Report on an FSBI Small Research Grant (awarded in 2007)

A preliminary study of non-native species impacts: how do clandestine introductions of goldfish impact pond ecosystems?[1]

Summary

Introductions of the Asian cyprinid, goldfish *Carassius auratus*, are common in the UK but are known to pose a genetic threat to crucian carp *Carassius carassius*, which is native to southeast England. However, there are no known studies in Europe of goldfish impacts on native fish species nor on the recipient ecosystems. The present study is the first such attempt, which examined six ponds: two containing only crucian carp (allopatry), two containing only goldfish (allopatry) and two containing both species (sympatry). Feral goldfish growth was greatest when living in sympatry with native crucian carp, whereas crucian carp growth was similar regardless of goldfish presence or absence. However, body condition of crucian carp was greatest in the crucian carp population living in sympatry with feral goldfish, where crucian carp relative fecundity (eggs per body weight) was also significantly higher than in absence of goldfish. Differences in the plant and aquatic invertebrate communities observed in the study ponds could not be attributed to the introduction and establishment of goldfish, however non-native plant and invertebrate species were observed only in ponds containing goldfish. Our results suggest that somatic growth and reproductive output may be maximized in crucian carp when confronted by coexistence with feral goldfish, the latter species appearing to growth best when in sympatry with crucian carp. It remains unclear whether introduced goldfish impact pond ecosystems, and along with crucian carp-goldfish interactions, this requires further study.

Introduction

One of the major threats to pond ecosystems is the introduction of non-native ornamental fishes. The first, and still the most prominent, of the ornamental fishes that have been released into ponds is the goldfish *Carassius auratus* L. A species introduced to the UK from Asia during in the late 1600s, the goldfish is ignored in current national legislation regarding non-native species. Pet goldfish are known to be released into both ponds and rivers, so the species is now widespread in the UK. However, the exact distribution is uncertain because the natural brown variety of goldfish bares a very strong physical resemblance to its close congener, crucian carp *Carassius carassius* (L.), which is native to southeastern England. As a consequence of this similarity, mis-identifications of brown goldfish as crucian carp are common-place.

The goldfish is believed to be a major cause of the decline of some fish species in the U.S.A as well as the displacement of native crucian carp in Europe. However, despite the long history of goldfish in the Europe, the environmental biology of feral goldfish populations have received little study in Europe and their impacts remain unstudied. To address the scarcity of information on goldfish impacts in European inland waters, the aim of the present, preliminary study was to examine the potential impact of feral goldfish on native pond organisms, with particular reference to crucian carp. The specific objectives were to: 1) compare the biological traits (age-specific growth, body condition, mean length and age at

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[1] This work was carried out in collaboration with A.S. Tarkan (Muğla University, Turkey), M. J. Godard and N. J. Edmonds (Cefas-Lowestoft), K.J. Wesley (Bedwell Fisheries Services, Welham Green, Hertfordshire), with contributions from J. Biggs and P. Williams (Pond Conservation).

maturity, gonado-somatic index, relative fecundity) of pond-dwelling populations of crucian carp and of feral goldfish living in allopatry and sympatry; and 2) assess the composition of aquatic plants and invertebrates in these ponds to identify impacts of pond community structure. The working hypothesis was that goldfish impacts on crucian carp would result in different growth and reproduction patterns between the populations living in sympatry and allopatry. And because the release of goldfish has previously been linked with the introduction of other non-native aquatic organisms such as Canadian pondweed *Elodea Canadensis*, ponds containing goldfish were expected to contain non-native species of aquatic plant and invertebrate not found in ponds without goldfish.

Material and methods

Sampling of aquatic plants, aquatic invertebrates, and fishes was undertaken between 23 April and 1 May 2007 in six ponds (Table 1) of the Epping Forest conservation area (northeast London). Invertebrate sampling was undertaken during the week of 23 April 2007 using UK National Pond Survey methods. Crucian carp and goldfish were collected on 31 April and 1 May 2007 from a fiberglass, electric motor-powered boat as catch per unit effort (CPUE) of time sampling. Some additional specimens of short body length were collected on 7–8 April 2008, but these were excluded from the CPUE estimates.

Table 1. Geographical location (Lat = latitude; Long = longitude), area (m^2) and mean water depth (m) of study ponds in Epping Forest (Essex, England), with fish species present (CC = crucian carp; GF = goldfish) as follows: crucian carp living in allopatry (CC-allo), goldfish living in allopatry (GF-allo) and these two species living in sympatry (CC/GF-sym). The site-specific numbers of fish captured are given (GF total = 182; CC total = 101).

