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# The decline of crucian carp *Carassius carassius* in its native English range: the example of rural ponds in north Norfolk

Report to the Norfolk Biodiversity Partnership

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# 1. SUMMARY

Small agricultural ponds are important sites for the conservation of freshwater biodiversity, including native fish such as the crucian carp *Carassius carassius* L., a cryptic, benthic species that is thought to have undergone a significant decline in England over recent decades. To assess the extent and causes of its decline, we focused on a discrete region of north Norfolk, in the heart of the species native range in England (UK). The study area included 29 ponds, 24 of which, were known (from interviews with local anglers and land owners) to have previously contained crucian carp in the 1970s–80s. Fish surveys revealed crucian carp to be present in just six of these ponds representing a 75% decline in its distribution over the last 20–30 years. Non-native carp species or their hybrids with crucian carp were observed in six of the 29 ponds, with common carp *Cyprinus carpio* L., goldfish *Carassius auratus* L., crucian carp × goldfish and crucian carp × common carp hybrids occurring in one, two, two and five ponds respectively. Causes of crucian carp extinction were determined for 16 of the ponds: desiccation during the droughts of 1976 (2 ponds) and 1988–1992 (4 ponds); terrestrialisation leading to a virtual loss of open water and/or to deteriorating habitat (5 ponds); hybridisation and/or competition with common carp (3 ponds); infilling for agricultural land reclamation (two ponds) and predation following introduction of pike *Esox lucius* L. (1 pond). The results of this study have led to the designation of crucian carp as a Biodiversity Action Plan (BAP) species in the county of Norfolk; a major advance in the conservation of this much overlooked species in the UK. This is aimed at halting the decline of crucian carp through conservation measures to protect and/or rehabilitate ponds that contain or used to contain crucian carp populations via collaborative efforts with landowners, anglers and the general public.

## 2. INTRODUCTION

Ponds are recognised as being important ecosystems for the conservation of invertebrates, aquatic plants and amphibian species (Oertli *et al.,* 2002), with this especially true in arable agricultural regions in the UK (Williams *et al.,* 2003; Davies *et al.,* 2009). A less well understood and recognised role of ponds, however, lies in the conservation of native fish species such as crucian carp *Carassius carassius* L. (Copp *et al.,* 2005; Copp *et al.,* 2008a), a cryptic, benthic species native to most of middle and northern Europe including south-eastern England (Wheeler, 1977, 1981). The current status of crucian carp in England is poorly defined largely due to its physical similarity with the brown (natural) variety of goldfish *Carassius auratus* L., a species with which crucian carp has often been confused (Wheeler, 2000; Hickley & Chare, 2004). Nonetheless, crucian carp is thought to have undergone a substantial decline in England, as well as Europe, due to a range of factors (e.g. Steiner, 1988, Navodaru *et al.,* 2002), including acidification (Holopainen & Ikari, 1992), loss of habitat (Copp, 1991; Schwevers *et al.,* 1999; Wheeler, 2000) and displacement by introduced species such as gibel carp *Carassius gibelio* Bloch, goldfish and common carp *Cyprinus carpio* L. via habitat degradation, competition and/or genetic contamination (Navodaru *et al.,* 2002; Hänfling *et al.,* 2005; Copp *et al.,* 2005; Smartt, 2007; Tarkan *et al.,* 2009).

Previous research on the environmental biology and conservation status of crucian carp in England has been limited to a few populations in Essex (Epping Forest) and Hertfordshire (Marlborough, 1967; Wheeler, 1998; Copp *et al.,* 2008a,b; Tarkan *et al.,* 2009) and a single, unpublished dietary study of an introduced population in Devon (Couchman, 2000). In parallel with the recent research in Essex and Hertfordshire, the species has become the subject of local conservation action, including pond rehabilitation (removal of accumulated sediments and overhanging trees), the eradication of goldfish, and re-introduction of crucian carp (Conservators of Epping Forest, 2002; Environment Agency, 2003; Copp *et al.,* 2005; Lambeth Borough Council, 2006; Copp *et al.,* 2008a). In most regions of England, however, the status of crucian carp is obscure, and similar conservation work is restrained by a lack of information on the species' distribution as well as the scale and causes of its decline.

