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Coupling insights from a carp, *Cyprinus carpio*, angler survey with feeding experiments to evaluate composition, quality and phosphorus input of groundbait in coarse fishing

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Abstract A carp angler survey indicated that specialised carp anglers used on average 215 kg groundbaits (mostly cereals, nuts, beans, boilies) per year which corresponded to a mean annual gross P-input of 1018 g P angler^{-1}. A feeding experiment was conducted with juvenile carp fed with a random sample of the main bait types used in coarse angling to estimate the nutritional quality and P-retention efficiency. The investigated groundbaits had a rather low nutritional quality. Based on the examined P-retention efficiencies, the net annual P-input was calculated to be 839 g P per angler. To counterbalance this P-input, an annual harvest rate of 175–225 kg carp biomass per angler would be necessary. Thus, under certain conditions, a substantial contribution by carp and other coarse angling to the P-loading is likely. Further studies on the issue of groundbaiting are needed to develop guidelines for more effective management of coarse angling.

KEYWORDS: angling, anthropogenic impact, eutrophication, fisheries management, groundbaiting, inland recreational fisheries.

Introduction

In 1952, an angler named Richard Walker caught a common carp, *Cyprinus carpio* L. weighing more than 20 kg from a small lake in Herefordshire (UK). In the years following this catch, carp angling became fashionable in the British coarse (non-salmonid) angling community (Linfield 1980) and specialised carp tackle, magazines, angling organisations and meetings developed. Since the 1980s, growing numbers of anglers have fished almost exclusively for carp in Central Europe as well, and in Germany alone in 1999 and 2000 it was estimated that between 800 and 900 specialised carp anglers were already catching the same amount of carp as was harvested by commercial freshwater fisheries (Arlinghaus & Mehner 2003). In modern coarse angling, selectivity for carp is mainly achieved by the use of special baits named 'boilies' (from 'to boil') made from different meals, eggs, flavours, feeding stimulants and are boiled in water until they become hard. This procedure ensures that only bigger cyprinid fishes are able to crush the baits with their pharyngeal teeth. However, it is well known that groundbaits are used to attract the fish in coarse angling (Cryer & Edwards 1987) and there seems to exist a positive relationship between catch and amount of groundbaits, at least in carp fishing (Wolos, Teodorowicz & Grabowska 1992; Arlinghaus & Mehner 2003). Furthermore, the efficiency of boilies both, in terms of total catch and catch of larger carp, seems to correlate with pre-baiting or groundbaiting with boilies before the angling day (Raat 1990).

Previous work on the effects of groundbaiting on aquatic ecosystems found that angler baits can reduce the density of benthic invertebrates through local deoxygenation in sediments (Cryer & Edwards 1987). Wolos *et al.* (1992) concluded that Polish coarse

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anglers using up to 2 kg bait per trip did not increase the nutrient load of the water bodies because nutrients stored in the fish were removed with the angler harvest. In the context of total P-load, the input by groundbaits was usually considered to be negligible (Edwards & Fouracre 1983; Wolos *et al.* 1992; Williams & Moss 2001). However, groundbaiting by carp anglers was assumed to contribute substantially to the deterioration of water quality (Stolzenburg 1995), partly because many coarse anglers practice catch-and-release fishing in the UK and Central Europe (North 2002; Arlinghaus & Mehner 2003) and thus P stored in the fish is not removed from the water body. In Germany, this resulted in the locally banning of the use of boilies, thus selectively excluding carp anglers. However, no scientific studies were available to support these regulatory measures which is not in agreement with the sustainability principle in inland fisheries management (Arlinghaus, Mehner & Cowx 2002).

As specialised carp anglers use different (e.g. boilies compared with potatoes and bread; Wolos *et al.* 1992) and probably more groundbaits than traditional carp anglers, the issue of groundbaiting needed to be re-examined in the light of modern developments in coarse angling practices by including fisheries-specific information such as chemical composition and P contents of the baits introduced to the waters, quantity and types of bait used, and an estimation of the P-retention potential of fish fed with the different angling groundbaits used. It is known that more than 50% of the total water column P in some lakes can be stored in the fish (Kitchell, Koonce & Tennis 1975). Therefore, it is possible that a certain percentage of P-inputs by groundbaits will be incorporated into fish biomass by fish feeding on angling baits (Schäperclaus 1966; Speczíár, Tölg & Bíró 1997). Hence, groundbaiting might contribute less to the P-loading than expected because fish can absorb a part of the P in the bait. However, there is no information available concerning the growth and P-retention potential of benthivorous coarse fish such as carp, bream, *Abramis brama* (L.), or tench, *Tinca tinca* (L.), fed with different angling baits.

The aims of this paper, based on a specialised carp angler survey in Germany and a feeding experiment with angling baits in carp, are: (1) to present the chemical composition, amount and type of groundbaits used in carp angling in Germany; (2) to evaluate the nutritional quality of the main types of groundbait; and (3) to calculate the total P balance for the average carp angler based either on gross or net P-inputs (NPI) to the water.