						Fish numbers		
Pond name	Code	Lat (N)	Long (E)	Area	Depth	GF	CC	Total
Fairmeads	CC/GF-sym	51°39'02"	00°02'07"	453	1.2	3	11	14
Earls Path Pond	CC/GF-sym	51°39'05"	00°02'38"	1760	1.5	65	4	69
Hawcock Pond	CC-allo	51°41'11"	00°05'10"	1181	0.5	–	55	55
Pizzole Pit Pond	CC-allo	51°40'08"	00°04'59"	563	0.6	–	31	31
Carroll's Farm	GF-allo	51°39'07"	00°00'23"	706	2.5	105	–	105
Johnson's	GF-allo	51°36'34"	00°01'19"	800	0.9	9	–	9

Plant and invertebrate sampling – All wetland macrophytes present in each sample area were recorded either by walking and wading shallow regions and the margins of waterbodies, or in deeper water using a grapnel thrown from the bank or a boat. 'Wetland macrophytes' were defined as those plants listed as wetland plants in the National Pond Survey methods guide (1998, Pond Action, Oxford). This included aquatic marginal, emergent, floating-leaved and submerged plants. For sampling macroinvertebrates a 1 mm mesh hand-net was used to sample for a total of three minutes, with the total sampling time being divided equally between the major mesohabitats present in the survey area, *e.g.* areas of distinctively different sediments, submerged tree roots, stands of vegetation with differing structure. Samples were live-sorted in the laboratory to remove all individual macroinvertebrates, with the exception of very abundant taxa (>100 individuals), which were sub-sampled. Macroinvertebrates were identified to species level for those groups where reliable distribution data and Red Data Book information were available.

Fish age, growth, body condition and reproduction – Age, growth and body condition were determined as described in Tarkan *et al.* (2009, *Aquat. Conserv.* DOI: 10.1002/aqc.1028). Using the data from these papers, comparisons of growth trajectories were made using the growth index of Hickley & Dexter (1979, *Fish, Manag*. **10**, 147–151), which was calculated as follows: first plotted standard lengths (SL) at mean ages (n) were plotted against SL at age (n+1) to obtain a straight line for the Walford method; then, SLs for age were obtained from the formula $l_n = L_\infty (1 - k^n)$ where $L_\infty = l_t/(1\text{-}k)$; l_t = interception on the y axis; l_n = length at age n; k = slope of the Walford plot (Hickley & Dexter, 1979). Relative body condition was assessed using Le Cren's index: LK = w/w', where w is the observed body weight and w' is the expected weight as estimated from the SL-to-weight relationship ($W = a + \mathrm{SL}^b$) for the respective species (crucian carp, a = 0.0268 and b = 3.1187; goldfish, a = 0.0425 and b = 2.962). LK values >1.0 indicate that the individual is in better condition than an average individual of the same SL range, whereas LK values <1.0 indicate that the individual is in worse condition than an average individual of the same length. Four reproductive indices from Tarkan *et al*. (2009) were examined: relative fecundity (*RF*), gonado-somatic index (GSI), mean age at maturity (AaM) and mean standard length at maturity (LaM). *RF* values were calculated as per Bagenal (1978, pp. 75–101 in *Methods for Assessment of Fish Production in Fresh Waters*), and gonado-somatic index as: GSI = (100 × ovary weight) ÷ total body weight. AaM and LaM were calculated as used in Tarkan *et al*. (2009).