One area that is believed to have been a stronghold for crucian carp in the past is Norfolk, a county in the East of England (Patterson, 1905; Ellis, 1965 and see Figure 1 in Wheeler, 2000). In recent years, crucian carp has rarely been reported by anglers in Norfolk, and a recent newsletter published by the UK Environment Agency (2008) stated that "*the species is thought to be almost extinct in Norfolk*". The aim of the present study was to assess the status of crucian carp in Norfolk, both historically and at present, and to determine possible reasons for its assumed decline. Our specific objectives were to: 1) identify ponds in an area of north Norfolk where crucian carp was known from local anglers to have been prevalent in the 1970s–80s; 2) determine the current distribution and abundance of crucian carp and other fish species in extant ponds, including those that contained crucian carp in the earlier period; 3) collate information on the known movements by humans of crucian carp between ponds since the 1970s, and 4) assess the likely causes of crucian carp extinction in different ponds and propose appropriate conservation measures.

## 3. STUDY SITES

The present study includes 29 ponds located within a 5 km radius of the village of Bodham (51:55:04N, 00:09:26E) on the north Norfolk coast, a low-lying (<100 m above sea level), predominantly agricultural region in eastern England, UK (Fig. 1a). All of the ponds are small (<0.2 ha. with the exception of one pond at 1.6 ha.) and shallow (<2 m) and land-use surrounding them is largely arable fields, although some ponds (n = 3) are located in woodland/heathland settings. Most of the ponds owe their existence to marl extraction (so called 'marl pits'), an agricultural practice involving the excavation of calcareous clays from shallow pits, which was subsequently spread over arable fields to improve their fertility. This practice was widespread in the region from perhaps the 13$^{th}$ century up to the end of the 19$^{th}$ century and resulted in the inadvertent creation of thousands of small ponds in Norfolk (Prince, 1962; 1964). Other ponds have a variety of origins: horse watering (n = 3), ornamental (n = 4), angling (n = 1), conservation (n = 1) and at least two ponds were probably created in the medieval era as 'fish ponds'.

# 4. METHODOLOGY

Information on the environmental management and fish histories of the ponds including desiccation events, fish kills and fish introductions was gathered by interviewing land owners, tenant farmers and local anglers. In particular, efforts were made to speak to local people who were actively angling in the ponds during the 1970s–80s and afterwards.

Sampling of fish populations was undertaken at 21 ponds on 6–7 October 2008 (n = 9) and 24–26 March 2009 (n = 12). The other eight ponds, all of which were known to contain crucian carp in the 1970s–80s, were not sampled because they were either too shallow for fish to be present (n = 3), had dried up in the recent past with no re-stocking (n = 4), or had been filled in (n = 1). Fish were captured mainly by fyke netting, a method known to be highly effective for catching crucian carp (see Copp *et al.,* 2008a). Where possible, six pairs of 'double' fyke nets were set perpendicular to the bank or to beds of aquatic vegetation and exposed overnight (for ≈16 hours). This provided catch-per-unit-effort (CPUE) estimates of fish densities (i.e. numbers of fish captured per fyke net per 16 hours exposure). Fyke netting was repeated in Ponds 1 and 9 on 24–26 March 2009 to confirm a low estimated density of crucian carp (Pond 1) and to collect additional crucian carp for a population study (Pond 9). Where fyke netting was not possible due to dense riparian vegetation (Pond 11), fish sampling was undertaken by electrofishing from a small dingy pushed through gaps in the thick bushes using a DEKA 3000 back-pack electrofishing unit (Deka-Gerätebau, Rudolf Mühlenbein, Vincentiusstraße 13, D-3538 Marsberg, Germany). Electrofishing was also undertaken on 6 October 2008 in Pond 4 and on 28 May 2009 in Ponds 6, 7, 8, 16, 17 and 20 to confirm the absence of crucian carp suggested by the fyke nets.

Where crucian carp was absent from ponds that used to contain it in the 1970s–80s, the likely causes of crucian carp local extinction were assessed from environmental changes to the ponds (e.g. desiccation, terrestrialisation, fish introductions) that could be derived from interviews with local landowners and anglers, from any documentation available and from observations (at the time of sampling) on lake habitat.