Materials and methods

Evaluation of chemical composition of groundbaits

The chemical composition and total P-content of a wide range of groundbaits used in coarse angling was investigated, either directly or compiled from the literature. Random samples of commercial baits were taken from bait shops in Berlin (Germany) or ordered by mail or internet from bait suppliers. Baits were milled and samples were chemically analysed in duplicate using the following procedures: dry matter (DM) and moisture by freeze-drying at −54 °C to constant weight; crude protein (nitrogen × 6.25) according to the Kjeldahl distillation method (Kjeltec System Tecator); crude fat by petroleum ether extraction in a Soxhlet apparatus (Soxtec System HT Tecator); ash by incineration for 4 h at 750 °C; nitrogen-free extracts (NFE) by subtracting the percentage values of crude protein, crude fat and ash from 100% of DM and total phosphorus photometrically by the standardised molybdenum blue method (Murphy & Riley 1962) after digestion with sulphuric acid and hydrogen peroxide.

Carp angler survey

In 2000/2001, a mail and internet-based survey was conducted among specialised carp anglers in Germany. A self-administered, four-page questionnaire was designed to obtain, *inter alia*, data on types and quantities of baits used each year. Questionnaires were made available to carp anglers: (a) during the only German specialised carp angling tradeshow in 2000 (Braunfels, November 2000); (b) on the leading German specialised carp angling web site (http://www.carp.de, December 2000 until May 2001); and (c) in the only two German specialised carp angling magazines (Carp Mirror, Issue 2, 2001; Carp Connect, Issue 7, 2001).

Feeding experiments

A controlled feeding experiment was conducted to obtain data on the nutritional quality and P-retention efficiency of the main types of groundbaits used in carp angling. Random samples of groundbaits were fed to carp, and growth, mortality and chemical composition of the whole body was examined.

Experimental fish. Feeding experiments were carried out using 1+ carp that originated from a pond carp strain cultivated in Peitz (Brandenburg, Germany). In

2001, a random carp sample with an average individual body weight of about 25 g was obtained and kept for 70 days indoors in a recirculating system under warm water conditions and fed with commercial fish pellets (see Table 1 for composition) at 2% of fish biomass day^{-1} (wet weight, ww) to acclimatise the fish to the new conditions and the dry feed diet. After 2 days, food intake became normal. On 10 July 2001, when the fish had reached a mean weight of about 134 g (compare Table 3), the feeding experiments commenced, lasting for 56 days when the control group had doubled average body mass (ww).

Culture conditions. Experiments were carried out in 825 L circular fibreglass reinforced plastic tanks, filled with 452 L of water. Water was exchanged at a rate of 0.31 L s^{-1}. Each tank was stocked with 30 fish, at a stocking density ranging from 8.9 kg m^{-3} at the beginning to 18.4 kg m^{-3} at the end of the experiment. During the experimental period, the mean ± SD water quality parameters were as follows ($n = 16$ measurements): water temperature 22.7 ± 0.8 °C, dissolved oxygen 5.1 ± 0.2 mg L^{-1}, conductivity 744.6 ± 9.9 μS cm^{-1}, pH 8.2 ± 0.1, ammonium 0.8 ± 0.1 mg L^{-1}, nitrite 0.7 ± 0.2 mg L^{-1} and nitrate 160 ± 22 mg L^{-1}. Light conditions were natural. All experiments were conducted in triplicate.

Test diets and feeding procedure. Four random angling bait test diets representing the main types of groundbaits used in carp angling (see Results) were formulated (Table 1): commercial ready-made boilies; commercial ordinary groundbaits used for coarse fishing; self-made boilies and particles (i.e. a mixture of cereals, beans, nuts, etc.). The latter two were prepared according to recipes published in the angling media. The feed samples were milled and mixed thoroughly. Pellets were then made by passing a water/feed mixture through a mincer with 1-mm diameter holes. The pellets were air-dried for 3 days and stored in a refrigerator at 4 °C to minimise loss of nutrients.

Four experimental groups were fed exclusively on the basis of the angling bait diets. In addition, a control group was fed with a commercial fish feed (see Table 1) that was milled and pelleted the same way as the groundbait test diets. The amount of feed (ww) was 2% of fish biomass (ww) per day. The feed was administered in small rations between 8.00 AM and 3.00 PM, small enough to be ingested quickly to minimise nutrient leaching. Visual inspection of the feed intake revealed that, with exception of the particles treatment, feed was ingested immediately. Thus, feed loss can be considered negligible in four feeding groups. At weekly intervals, individual fish were weighed and the feed amount adjusted to the new biomass. Before and after the experiments, 10 individual fish from each group

Table 1. Chemical composition and total phosphorus (P) contents (% of dry matter, DM) of four angling groundbait test diets and a commercial fish feed (control) used in the feeding experiment with juvenile carp

Test diet	Dry matter	Crude protein	Crude fat	Ash	NFE*	P	Gross energy (MJ kg^{-1} DM)†
Ready-made boilies‡	92.4	19.0	6.6	3.5	70.8	0.36	19.7
Self-made boilies§	92.4	42.2	10.8	7.3	39.7	0.83	21.4
Particles¶	92.2	17.9	7.1	3.1	71.9	0.42	19.8
Ordinary groundbait**	94.0	11.2	5.9	4.6	78.3	0.28	18.8
Commercial fish feed††	92.4	47.4	15.5	11.1	26.1	1.40	22.1

*Nitrogen-free extracts + crude fibre.

†Calculated according to the gross energy values per g DM in Steffens (1989): Crude protein (23.9 kJ), crude fat (39.8 kJ) and carbohydrates (NFE) (17.6 kJ).