Statistical analyses – Species richness (*S*) was calculated as the total number of plant or invertebrate species recorded in each pond. Species rarity (*R*) was calculated using a species rarity index (SRI). This index is conceptually based on the Species Quality Score (Foster *et al*. 1990, *Freshwat. Biol.* **22**, 343–354) and was derived in the following manner: (I) all species present were given a numerical value depending on rarity/threat, (ii) the score of all species in each sample were summed to give a Species Rarity Score, (iii) the Species Rarity Score was divided by the number of species recorded in the sample to give the SRI. Six rarity categories were recognized and given the following conservation scores: Score 1 = 'Common species'; Score 2 = 'Local' (for invertebrates, either confined to certain limited geographical areas, where populations may be common or of widespread distribution, but with few populations. For plants, recorded from ≤ 25% [≤ 705] of 10×10 km grid squares in Britain); Score 4 = 'Nationally Scarce' (recorded from 15–100 of 10×10 km grid squares in Britain); Score 8 = 'Red Data Book - conservation dependent or near threatened'; Score 16 – 'Red Data Book - endangered or vulnerable'; Score 32 = 'Red Data Book—critically endangered'. The 'Priority' status of the ponds was evaluated using a series of status criteria (http://www.pondconservation.org.uk/pond_hap/prioritypondcriteria. htm), which include the presence of: i) European priority habitats, ii) species of conservation concern, or iii) exceptionally rich assemblages (*e.g*. occurrence of ≥ 50 macro-invertebrate species in 3-minute samples, three or more Nationally Notable invertebrate species, one of more Nationally Scarce plant, one of more Red Data Book species, one or more species of Biodiversity Action Plan (BAP) designation).

Relationships between fish density, invertebrate density and plant parameters, plant richness, rarity scores, water chemistry (pH and conductivity) were tested using linear regressions while relationships between scale length, relative fecundity, egg diameter and SL were tested using non-linear (power curve) regressions. Differences in condition values between each population, between back-calculated lengths and observed lengths and between mean relative fecundity values of the populations were tested using Students' *t* tests. Mean calculated SL values were tested for differences between allopatry and sympatry using the Mann-Whitney test.

Results

The growth trajectories revealed that goldfish growth was faster when living in sympatry with crucian carp (Mann-Whitney, $P < 0.01$), with no change in crucian growth (Fig. 1). Crucian carp growth was also faster when living in sympatry, but its magnitude compared to goldfish growth case in sympatry was much smaller (Fig. 1). *LK* values showed that crucian and goldfish are plumper in sympatry ($t = 9.966$, $P < 0.001$ for crucian carp; $t = 1.775$, $P < 0.05$ for goldfish), with the lowest condition in crucian carp living alone (Fig. 2). *LK* of crucian carp living in sympatry was much higher than goldfish living in sympatry ($t = 5.427$, $P < 0.001$). LaM values were generally similar for both females and males, regardless of the presence or absence of the other species. However, in males, the estimated AaM values in crucian carp was almost one year younger in the presence of goldfish, which showed a similar but less pronounced pattern. In both species, *RF* was much higher in sympatry than those in allopatry ($t = 4.178$, $P < 0.001$ for goldfish; $t = 6.620$, $P < 0.001$ for crucian carp), with values for goldfish being almost the double of the native species (Table 2).

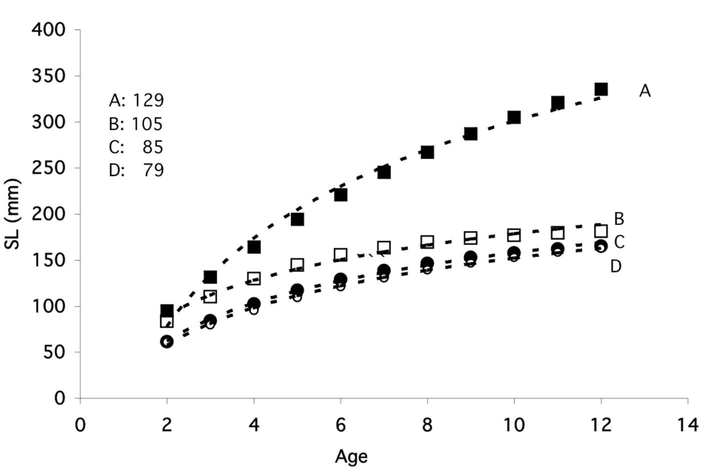

Fig. 1. Growth curves based on back-calculated standard lengths (SL), using the Walford (1946) method together with calculated growth indices (Hickley & Dexter 1979: letters A–D), for goldfish (square dots) and crucian carp (round dots) in ponds of Epping Forest (Essex, England) living in allopatry (open dots) and in sympatry (filled dots).

Table 2. Mean standard length at maturity (LaM), mean age at maturity (AaM) and mean relative fecundity (RF) and gonado-somatic index for crucian carp in ponds of Epping Forest (Essex, England), where they were living in allopatry (CC-allo) and in sympatry (CC-Sym) with goldfish, and goldfish living in allopatry (GF-allo) and in sympatry (GF-sym) with crucian carp (derived from data in Tarkan *et al*. 2009 and unpublished).

