*, *CS*)	1355.1	620.8	113.9	119.0	52.2	190.0	10.0	16.0	205.9	3	$< 10^{-16}$	0.061
	(*S*, *CE*)	1313.6	662.4	68.3	205.4	97.7	103.6	10.7	15.3	267.9	3	$< 10^{-16}$	0.087
	(*C*, *E*, *S*)	1274.8	701.2	107.1	199.4	58.9	109.7	16.8	9.2	315.0	4	$< 10^{-16}$	0.100
		Zero	C	A	S	C-A	C-S	A-S	C-A-S				
C-A-S	O	1451	620	18	125	53	173	4	33				
	(*CA*, *CS*, *AS*)	1450.6	620.4	18.4	125.4	52.6	172.6	3.6	33.4	0.056	1	0.81	0.001
	(*CA*, *CS*)	1448.8	607.2	20.2	127.2	65.8	185.8	1.8	20.2	13.1	2	0.001	0.012
	(*AS*, *CS*)	1420.3	650.7	48.7	114.8	22.3	183.2	14.2	22.8	90.5	2	$< 10^{-16}$	0.033
	(*CA*, *AS*)	1377.8	693.2	14.5	198.2	56.5	99.8	7.5	29.4	73.9	2	$< 10^{-15}$	0.062
	(*A*, *CS*)	1404.9	643.7	64.1	123.4	29.3	197.0	5.6	8.9	105.6	3	$< 10^{-16}$	0.038
	(*S*, *CA*)	1362.9	685.8	19.0	213.1	74.3	107.2	3.0	11.6	122.2	3	$< 10^{-16}$	0.071
	(*C*, *AS*)	1336.1	734.9	45.8	192.3	25.2	105.7	23.9	13.1	183.0	3	$< 10^{-16}$	0.093
	(*C*, *A*, *S*)	1321.6	727.0	60.3	206.7	33.1	113.7	9.4	5.2	214.7	4	$< 10^{-16}$	0.095

A, bream; C, carp; E, pike; S, pikeperch; zero, anglers who caught none of the fish in the pair/triplet; G^2, residual deviance; DI, dissimilarity index; O, observed numbers of anglers; (*Model*), fitted values for the given log-linear model; see Methods for details

three models of joint independence [(*C*, *ES*), (*E*, *CS*) and (*S*, *CE*)] and model (*C*, *E*, *S*) of mutual independence of all three species. Moreover, comparison of fitted values of model (*C*, *E*, *S*) to observed data showed that the three- and two-species generalists occurred more frequently than expected under mutual independence at the expense of the specialists and unsuccessful anglers in 2008 (Table 1). Similar results were found for the contingency table describing the presence of bream, carp and pikeperch in individual annual catches; along with model (*CA*, *AS* and *CS*) of homogeneous associations, model (*CA*, *CS*) of conditional independence of bream and pikeperch presence in annual catches also provided a reasonable fit (Table 1).

These relationships are reflected in the lack of independence of angler group sizes for the species pairs (Table 2). In all pairs, unsuccessful and generalist anglers were significantly more frequent and both types of specialists rarer than expected under independence; the number of generalists was about 2–4 times higher than expected (a difference of 22–97 anglers, depending on species). The differences were least pronounced, in terms of residual deviance, for species pairs that could be considered conditionally independent in the respective three-species model, i.e. for carp–pike and bream-pikeperch (Table 2).

Observed bias towards generalist anglers is further strengthened by differences in the annual catches of the generalists and the specialists (Table 3). There were significant differences among the angler groups in catches of all three species in the C-E-S triplet (Kruskal–Wallis test: carp $\chi^2_3 = 9.59$, $P = 0.02$; pike $\chi^2_3 = 19.5$, $P = 0.0002$; pikeperch $\chi^2_3 = 12.8$, $P = 0.005$) and in catches of carp and pikeperch in the C-A-S triplet (Kruskal–Wallis test: carp $\chi^2_3 = 15.7$, $P = 0.001$; bream $\chi^2_3 = 6.93$, $P = 0.07$; pikeperch $\chi^2_3 = 19.9$, $P = 0.0002$). In all five cases, catches of specialists were significantly lower than those of three-species generalists, with catches of the two-species generalists being intermediate. Consequently, catches of specialists were significantly lower than those of generalists for all species in all species pairs except in the bream-pikeperch pair (Table 3).