‡Companies included in the random bait sample: Nutrabaits, Top Secret, Mosella, Eurobaits, Pelzer Baits, Enforcer, Mistral, Nash Bait (see Table 2 for addresses of companies).

§Ingredients supplier for the random sample was M + M Baits (see Table 2 for address) using the following boilie ingredients: acid casein, bird food, blood plasma, calf milk powder, egg albumin, low temperature fish meal, lactalbumin, maize meal, semolina, rice meal, soya bean meal fullfat, soya bean protein and spices.

¶Types of particles included in the random sample: barley, hemp, maize, maple peas, peanuts and a commercial dove feed composed of various cereals, nuts and beans (Mariman ZRW OPTI-Max 27 M, n.v. Molens Mariman, Molenweg 200, 2830 Willebroek, Belgium).

**Companies and ingredients included in the random sample: Grebenstein, Marcel van den Eynde, Mosella, Sensas, Tubertini, Top Secret (see Table 2 for addresses) and breadcrumbs.

††Kraft Futterwerk Beeskow GmbH, Hafenstraße 11, 15848 Beeskow. Feed: FM 48/14.

were weighed and the whole body composition analysed according to the procedures mentioned above.

Statistical analysis. Following recommendations by Lozán & Kausch (1998), group differences of mean initial body mass and growth performance parameters at the end of the experiment were analysed by one-way ANOVA and a Tukey *post hoc* tests at a type one error probability of $P < 0.05$. Tests on homogeneity of variances (Levene test) and normal distribution (Kolmogorov–Smirnov test) were conducted to verify ANOVA. The feed conversion ratio (FCR) was calculated as grams of feed (ww) per gram of biomass gain (ww). The specific-growth rate (SGR) was estimated as $(\ln W_2 - \ln W_1)/(T_2 - T_1) \times 100$, where W_2 and W_1 are the final and initial average live body masses (g) divided by the duration of the experiment $T_2 - T_1$ (days).

Calculation of P-mass balance

To evaluate the impact of carp angling, two scenarios concerning P-input by groundbaiting were assumed. The gross P-input (GPI) scenario assumed that no angling bait is eaten by the fish. Hence, the total P introduced by groundbaiting is available for primary production after remineralisation. In this scenario, groundbaits of several types *i* once introduced by angling to the water provide for a mean GPI angler^{-1} yr^{-1} as follows:

$$\mathrm{GPI} = \sum_{i=1}^{n} B_\mathrm{i} P_{B_\mathrm{i}} \tag{1}$$

where B_i is the mean amount of bait of type *i* introduced (g angler^{-1} yr^{-1}) and (P_{B_i}) is the P-concentration (%) of bait type *i*.

Alternatively, the NPI scenario is based on the assumption that carp feed exclusively on groundbaits introduced by carp angling and all baits are consumed by the fish. This may be the case in heavily stocked carp fisheries where the carp are dependent on angling baits to meet their energy requirements. Thus, part of the P in the baits is incorporated into fish biomass and consequently does not immediately contribute to the P-load of the water. This reduces the P-input, estimated as GPI to NPI. On the assumption that the body P-concentration (P_C) is more or less constant in carp (0.48% of wet biomass according to Schreckenbach, Knösche & Ebert 2001) and considering the FCR of the different baits as revealed by the above feeding experiments with carp, the NPI (g angler^{-1} yr^{-1}) of *i* types of angling bait can then be calculated as (developed from Einen, Holmefjord, Åsgård & Talbot 1995):

$$\mathrm{NPI} = \sum_{i=1}^{n} B_\mathrm{i}[(P_{B_\mathrm{i}}) - (P_C)/\mathrm{FCR_i}] \tag{2}$$

By means of removing fish caught by carp angling, P incorporated into carp biomass can be removed from the system. The P-mass balance for the average carp angler consisted of the mean amount of P introduced to the aquatic ecosystem by the use of groundbaits (input), and the hypothetical P-removal with the catch (harvest, output) (Wolos *et al.* 1992). The gross P-mass balance according to GPI, or the net P-mass balance according to NPI (g angler^{-1} yr^{-1}) was then calculated as follows:

$$\mathrm{P-mass_{gross}} = \mathrm{GPI} - C \tag{3a}$$

$$\mathrm{P-mass_{net}} = \mathrm{NPI} - C \tag{3b}$$

where C is the removal of carp biomass (g) multiplied by the average (P_C) of the wet mass of carp (0.48%).

Results

Chemical composition of groundbaits

The chemical composition of a range of boilies, particle feeds and commercial groundbait used in carp fishing exhibited three distinct patterns (Table 2). First, commercial ready-made boilies and ready mixes for home boilie production could be differentiated into two groups: one was comparatively rich in crude protein and crude fat and the other group was rich in NFE. In the former group, visual inspection of boilies showed that these baits had a higher content of fish meals. Consequently, the P-content seemed to be higher in the former than in the latter group whose chemical composition in many cases resembled the composition of cereals. Among the particles used in carp fishing, protein and fat rich seeds such as soya beans, peanuts and hemp could be distinguished from ordinary cereals rich in NFE but low in protein and fat. Based on DM, the P-content of particles varied widely between 0.33% in maize and 0.89% in hemp. The chemical composition of commercial groundbait was rather homogenous, characterised by a high NFE and a comparatively low P-content. The visual inspection suggested that the level of fish meal inclusion was likely to be low. Therefore, depending on the type of groundbait used by carp anglers, the P-input will vary and it became necessary to know the amount and type of groundbait used.