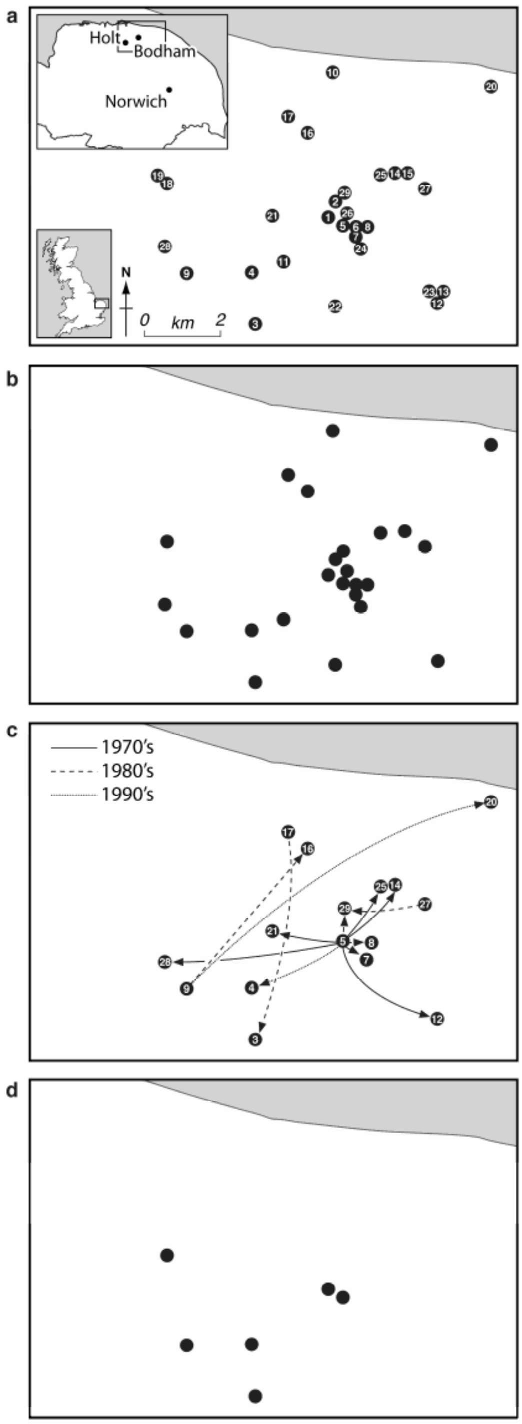


**Figure 1 (a) Locaton of the study ponds in north Norfolk, England (UK), (b) crucian carp distribution in the 1970s–1980s, (c) crucian carp transfers between the ponds in the 1970s, 1980s and 1990s, (d) crucian carp distribution in 2008–2009. Crucian carp were transferred from Pond 5 to Pond 29 in the 1970s and from Pond 5 to Ponds 7 and 8 in the 1980s (ponds too close for arrows to show dates of transfers).**

| | | | | Native species | | | | | | | | Non-native species | | | Hybrids with Cr | | | Total | CPUE | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Date[1] | fykes | %RS | Cr | Pf | Rr | Se | Ga | An | Gg | Tt | B-Ca | R-Ca | M-Cc | Ca×Ch | Cr×Cc | Cr×Ca | no. fish | Cr | All sp. |
| 1 | A | 4 | 10 | 1 | | | | | | | | | | | | | | 1 | 0.3 | 0.3 |
| " | B[2] | 4 | | 4 | | | | | | | | | | | | | | 4 | 0.5 | 0.5 |
| 2 | A | 6 | 55 | | | | | | | | | | | | | | | 0 | - | - |
| 3 | A | 6 | 10 | 26 | | 147 | | | | | | | | | | | | 173 | 4.3 | 28.8 |
| 4 | A | 10 | 5 | | 24 | | | | | | | | | | | | 1 | 25 | 0 | 2.5 |
| " | Ae | – | | 6 | | | | | | | | | | | | 4 | | 10 | - | - |
| 5 | A | 4 | <5 | 14 | 1 | 5 | 1 | | | | | | 1 | | | 12 | | 34 | 3.5 | 8.5 |
| 6 | A | 4 | 20 | | | | 1 | | | | | | | | | 4 | | 5 | 0 | 1.3 |
| " | Ce | – | | | | | | | | | | | | | | 1 | | 1 | - | - |
| 7 | B | 6 | 20 | | | | 1 | | | | | | | | | | | 1 | 0 | 0.2 |
| " | Ce | – | | | | | 20 | | | | | | | | | | | 20 | - | - |
| 8 | B | 6 | 5 | | | | | | | | | | | | | | | 0 | - | - |
| " | Ce | – | | | | | | | | | | | | | | | | 0 | - | - |
| 9 | A | 6 | 5 | 92 | | | 10 | | | | | 5 | 1 | 1 | 1 | | 11 | 121 | 15.3 | 20.2 |
| " | B[3] | 6 | | 125 | | | 15 | | | | | 19 | | | | 3 | 16 | 178 | 20.8 | 29.7 |
| 10 | A | 6 | 2 | | | | | | | | | | | | | | | 0 | - | - |
| 11 | Ae[4] | – | 70 | | | | | | | | | | | | | | | 0 | - | - |
| 12 | B | 6 | 30 | | | | | | | | | | | | | | | 0 | - | - |
| 13 | B[5] | 6 | <5 | | | | | | | | | | | | | | | 0 | - | - |
| 14 | B[6] | 6 | 10 | | | | | | | | | | | | | | | 0 | - | - |
| 15 | B | 6 | 10 | | | | | | | | | | | | | | | 0 | - | - |
| 16 | B | 6 | 0 | | | | 4 | 21 | | | | 1 | | | | | | 26 | 0 | 4.3 |
| " | Ce | – | | | | | 2 | 20 | | | | 1 | | | | | | 23 | - | - |
| 17 | B | 6 | <5 | | 12 | 1 | | | 1 | | | | | | | | | 14 | 0 | 2.3 |
| " | Ce | – | | | 82 | 301 | | | 2 | 1 | | | | | | | | 386 | - | - |
| 18 | B | 6 | 5 | 18 | | 1 | | | | | 2 | | | | | | | 21 | 3.0 | 3.5 |
| 19 | B[7] | 6 | 5 | | 4 | | | | | | | | | | | | | 4 | 0 | 0.7 |
| 20 | B | 6 | <5 | | | | | 1 | | | | | | | | | | 1 | 0 | 0.2 |
| " | Ce | – | | | | | | | | | | | | | | | | 0 | - | - |
| 21 | B | 6 | <5 | | 14 | 6 | | | | | 1 | | | | | | | 21 | 0 | 3.5 |