	Male			Female				
	n	LaM	AaM	n	LaM	AaM	GSI	RF
CC-allo	86	55.0	2.20	100	45.0	2.05	8.4	119.2
CC-sym	51	52.5	1.50	40	50.0	1.50	6.4	231.0
GF-allo	126	59.6	1.45	114	56.7	1.35	7.1	251.7
GF-sym	66	56.1	1.10	65	54.2	1.20	9.0	455.8

None of the ponds were of sufficient biological quality to be recognised as Priority Ponds under the UK BAP. There are no significant relationships between fish density and invertebrate and plant indices, but plant richness and rarity scores tended to be higher with higher crucian carp CPUEs. Whereas, the opposite tendency was observed for goldfish

CPUEs. Indeed, non-native plant species, as well as the non-native tadpole snail *Physella* (*acuta*) (Draparnaud), were present only in ponds containing goldfish, either in allopatry or in sympatry with crucian carp (Table 3). The non-native freshwater shrimp *Crangonyx pseudogracilis* Bousfield was present in all ponds surveyed (Annex 1). Goldfish were present in ponds of both lower and higher water conductivity, where crucian carp was present only in ponds of lower water conductivity (Table 3).

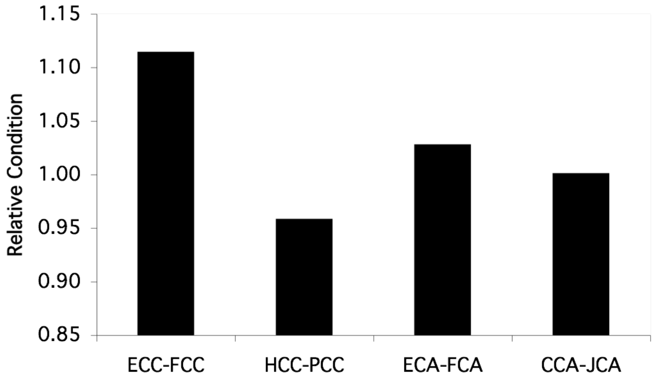

Fig. 2. Le Cren (1951) relative fish body condition (*LK*) in ponds of Epping Forest (Essex, England) for crucian carp living in sympatry (ECC-FCC) and in allopatry (HCC-PCC) with goldfish, and goldfish living in sympatry (ECA-FCA) and in allopatry (CCA-JCA) with crucian carp.

Unadjusted invertebrate species *S* and *SRI* were weakly related (ANOVA, $P < 0.10$) to goldfish density (CPUE), but this was not the case with crucian carp – both *S* ($S = -1.40\text{CPUE} + 29.74$; $F_{2,4} = 4.60$, $P = 0.099$) and *R* ($R = -1.66\text{CPUE} + 32.33$; $F_{2,4} = 5.76$, $P = 0.074$) decreased with increasing goldfish density (Fig. 3). These relationships were also significant for both fish species combined ($S = -1.85\text{CPUE} + 31.36$; $F_{2,4} = 16.46$, $P = 0.025$)($R = -2.02\text{CPUE} + 33.9$; $F_{2,4} = 12.39$, $P = 0.015$).

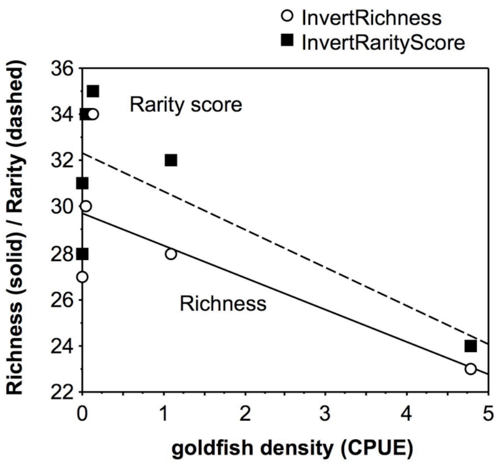

Fig. 3. Invertebrate species richness (*S*) and rarity (*SRI*) as a function of goldfish density in ponds of Epping Forest (Essex, England) without adjustment for invertebrate density.

However, when *S* is adjusted to invertebrate density (*i.e.* $S' = S \div$ invertebrate density), to account for the well-known positive relationship between *S* and organism density, then all of the relationships were non-significant.