Table 2. Chemical composition (% of dry matter) and total phosphorus (P) content of a range of commercially available groundbaits used in carp angling in Germany. The values were arranged according to type of bait and assumed nutritional quality

Bait type and trade name	Dry matter	Crude protein	Crude fat	Ash	NFE*	P	Reference
Higher nutritional quality boilies: crude protein + crude fat > 35%							
M + M Baits† Betamix	77.9	38.5	11.3	7.4	42.9	–	1
M + M Baits† Creammix	78.6	40.4	12.7	3.4	43.5	–	1
M + M Baits† Economy Birdymix	74.3	33.8	14.8	4.0	47.4	–	1
M + M Baits† Liver & Marinemix	76.6	33.8	9.4	6.3	50.5	0.84	2
M + M Baits† Redfishmix	69.8	62.5	11.2	11.6	14.7	–	1
Nash Bait‡ Formula One	76.5	27.2	9.6	4.6	58.7	–	1
Nutrabaits§ Chocolate Orange	85.8	30.3	13.4	3.4	53.0	–	1
Nutrabaits§ Fruit Special	79.1	29.1	11.8	4.2	54.9	0.54	2
Nutrabaits§ Tutti Frutti	80.8	24.0	12.1	2.6	61.3	0.33	2
Richworth¶ Strawberry Jam	85.2	29.5	12.9	3.5	54.2	–	1
Successful Baits** Excl. Fischmix	76.6	31.1	8.9	5.5	54.6	–	1
Successful Baits** Gammakus	81.1	27.4	7.4	7.1	58.2	–	1
Lower nutritional quality boilies: crude protein + crude fat < 35%							
KB Carp Hunter Products†† Zebra Mussel Liver	69.1	22.4	2.8	2.6	72.3	–	1
KB Carp Hunter Products†† Zebra Mussel Stinker	70.4	20.3	4.0	2.5	73.2	–	1
Concept For You‡‡ Strong Salmon	70.3	26.7	5.1	5.2	63.0	–	1
Enforcer§§ Banana Birdy	76.0	15.0	1.3	1.8	81.9	–	1
Enforcer§§ Tiger Nut	70.5	11.2	1.1	0.9	86.8	0.14	2
Eurobaits¶¶ Red Bull	74.9	13.8	0.9	2.4	82.9	–	1
Future Baits*** Birdy Tutti Frutti	67.8	32.2	0.9	3.9	63.0	–	1
Mistral††† Peach and Tangerine Isotonic	78.8	18.9	8.2	2.3	70.7	–	1
Nash Bait‡ White Chocolate	72.6	16.0	7.6	4.9	71.5	0.29	2
Pelzer Baits‡‡‡ Bun Spice	70.8	13.2	2.0	1.2	83.7	0.16	2
Successful Baits** Spicemix	83.3	19.4	9.7	7.8	63.2	–	1
Team Supra Baits§§§ Birdy Special	80.8	18.7	0.9	1.5	78.9	–	1
Team Supra Baits§§§ Fischmix	71.4	18.3	2.5	3.1	76.1	–	1
Top Secret¶¶¶ Fisch	69.1	16.9	4.3	1.9	76.9	0.26	2
Particles rich in protein and fat							
Hemp	96.0	21.3	34.9	4.8	38.0	0.89	5
Pea	–	22.3	4.6	11.0	62.0	0.43	5
Peanut	–	27.5	44.6	3.6	24.3	0.45	5
Soya bean	90.0	40.8	19.8	5.5	33.9	0.71	5
Sunflower seeds	92.0	21.0	36.5	3.5	39.0	0.85	5

Amount and types of groundbaits used in carp angling

A total of 710 questionnaires from anglers in Germany was used for analysis (see Arlinghaus & Mehner 2003 for methodological details). The angler survey indicated that each specialised carp angler used on average 214.9 kg groundbait yr^{-1}, mainly consisting of particles and various types of boilies (Fig. 1). Ready-made boilies and boilies made of ready mixes constituted the majority of the boilie types used. On average, 36% of the boilies were self-made composed of single ingredients which are regularly supplied by bait companies. Furthermore, some miscellaneous feedstuffs, mainly commercial groundbait and commercial fish feed were used.

Effects of groundbaits on growth and body composition of juvenile carp

In the feeding experiment with juvenile carp, all growth variables were significantly affected by the dietary treatments (Table 3). Mortality during the experiment was zero. The highest final body mass and SGR as well as the lowest FCR were obtained with the commercial fish feed. Comparing the angling baits, self-made boilies yielded a higher final mass, SGR, and a lower FCR than the other three groundbaits. The nutritional quality of the particles and commercial groundbait was too low to provide the juvenile carp with minimum dietary requirements. Consequently, the growth performance was nearly zero (particles) or very low (commercial groundbait). The test diet consisting of

Table 2. (continued)