Differences in catches could stem from two sources: unequal effort and/or unequal CPUE among the angler groups. Differences in effort among all angler groups were highly significant both for the C-E-S triplet (Kruskal–Wallis test: $\chi^2_7 = 70.8$, $P < 10^{-11}$) and for the C-A-S triplet (Kruskal–Wallis test: $\chi^2_7 = 62.0$, $P < 10^{-10}$), mainly because of a higher effort of the generalists (Table 4). A similar pattern consequently emerged for the species pairs: effort of

Table 2. Classification of anglers based on the presence of five pairs of fish species in their annual catch. Each two-way contingency table collapsed into one row; species and angler group abbreviations as in Table 1

Pair	Data/ Model	Angler group										G^2	d.f.	*P*
		Zero	C	A	E	S	C-A	C-E	C-S	A-S	E-S			
C-A	O	1576	793	22	–	–	86	–	–	–	–			
	(*C*, *A*)	1528.3	840.7	69.7	–	–	38.3	–	–	–	–	92.5	1	$< 10^{-16}$
C-E	O	1519	766	–	79	–	–	113	–	–	–			
	(*C*, *E*)	1474.1	810.9	–	123.9	–	–	68.1	–	–	–	47.16	1	$< 10^{-11}$
C-S	O	1469	673	–	–	129	–	–	206	–	–			
	(*C*, *S*)	1381.9	760.1	–	–	216.1	–	–	118.8	–	–	109.1	1	$< 10^{-16}$
A-S	O	2071	–	71	–	298	–	–	–	37	–			
	(*A*, *S*)	2048.6	–	93.4	–	320.4	–	–	–	14.6	–	31.7	1	$< 10^{-7}$
E-S	O	2052	–	–	90	233	–	–	–	–	102			
	(*E*, *S*)	1976.0	–	–	166.0	309.0	–	–	–	–	26.0	192.2	1	$< 10^{-16}$

G^2, residual deviance; O, observed numbers of anglers in the group; (*Model*), expected numbers under complete independence; see Methods for details.

Table 3. Breakdown of individual annual catches (number of focal fish) by angler groups defined in Tables 1 and 2. Data given as median ± median absolute deviation, with 90% quantile in parentheses; all values rounded off to nearest integer

Combination	Focal fish	Pair/ Triplet	Angler group						
			C	E	S	C-E	C-S	E-S	C-E-S
C-E-S	C	C-E-S	2 ± 1 (11)^{a}	–	–	2 ± 1 (9)^{a,b}	3 ± 2 (15)^{b,c}	–	5 ± 3 (19)^{b,c}
		C-E	2 ± 1 (11)^{a}	–	–	4 ± 3 (16)^{b}	–	–	–
		C-S	2 ± 1 (11)^{a}	–	–	–	4 ± 3 (16)^{b}	–	–
	E	C-E-S	–	1 ± 0 (1)^{a}	–	1 ± 0 (3)^{a,b}	–	1 ± 0 (3)^{a,b}	1 ± 0 (5)^{b}
		C-E	–	1 ± 0 (2)^{a}	–	1 ± 0 (5)^{b}	–	–	–
		E-S	–	1 ± 0 (2)^{a}	–	–	–	1 ± 0 (4)^{b}	–
	S	C-E-S	–	–	1 ± 0 (5)^{a}	–	2 ± 1 (7)^{b}	2 ± 1 (6)^{a,b}	2 ± 1 (11)^{b}
		C-S	–	–	1 ± 0 (5)^{a}	–	2 ± 1 (9)^{b}	–	–
		E-S	–	–	2 ± 1 (6)^{a}	–	–	2 ± 1 (10)^{b}	–
			C	A	S	C-A	C-S	A-S	C-A-S
C-A-S	C	C-A-S	2 ± 1 (10)^{a}	–	–	4 ± 3 (16)^{a,b}	3 ± 2 (14)^{b}	–	6 ± 5 (25)^{b}
		C-A	2 ± 1 (11)^{a}	–	–	5 ± 4 (19)^{b}	–	–	–
		C-S	2 ± 1 (11)^{a}	–	–	–	4 ± 3 (16)^{b}	–	–
	A	C-A-S	–	1 ± 0 (4)	–	2 ± 1 (10)	–	2 ± 1 (3)	3 ± 2 (12)
		C-A	–	1 ± 0 (4)^{a}	–	2 ± 1 (11)^{b}	–	–	–
		A-S	–	2 ± 1 (7)	–	–	–	2 ± 1 (12)	–
	S	C-A-S	–	–	1 ± 0 (5)^{a}	–	2 ± 1 (9)^{b}	1.5 ± 0.5 (3)^{a,b}	2 ± 1 (5)^{a,b}
		C-S	–	–	1 ± 0 (5)^{a}	–	2 ± 1 (9)^{b}	–	–
		A-S	–	–	2 ± 1 (8)	–	–	2 ± 1 (4)	–