Table 3. Summary of water chemisty and aquatic invertebrates (mean values for aquatic invertebrates are given for sympatry and the two types of allopatry) and plants in ponds (FM = Fairmeads; EP = Earl's Path; HC = Hawcock; CP = Carroll's; PP = Pizzole Pit; JP = Johnson's) sampled the week of 23 April 2007 in Epping Forest, England (see Table 1).

	Sympatry		Crucian only		Goldfish only	
	FM	EP	HC[1]	PP	CP	JP
Water chemistry						
Conductivity	273	359	288	311	789	1371
pH	6.7	6.8	7.1	7.4	8.7	8.2
Invertebrates						
Species richness (total)	30	28	27	28	23	34
Species richness (non-natives)	1	1	0	0	0	1
Species Rarity Score	34	32	31	28	24	35
Species Rarity Index	1.13	1.14	1.15	1.00	1.04	1.03
Total number of inverts netted[2]	871	251	358	480	522	224
Mean number of inverts:	561		419		373	
Conservation value	Mod.	Mod.	Mod.	Low	Mod.	Mod.
Plants						
Submerged[3]	5.5	3	10	15	62	0
Floating-leaved	6.0	1.0	0.1	28.0	0.5	0
Emergent	12	12	20	12	38	6
Total cover[4]	24	16	30	55	98	6
Species richness (total)[5]	24	17	21	20	14	7
Species richness (non-natives)	1	2	0	0	1	0
Species Rarity Score	28	18	23	22	16	7
Species Rarity Index	1.17	1.06	1.10	1.10	1.10	1.00
Conservation value	High	Mod.	Mod.	Mod.	Mod.	Low

[1] Contained palmate newt *Triturus helveticus*; [2] Indicates relative abundance, not true abundance per unit area and excludes organisms recorded in absence presence only (see Annex 1); [3] Cover of submerged, floating-leaved, emergent and total were estimated in the field, so values given are not the sum of all individual species values in the column above; [4] total cover is not the sum of submerged, floating and emergent but is estimated separately; [5] Excludes *Salix* spp. and algae.

Discussion

The composition of pond organisms could not be attributed to the presence of goldfish, though whereas the observed differences in crucian carp body condition and relative fecundity may be influenced by goldfish presence. Crucian carp growth is known to be influenced by environmental factors, such as temperature and food availability, with adverse effects having been attributed to intra-specific competition in cases of food shortage (Holopainen *et al.* 1997, *Annal. Zool. Fenn.* **34**, 1–22). Temperature does not appear to be a major factor in the present case, as the ponds are situated within a few kilometers of each other, and the fastest growing goldfish were in a well-shaded pond (Earl's Path). Similarly, food availability also did not appear to be important, as crucian carp growth was similar in both allopatry and sympatry with goldfish (Fig. 1), and the majority of fast-growing (sympatric) goldfish were from Earl's Path Pond (Table 1, Fig. 1), which had the second lowest number of invertebrates (Table 3). Coexistence of crucian carp and goldfish may even incite these two congeners to maximize their growth potential. Relative to allopatric populations, sympatric crucian carp had an elevated *LK* (plumpness) value (Fig. 2), they are the fastest-growing crucian carp so far recorded for England, and they were intermediate compared with populations elsewhere in similar latitudes (Tarkan *et al.* 2009). Similarly, the fast-growing sympatric goldfish were intermediate relative to populations elsewhere in Europe, which contrasts the slow growth of alloptric goldfish relative to other European populations (unpublished data).

Both forms of growth response to sympatry, faster incremental growth in goldfish and greater plumpness in crucian carp, are expected to influence reproductive output and this appears to be manifest in the relative fecundities observed (Table 2). However, no consistent pattern was observed in length or age at maturity. Variations in reproductive output have been reported for introduced species, and increased fecundity was observed in both species in sympatry in the present study, with almost double the number of eggs per body weight relative to females existing in allometry. Also in sympatry, male crucian carp matured almost a year earlier with did those in allopatry. Comparative data for feral goldfish in Europe are scarce, but in the warm climate of Lake Trasimeno, Italy (Lorenzoni *et al.* 2007, pp. 259–273 in *Freshwater Bioinvaders: Profiles, Distribution, and Threats*), the *RF* of goldfish was lower, and mean AaM was higher, than observed in the ponds of Epping Forest (unpublished data). This runs contrary to life-history theory, which predicts that ectotherm organisms will experience faster juvenile growth, precocious maturity, and a shorter life-span, in response to elevated water temperatures. Fast juvenile growth and precocious maturation have been linked to invasiveness potential in pumpkinseed *Lepomis gibbosus* (L.) introduced to European waters, and this pattern may also apply to goldfish, but a much larger data set would be necessary to test this hypothesis.