Bait type and trade name	Dry matter	Crude protein	Crude fat	Ash	NFE[*]	P	Reference
Particles low in protein and fat							
Barley	87.0	11.8	2.2	2.8	83.2	0.38	5
Maize	88.0	10.8	4.7	1.7	82.8	0.33	5
Wheat	88.0	13.9	2.2	2.4	81.5	0.37	5
Ordinary groundbaits for coarse fishing							
Sensas[****] 3000 Breames	–	13.4	11.1	8.1	67.4	0.16	3,4
Mosella[††††] Explosiv	–	12.1	8.7	3.6	75.6	–	3
Mosella[††††] Canal Brassen	–	11.5	8.0	3.5	77.0	–	3
Marcel van den Eynde[‡‡‡‡] Allround	–	16.3	4.1	3.3	76.3	–	3
Grebenstein[§§§§] Bisquit	–	16.8	5.5	8.5	69.2	–	3
Tubertine[¶¶¶¶] Carpe–Tinche	87.4	12.9	4.7	3.5	78.9	0.31	3
Mean of various groundbaits	–	–	–	–	–	0.33	4

–, data not available.
References: 1, this study; 2, Niesar (2002); 3, company declaration; 4, Coussement, van den Bergh & Breine (1997); 5, Kling & Wöhlbier (1983).
[*]Nitrogen-free extracts + crude fibre.
[†]http://www.mm-baits.de
[‡]http://www.nashtackle.co.uk
[§]http://www.nutrabaits-hq.com
[¶]http://www.richworth.com
[**]http://www.successful-baits.de
[††]http://www.carphunter.de
[‡‡]http://www.maxno-ek.com
[§§]Distributed by Blanchard's Angling, Hafenstr. 69–75, 48432 Rheine, Germany.
[¶¶]http://www.eurobaits.de
[***]http://www.carp.de/banner/future/index.shtml
[†††]Mistral Products, available at http://www.bosfish.co.uk/PRODUCTS/carp/mistralboilies.html
[‡‡‡]http://www.pelzerbaits.de/
[§§§]http://www.teamsuprabaits.de
[¶¶¶]Top Secret, Wilhelm Baumeister, Burloer Str. 129–131, 46325 Borken.
[****]http://www.sensas.com
[††††]Mosella Angelköder GmbH, Zum Bieberach 1, 54518 Platten, Germany.
[‡‡‡‡]http://www.vandeneyndebaits.com/
[§§§§] http://www.grebenstein.com
[¶¶¶¶]Tubertini di Tubertini Gabriele & C. SNC, Via Muzza Spadetta 35/37, 40053 Bazzano BO, Italy.

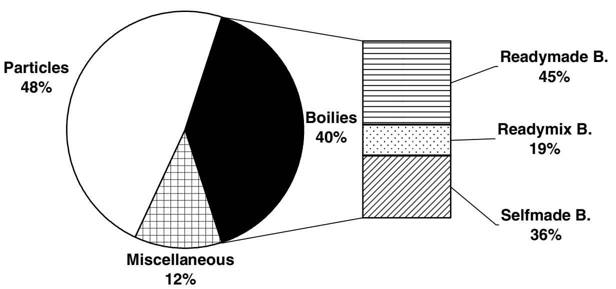

Figure 1. Distribution (%) of the bait types used in carp angling in Germany. Percentages refer to an average annual groundbaiting quantity of 214.9 kg angler^{-1}. B. = boilies.

ready-made boilies achieved an intermediate growth. The mean SGR of carp correlated significantly (linear regression) with the combined crude protein and crude fat content of the test diets (Fig. 2).

All the test diets significantly altered the body composition of the juvenile carp (Table 4). Water, protein and ash content decreased whereas the fat content increased. There was no significant change in protein content in the control group. Thus, compared with the control group fed with the commercial fish feed, the angling groundbaits test diets resulted in a significantly lower protein and a significantly higher body fat content.

Groundbaiting induced P-inputs

To combine the results of the feeding experiment using random samples of groundbaits, with the carp angler survey, and to calculate the P-inputs, it was assumed that the miscellaneous bait types were equally composed of commercial groundbait and fish feed (compare Fig. 1, Table 5). The ready-made and

Table 3. Mean ± SD initial and final body mass, food conversion ratio (FCR) and specific growth rate (SGR) of juvenile carp fed four different angling groundbaits and a commercial fish feed as control

Test diet	Initial mass (g)	Final mass (g)	FCR*	SGR
Ready-made boilies	134 ± 25[a]	168 ± 31[a]	5.75 ± 3.05[a]	0.41 ± 0.16[a]
Self-made boilies	133 ± 23[a]	229 ± 44[c]	1.94 ± 0.33[b]	0.98 ± 0.15[c]
Particles	134 ± 29[a]	137 ± 29[b]	34.34 ± 34.19†	0.08 ± 0.11[b]
Ordinary groundbait	135 ± 24[a]	149 ± 30[ab]	22.41 ± 27.55†	0.18 ± 0.18[ab]
Fish feed (control)	134 ± 25[a]	277 ± 47[d]	1.50 ± 0.25[c]	1.30 ± 0.18[d]

Different superscripts indicate significant differences (ANOVA, Tukey's *post hoc* test, $P < 0.05$)
*Because of heterogeneity of variances (Levene test, $P < 0.001$), a Dunnet-T3 *post hoc* test was used.
†Because of very low (ordinary groundbait) or nearly zero (particles) growth and the resulting extremely high FCR, these values were omitted from statistical analysis.