Angler groups with significantly different catches ($P < 0.05$) indicated by different superscripts (a, b and c). Species abbreviations as in Table 1.

the generalists was higher than that of the specialists and unsuccessful anglers (Table 4).

Differences in CPUE were significant for all three fish species in the C-E-S triplet (ANOVA: carp $F_{3,356} = 3.78$, $P = 0.01$; pike $F_{3,149} = 7.70$, $P < 10^{-4}$; pikeperch $F_{3,258} = 4.80$, $P = 0.003$) and for carp and pikeperch in the C-A-S triplet as the differences for bream were marginally insignificant (ANOVA: carp $F_{3,356} = 5.73$, $P = 0.0008$; bream $F_{3,92} = 2.63$, $P = 0.055$; pikeperch $F_{3,258} = 7.72$, $P < 10^{-4}$). Contrary to the relationships between catches of the specialist and generalist anglers, *post hoc* comparisons detected significantly higher, not lower, CPUE in specialists than in the three-species generalists for carp and pike in the C-E-S triplet and for pikeperch in the C-A-S triplet (Fig. 3). The estimated ratio of the mean CPUE of the three-species generalists relative to specialists was 1.47 (95% CI: 1.04–2.05) for carp in the C-E-S triplet, 2.31

Table 4. Effort data for angler groups defined in Tables 1 and 2. Data given as median ± median absolute deviation of fishing days, with 90% quantile in parentheses; all values rounded off to nearest integer

Combination	Pair/ Triplet	Angler group							
		Zero	C	E	S	C-E	C-S	E-S	C-E-S
C-E-S	C-E-S	7 ± 2 (11)^{a}	15 ± 9 (47)^{a,b}	8 ± 6 (30)^{a,b}	9 ± 4 (23)^{a}	12 ± 7 (39)^{a,b}	21 ± 14 (57)^{b}	10 ± 6 (32)^{a,b}	9 ± 14 (72)^{c}
	C-E	8 ± 4 (23)^{a}	17 ± 10 (53)^{b,c}	10 ± 7 (30)^{a,b}	–	26 ± 14 (58)^{c}	–	–	–
	C-S	8 ± 3 (19)^{a}	14 ± 9 (46)^{a}	–	10 ± 6 (30)^{a}	–	26 ± 14 (60)^{b}	–	–
	E-S	13 ± 8 (43)^{a}	–	11 ± 6 (38)^{a}	18 ± 11 (55)^{a,b}	–	–	26 ± 13 (59)^{b}	–
		Zero	C	A	S	C-A	C-S	A-S	C-A-S
C-A-S	C-A-S	8 ± 4 (18)^{a}	14 ± 8 (44)^{a}	8 ± 1 (19)^{a,b}	11 ± 6 (32)^{a}	14 ± 9 (46)^{a}	25 ± 13 (57)^{b}	9 ± 0 (9)^{a,b}	11 ± 19 (63)^{b}
	C-A	10 ± 6 (29)^{a}	21 ± 12 (54)^{b}	8 ± 1 (11)^{a,b}	–	20 ± 14 (59)^{b}	–	–	–
	C-S	8 ± 3 (19)^{a}	14 ± 9 (46)^{a}	–	10 ± 6 (30)^{a}	–	26 ± 14 (60)^{b}	–	–
	A-S	13 ± 8 (39)^{a}	–	13 ± 8 (42)^{a,b}	20 ± 12 (62)^{b}	–	–	32 ± 21 (62)^{b}	–

Angler groups with significantly different effort ($P < 0.05$) indicated by different superscripts (a, b and c). Species abbreviations as in Table 1.