Wider ecosystem impacts have been attributed to introductions of goldfish, including a decrease in invertebrate numbers, the local eradication of aquatic macrophytes through direct consumption, and the alteration of aquatic community composition associated with nutrient re-suspension due to the species' benthic feeding habits. Indeed, recent research has found the growth of cyanobacteria to be stimulated during its passage through goldfish intestines. In conclusion, evidence of impacts by feral goldfish in the present study are less apparent than observed elsewhere. Differences in the plant and aquatic invertebrate communities of the ponds in the present study could not be attributed to the introduction and establishment of goldfish. However, in support of our prediction and with the exception of the ubiquitous freshwater shrimp *Crangonyx pseudogracilis*, all non-native plant and invertebrate species were encountered only in ponds containing goldfish. The present, preliminary study did reveal a possible goldfish impact on crucian carp biology. Both body condition and relative fecundity in crucian carp were greater in ponds co-inhabited with goldfish. And because crucian carp egg diameter was similar in sympatry and allopatry with goldfish (Tarkan *et al.* 2009), crucian coexistence with goldfish appears to lead to a greater growth allocation to weight, leading to higher relative fecundity. However, crucian carp relative fecundities are approximately half those of goldfish, regardless of sympatry or allopatry. Thus, in addition to their genetic contamination of crucian carp populations through hybridization (Hänfling *et al.* 2005, *Freshwat. Biol.* **50**, 403–417), goldfish are able to out-populate crucian carp by two-fold when confronted with similar food resources. The decline of crucian carp within parts of its native range would therefore appear to be due to a combination of two factors, loss of habitat and the introduction of an exotic but closely related congener fish species.

Acknowledgements

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Outputs related directly to or emanating directly from this grant

Journal papers

Tarkan, A. S., Copp, G. H., Zięba, G., Godard, M. J. & Cucherousset, J. (2009). Growth and reproduction of threatened native crucian carp *Carassius carassius* in small ponds of Epping Forest, southeast England. *Aquatic Conservation* DOI: 10.1002/aqc.1028

Tarkan, A.S., Cucherousset, J., Zięba, G., Godard, M.J. & Copp, G.H. (submitted). Growth and reproduction of introduced goldfish *Carassius auratus* in small ponds of southeast England.

Copp, G.H., Tarkan, A.S., Godard, M.J., Edmonds, N. & Wesley, K.J. (submitted). The impact of feral goldfish *Carassius auratus* populations introduced to ponds, with particular reference to native crucian carp *Carassius carassius*.

Conference communications

Tarkan, A.S., Godard, M.J. & Copp, G.H. 2008. Does coexistence affect the growth and condition of native crucian carp *Carassius carassius* and introduced goldfish *C. auratus* in small ponds? (Oral communication, EIFAC conference, Antalya, May 2008)

Copp, G.H., Tarkan, A.S., Godard, M.J. & Cucherousset, J. 2008. Conservation of native pond fishes — How is the growth and condition of native crucian carp *Carassius carassius* affected by feral goldfish *C. auratus*? (Poster communication, EPCN workshop, Valencia, May 2008; FBA Annual Scientific Meeting, London, June 2008)

Copp, G.H., Tarkan, A.S., Godard, M.J., Zięba, G., Wesley, K., Biggs, J., Sayer, C. & Cucherousset, J. 2009. Non-native fish introductions to ponds: risks & impacts (Invited oral communication, London Freshwater Group meeting, London, March 2009)

Sayer, C. & Copp, G.H. 2009. Why crucian carp should be a BAP species in Norfolk. (Invited oral communication, Meeting of the Norfolk Waterbodies Group, Norwich, January 2009)

Copp, G.H., Tarkan, A.S., Godard, M.J., Zięba, G., Wesley, K.K., Biggs, J., Sayer, C. & Cucherousset, J. 2009. The risks & impacts of non-native fish introductions to ponds in Epping Forest and north Norfolk. (Invited oral communication, Norfolk Non-native Species Forum, Norwich, February 2009)

Expenditure

Cost of invertebrate sampling and processing:	**£4,100**
Total sum received*:	**£4,100**

*Paid directly to Pond Conservation by the FSBI

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