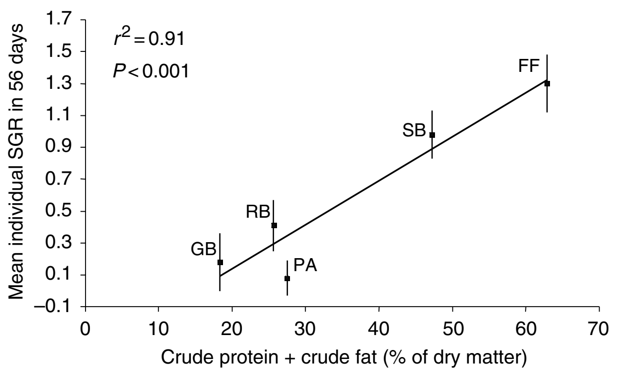

Figure 2. Linear regression between the combined crude protein and crude fat content (% of dry matter) and the mean specific growth rate (SGR) ± SD of juvenile carp fed 56 days with five different test diets. FF, commercial fish feed; GB, ordinary groundbait used in coarse angling; RB, ready-made boilies and SB, self-made boilies.

ready-mix boilies were combined in a ready-made boilies group.

The GPI was calculated as 1018 g P angler^{-1} yr^{-1} (Table 5), particles and boilies contributing mostly to this GPI. By taking into account the P amounts that might potentially be retained by carp feeding on the groundbaits, the NPI was estimated as 839 g P angler^{-1} yr^{-1}. The P-retention efficiency was highest in the self-made boilies and lowest in the particles. Because of the high P-content, the net P-content remained highest in the self-made boilies compared with ready-made boilies, particles and commercial groundbait. According to the NPI, the majority of the P-input originated from particles.

Based either on GPI or NPI, the absolute annual P-input could be counterbalanced by a carp biomass removal of 175–225 kg fish angler^{-1} yr^{-1} (Fig. 3). Thus, at fish removal rates below 175–225 kg yr^{-1}, the average carp angler would contribute to the P-load of the water bodies and consequently to eutrophication. At fish removal rates above 175–225 kg yr^{-1}, assuming the same groundbaiting level, carp anglers would be net removers of P from the waters.

Discussion

For anglers, the nutritive value of groundbaits is presumably of minor importance as long as the groundbaits attract fish but is not noxious to them. However, because of the substantial quantity of groundbait introduced to the waters in modern carp

Table 4. Initial and final chemical composition (mean ± SD, % of dry matter) of whole bodies of juvenile carp fed four angling groundbait test diets and a commercial carp feed (control)

Test diet	Dry matter	Crude protein	Crude fat	Ash
Initial whole body composition	25.9 ± 1.3[d]	56.9 ± 3.5[c]	33.2 ± 3.6[c]	10.2 ± 0.8[c]
Final whole body composition				
Ready-made boilies	32.6 ± 1.6[ab]	44.3 ± 2.9[ab]	48.7 ± 3.8[a]	7.6 ± 0.9[a]
Self-made boilies	30.7 ± 0.9[a]	46.9 ± 3.3[a]	44.1 ± 3.1[ab]	7.2 ± 0.6[a]
Particles	31.9 ± 1.4[ab]	44.5 ± 3.9[ab]	45.9 ± 3.2[a]	8.2 ± 0.6[ab]
Ordinary groundbait	33.4 ± 2.3[b]	40.9 ± 4.8[b]	46.9 ± 6.2[a]	8.9 ± 0.9[b]
Fish feed	28.7 ± 1.0[c]	52.8 ± 3.7[c]	40.4 ± 4.7[b]	7.9 ± 0.8[ab]

Different superscripts indicate significant differences (ANOVA, Tukey *post hoc* test, $P < 0.05$).

Table 5. Mean amount, type and total phosphorus (P) contents (based on wet mass) of baits used in carp angling in Germany and the calculated mean gross P-input (GPI) based and net P-input (NPI) per carp angler and year

Bait type according to carp angler survey	Amount used (g angler^{-1} yr^{-1})	P_B gross (%)*	GPI† (g angler^{-1} yr^{-1})	P_B net (%)‡	NPI§ (g angler^{-1} yr^{-1})	P_{ret} (%)¶
Ready-made boilies	55.8×10^3 (26.0)	0.33	184.1 (18.1)	0.25	137.6 (16.4)	25.3
Self-made boilies	30.1×10^3 (14.0)	0.77	231.8 (22.8)	0.52	157.3 (18.8)	32.1
Particles	103.2×10^3 (48.0)	0.39	402.5 (39.5)	0.37	388.1 (46.3)	3.6
Ordinary groundbait	12.9×10^3 (6.0)	0.26	33.5 (3.3)	0.24	30.8 (3.7)	8.2
Fish feed	12.9×10^3 (6.0)	1.29	166.4 (16.3)	0.97	125.1 (14.9)	24.8
Sum	214.9×10^3		1018.3		838.8	

Percentage values are given in parenthesis.
*Taken from the random groundbait sample used in the feeding experiment (see Table 1).
†Calculated according to eqn 1.
‡P_B net subtracts from P_B gross the P amount that is converted into carp biomass according to the feeding experiment (see parenthesis in eqn 2).
§Calculated according to eqn 2.
¶P_{ret} is the P retention efficiency = 100 × (GPI−NPI)/GPI.