(95% CI: 1.05–5.12) for pike in the same triplet and 2.39 (95% CI: 1.43–3.99) for pikeperch in the C-A-S triplet. In the remaining nonsignificant cases, the estimated ratio of mean CPUE of the three-species generalists and specialists varied between 1.00 and 2.15. Finally, CPUE of the three-species generalists was significantly lower than at least one group of two-species generalists for pike and pikeperch in the C-E-S triplet and for pikeperch in the C-A-S triplet (Fig. 3).

Discussion

Long-term commercial or recreational fishery statistics can shed light on trends in population abundance and exploitation of individual fish stocks (Vostradovský & Tichý 1999; Gudbergson 2002) and whole fish communities (Kangur *et al.* 2007). They have also been used in studies of oceanic circulations and upwelling temperature oscillations (Binet 1997; Zeeberg *et al.* 2008), changes in water quality (Humpl *et al.* 2009), limnology (Draštík *et al.* 2004) and fish ecology (Lusk *et al.* 2003).

Time series of anglers' catches from some Czech reservoirs show synchronous fluctuations of some fish species, which might be driven by both endogenous and exogenous factors. The four cases of significant positive pairwise correlations in the 1988–2008 time series of catches of seven frequently caught species at Slapy Reservoir involve both species, the catches of which increased over time (carp, pike and pikeperch) and species that declined over time (perch and eel) (Fig. 1). Even if these simple correlations do not constitute a full-fledged analysis of the time series, they indicate that some unknown processes are affecting the catches over time. Year-to-year variation in fishing pressure is unlikely to cause these fluctuations: CAU membership was relatively stable between 1988 and 2008, and angling practices or stocking management policy did not change markedly. Length limits and daily catch limits for individual species remained the same during this period.

Anglers' activity and fishing skills and strategies might be responsible for such long-term correlations in catches. For example, Pivnička and Rybář (2001) reported a positive correlation between perch and pikeperch from another reservoir, which might have been caused by random catches on the same rod, as both species occupy the same habitats (Vašek *et al.* 2004; Prchalová *et al.* 2008). This study proposes a method to evaluate such hypotheses using data on individual annual catches at Slapy Reservoir in 2008 as a case study. Categorical data analysis and ANOVA were used to address the following questions: Is there a