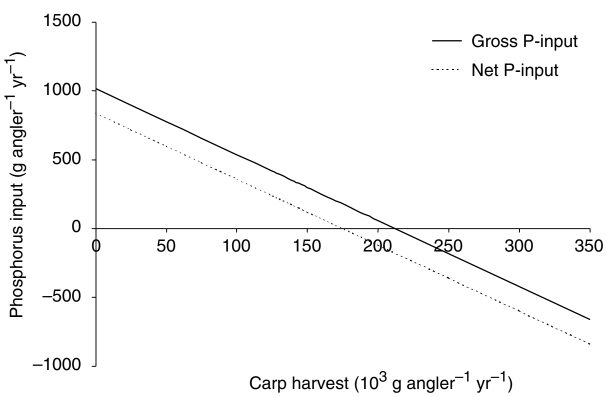

Figure 3. Hypothetical total phosphorus (P) mass balance (g angler^{-1} yr^{-1}) based either on the gross P-input (GPI, according to eqn 3a) or the net P-input (NPI, according to eqn 3b) of an average carp angler in Germany relative to the carp biomass harvest (g angler^{-1} yr^{-1}). Positive values indicate a NPI to the water.

angling (Fig. 1) and because carp will feed on this artificial food (Schäperclaus 1966; Specziár *et al.* 1997), the nutritional quality of angling baits gains importance. This is particularly true in Germany, where the feedstuff law demands that every feed given to animals should: (1) maintain or improve the productive efficiency of farm animals; (2) ensure the quality product from farm animals remains harmless with respect for human health; and (3) guarantee the well-being of the animals in general. If one considers that in Germany angling is often only tolerated if the catch is removed for consumption (see Arlinghaus & Mehner 2003 for a discussion on catch-and-release), it could be argued that freshwater fish can no longer be regarded as wild animals but are farm animals held extensively in natural water bodies. Consequently, angling groundbaits would need to follow the legal requirements of the feedstuff laws and byelaws and their nutritional quality has to be investigated.

Depending on the amino and fatty acid profile and the vitamin and mineral composition and content based on DM, practical carp diets in aquaculture should contain 33–41% crude protein and 6–12% crude fat (Schwarz 1998). Figure 1 and Tables 1–3 show that most groundbaits used in carp angling do not reach these values. Consequently, in the feeding experiment, both final body mass and SGR of carp, were lower and the FCR considerably higher than in the control group fed with a commercial fish feed (Table 4). Fish growth is ultimately dependent on the availability of essential nutrients and the provision of energy (e.g. Steffens 1989). This well-known relationship was demonstrated in angling baits as well, where the mean SGR increased almost linearly with the combined crude protein and crude fat content in the angling groundbaits (Fig. 2). Resulting from the divergent inclusion level of macronutrients in the test diets (Table 1), the body composition of the carp differed markedly between the experimental groups (Table 4). Generally, significant differences detected were in accordance with the fish nutrition literature on the effects of dry diets on the body composition of carp (compare Zeitler, Kirchgessner & Schwarz 1984; Oberle, Schwarz & Kirchgessner 1997; Schwarz 1998). The reduced body protein content of the fish fed with angling groundbaits and the insignificant changes in the control group indicate nutrition deficiencies in the angling baits which partly led to the reduction of the protein content similar to the reduction of body protein in starving carp (Schwarz, Kirchgeßner & Zeitler 1984). The increase in the body fat content in the angling groundbait feeding experiments with simultaneous protein content reduction, is the result of the accumulation of fatty acids synthesised from the absorbed glucose of the NFE rich angling diets. Although this high fat accumulation in the groundbait feeding experiments suggests a reduction in the overwinter mortality of carp under natural conditions (e.g. Steffens 1996), it is concluded that most groundbaits used in carp angling can only supplement natural food by providing additional energy but are not sufficient to meet the nutritional requirements of carp. This is interesting because advertisement of ready-made boilies often claims that the baits fully meet the nutritional demands of carp. According to legal requirements in Germany, in the future angling groundbaits should be treated as supplemental feeds and not as complete feeds. At present, the commercial boilie suppliers rarely meet legal requirements by the German feeding stuff byelaw; in particular they fail to indicate the feed composition and the 'best before' dates.

Irrespective of the above, the goal of formulating groundbaits should not be to maximise growth of fish. Instead, from the nutrient loading point of view the aim of ecological groundbaits should be to minimise the P-input by maximising the P-retention efficiency and minimising the P-level of the groundbaits. Although P is an essential nutrient for fish, and maximum growth of carp is achieved at a P content of 0.6–0.7% available P per DM (Ogino & Takeda 1976), the P-retention efficiency seems to be limited in compounded dry feeds, and is dependent on water temperature and feed composition (Schäfer, Koppe, Meyer-Burgdorff & Günther 1995; Kim, Kim, Song, Lee & Jeong 1998). In experiments with carp fed with dry diets the P-retention efficiency ranged between 30.4 and 37.9% (Schäfer *et al.* 1995; Kim *et al.* 1998; Jahan, Watanabe, Satoh & Kiron 2001). Although the P-retention efficiency may increase with an increase in total P in the diet (Schäfer *et al.* 1995), the P loss also increases (Kim *et al.* 1998). These relationships were evident in the angling baits as well, where self-made boilies richer in fish meal had the highest P-retention efficiency of 32.1%, but also the highest net P-concentration (P_B net) (Table 5). Thus, increasing the inclusion level of fish meals to enhance the nutritional quality of baits (e.g. self-made boilies compared with ready-made boilies in Tables 2 and 3; see also Jahan *et al.* 2001) also increases the P-content. Excess supply of P, in particular excess of indigestible tricalcium phosphate contained in fish meal, reduces the P-retention efficiency and availability of P as well as of other micronutrients (Satoh, Izume, Takeuchi & Watanabe 1992). For example, in the present experiment the P-retention efficiency of the commercial fish feed rich in fish meal with a P-content of 1.29% of DM was only 25% (Table 5). Low nutritive groundbaits such as ready-made boilies or commercial groundbait revealed a lower absolute net-P-content than both self-made boilies or commercial fish feed despite the higher growth rates achieved with these test diets (Tables 3 and 5). Thus, according to the present study, it is recommended to use predominantly carbohydrate rich groundbaits with a low P-content instead of a fish meal rich bait, because higher nutritional quality baits stimulating fish growth and enhancing the P-retention do not necessarily reduce the NPI.

This study reported that the GPI or NPI of the average carp angler would become counterbalanced by a carp biomass removal of more than 175–225 kg angler^{-1} yr^{-1} (Fig. 3). This harvest rate, however, is unrealistic because carp anglers as many other coarse anglers are mainly practising catch-and-release fishing (North 2002; Arlinghaus & Mehner 2003). Therefore, in contrast to the early study of Wolos *et al.* (1992), modern carp anglers certainly contribute to the P-load in their preferred waters because of: (1) higher absolute groundbait quantities; (2) qualitatively different groundbaits richer in P; and (3) the practice of catch-and-release fishing. This total P-input may contribute either directly or indirectly to primary production, increase in algal biomass and ultimately to the degradation of water quality. However, with respect to feeding groundbaits to carp, a time lag between groundbaiting-induced P-input and a direct increase in algal production is likely because in carp the predominant part of the total P-release from dry feeds consists mainly of particulate P (about 61% according to Sternik 1983). In contrast, about 50% of the P excreted by carp feeding on natural food is in the form of soluble reactive P (SRP) readily available to primary producers (Lamarra 1975). Furthermore, about 62% of the P originating from groundbaits fed to long living and large growing carp (Steffens 1980) and incorporated into carp biomass (difference between GPI and NPI in Table 5) is fixed in the skeleton (Pfeffer 1978) which is resistant to remineralisation (Kitchell *et al.* 1975). Thus, more than 50% of groundbaiting-induced P accumulated in fish bones and scales will not be recycled from fish carrion. However, groundbaits fed by carp anglers may not be ingested immediately after being introduced. Consequently, substantial P quantities can be released within a few hours, which greatly exceeds the P-release from particulate P in fish faeces (Sternik 1983). At a water temperature of 15 °C, over 66% of the total P and over

80% of SRP is released from dry feeds not ingested by carp within the first 8 h (Sternik 1983).

Implications for inland fisheries management and research

The evidence presented shows that the potential negative impact of excessive ground- and pre-baiting should be taken seriously. The interests and benefits of coarse anglers should be balanced against groundbaiting-induced P-inputs, which is the detrimental side of coarse angling. Local anglers should be made aware of the risk of the impact of groundbaiting on water quality and the need to counterbalance the P-inputs by appropriate amounts of fish biomass removal. If voluntary reduction of bait amounts is not practised in sensitive water bodies (small, shallow, nutrient poor, long water retention time) with high angler densities and low harvest rates (see Arlinghaus & Mehner 2003), it is recommended that there should be restrictions on catch-and-release fishing, banning of P-rich bait types, daily bait limits, or banning of groundbaiting in general. If this is not successful, reduction or even banning of coarse angling might be the very last resort. First of all, however, the use of particles, commercial groundbait and P-rich commercial fish feed should be limited because the use of boilies is restricted by the high market price (up to 15 € kg^{-1}). Furthermore, the angling press recommends that the relatively cheap particles (1–2 € kg^{-1}) should be used in high amounts because they are supposed to be ineffective when used in small quantities. Nevertheless, there remains the necessity of some form of control and enforcement, which may be implemented through local-level informal institutions and co-management schemes (see Arlinghaus *et al.* 2002 for a review). However, the results presented in this paper should not be misinterpreted as a call to ban groundbaiting in all cases because a significant contribution of coarse angling to anthropogenic or 'cultural' eutrophication is strongly dependent on local conditions. A total ban of groundbaiting would severely reduce the coarse angling experience, decrease angler benefit and satisfaction, and is not in agreement with the sustainable development approach in recreational fishing management (Arlinghaus *et al.* 2002). Limiting groundbaiting might ultimately decrease coarse angling, which in turn would also reduce the economic benefits derived from coarse angling in regional economies (compare estimates in Arlinghaus & Mehner 2003). Further studies on the issue of groundbaiting are needed to develop guidelines for a more effective management of coarse angling. To improve the estimates of the P-retention potential of carp fed with groundbaits, studies are necessary in which groundbait is given to the fish in addition to natural food. Furthermore, the effects of different feedstuff compositions of groundbaits (e.g. fish meals vs. plant materials) should be investigated to develop ecological groundbaits that minimise nutrient inputs and maximise attractiveness (compare Loeb 1960).

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