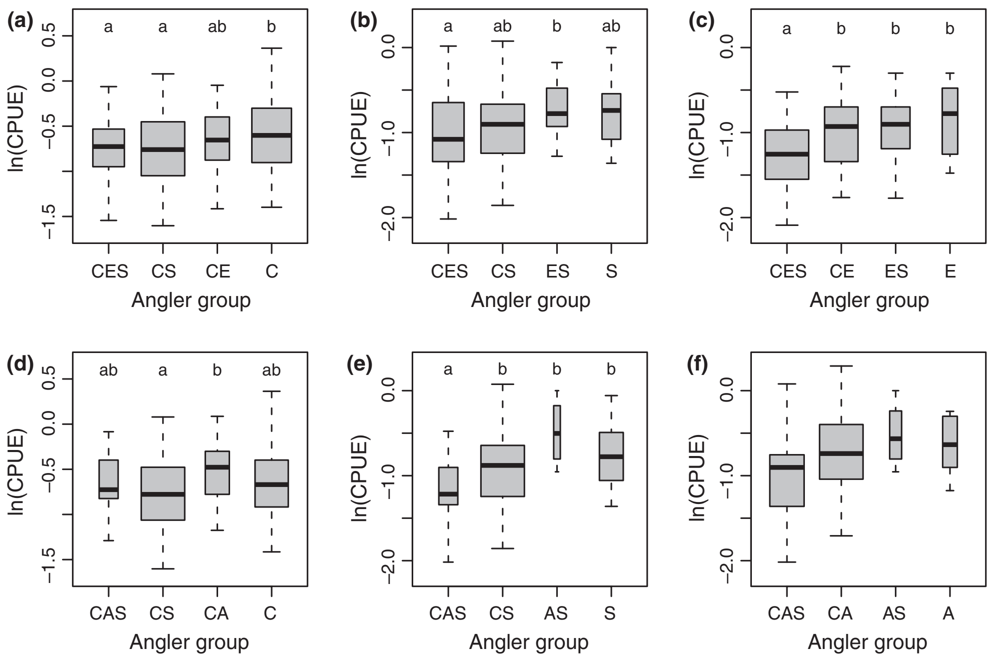

Figure 3. Boxplots of CPUE of different groups of anglers at the Slapy Reservoir in 2008 (data for anglers who caught at least two species during 2008). Groups defined for: (a–c) carp–pike–pikeperch and (d–f) carp–bream–pikeperch triplet. (a) and (d) CPUE for carp; (b) and (e) CPUE for pikeperch; (c) CPUE for pike; (f) CPUE for bream. Species abbreviations and angler groups as in Table 1. Box width proportional to square root of group size; whiskers covering full range of data; groups with significantly different CPUE ($P < 0.05$) indicated by different letters.

sufficiently large group of anglers who report more than one species? Do they catch many fish of these species? Are anglers who catch more than one species more or less efficient than specialists who report a single species?

Answers to the first two questions were positive: the group of generalist anglers was larger than expected under the assumption of jointly independent appearance of individual species in annual catches. Moreover, generalist anglers regularly reported more fish than anglers who caught only one species from the species pair. Generalist anglers (i.e. those who reported both species in 2008) were thus responsible for a large part of the total annual catch. For example, 206 generalists caught 2.4 times as many pikeperch (772 fish) as the 129 pikeperch specialists (316 fish) and 0.44 times as many carp (1402 fish) as the 673 carp specialists (3157 fish) in the carp–pikeperch pair. However, CPUE of individual specialist anglers was typically higher than that of the generalists; higher catches of the generalists were primarily caused by increased effort, measured as the number of days spent fishing. These results indicate that anglers with a low degree of specialisation and high effort might be responsible for the observed long-term correlations in species catches. Highly skilled anglers with high CPUE do not seem to play a major role in the correlations, as they fall mainly among the specialists.

These answers could have been obtained with anglers classified only with respect to two factors, corresponding to the presence/absence of the two fish species in question in their annual catches. The merit of the more detailed classification using species triplets lies in showing that the relationship between catches of different species can go beyond simple pairwise correlations and is worth additional studies in the future.

The analyses of individual logbook data are in line with the long-term catch statistics: strong bias towards generalist anglers with high fishing effort and strong differences in total catches of different angler groups occurred in carp, pike and pikeperch, i.e. species involved in three of the four significantly positive long-term correlations at Slapy Reservoir. In the pairs involving bream, generalists were also more numerous and had larger catches than the specialists, but there were no clear-cut differences in the effort and CPUE. Lack of significant long-term correlation between bream and other species thus suggests that the relationship between angler behaviour and long-term patterns in catches can be complex.

This study was not designed to address other factors required to generate the observed synchronous fluctuations in catches. The analyses could only be based on a subset of logbooks from a single year. Although it was not possible to determine whether variable fishing effort or success caused the observed long-term fluctuations, this explanation is unlikely. Total CAU membership and proportions of the catches by anglers in the selected local organisations at Slapy Reservoir did not change markedly during 2003–2008 (see Results). Most of the variation in the catches was probably driven by intrinsic fluctuations in recruitment and survival in naturally reproducing species (e.g. pikeperch at Slapy Reservoir) and by numbers of released fish and their subsequent survival in species that rely on stocking (e.g. carp and pike at Slapy Reservoir). This study could also not address the proximate causes underlying the correlations. For example, correlations between carp and other species might be driven by anglers who fish for carp, the prime target at many Czech water bodies, and catch the other species as by-catch. More detailed studies are required to address these issues in the future.

Overall, the proposed analyses of individual logbooks suggest that fishing pressure by generalist anglers (i.e. those who catch multiple species each season) can be sufficiently high to contribute to long-term synchronous fluctuations in catches. More data are needed to evaluate how common and strong this phenomenon could be. If more widespread, it could diminish the utility of catch statistics as proxies for the true state of the stocks (Sullivan 2003; Page *et al*. 2004). Conversely, various authors have repeatedly called for data on angler behaviour (Wilde *et al*. 1998; Bray & Schramm 2001; Arterburn *et al*. 2002; Arlinghaus & Mehner 2004), and the method proposed could yield new insights into angler fishing skills and strategies.

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