**Table 1. Data for the 21 sampled ponds giving sampling date ('e' indicates electrofishing on that date), percentage riparian shade (%RS), and fish numbers (catch per unit effort (CPUE) = number of fish per fyke per 16 hours). Fish codes: Cr=crucian carp, Pf=Eurasian perch, Rr=roach, Se=rudd, Ga=3-spined stickleback, An=eel, Gg=gudgeon, Tt=tench, B-Ca=brown goldfish, R-Ca=red goldfish, M-Cc=mirror carp, Ca×Ch=goldfish×Chagoi (ornamental variety of *C. carpio*), Cr×Cc=crucian×common carp, Cr×Ca=crucian×goldfish. [1)] A=October 2008, B=March 2009, C=May 2009; [2)] Fykes exposed for 2 nights (i.e. 2×16 hours); [3)] Fyke nets contained one great crested newt; [4)] Insufficient water for fykes, so pond electrofished; [5)] Fyke nets contained 7 great crested newt and 1 smooth newt; [6)] Fyke nets contained 2 great crested newts; [7)] a dying northern pike was observed but not captured. Fish caught by electrofishing were not included in CPUE estimates.**

# 5. RESULTS

Of the 29 study ponds, at least 24 are known to have contained crucian carp in the 1970s–80s (Fig. 1b). For the majority of these ponds, crucian carp was the only species known to be present during this period. However, at least two ponds (Ponds 5, 8) also contained varieties of common carp (mainly the wild form aka 'wild carp'), and a few other ponds contained populations of tench *Tinca tinca* L., roach *Rutilus rutilus* L., Eurasian perch *Perca fluviatalis* L. and European eel *Anguilla anguilla* L. Several between-pond transfers of crucian carp were documented for the past 30–40 years, including eight, five and two fish movements in the 1970s, 1980s and 1990s, respectively (Fig. 1c). No fish transfers were reported for post–2000. The water body most commonly involved in the transfers was Pond 5, a donor of crucian carp for nine different ponds since the 1970s. The number of documented fish movements presented here is likely to be a substantial underestimate of the real number.

Despite intensive fish sampling, crucian carp were observed in only six (≈ 25%) of the 24 ponds known previously to contain the species. This represents a 75% decline in crucian carp distribution since the 1970s–80s (Table 1, Fig. 1d). Varieties of common carp, common carp × crucian carp hybrids, goldfish, and goldfish × crucian carp hybrids occurred in one, five, three and two ponds respectively. Both the natural brown (in three ponds) and the ornamental red varieties (in two ponds) of goldfish were encountered. Common carp occurred mainly as 'wild carp' (five ponds), once as mirror carp and once as the ornamental variety 'Chagoi' (represented by a hybrid with goldfish). The occurrence of crucian carp without any other non-native fish species (or hybrids thereof) was limited to two ponds, with only one of these having >20 specimens. Other (native) fish species observed were: Eurasian perch (five ponds), roach (five ponds), rudd *Scardinius erythrophthalmus* L. (five ponds), three-spined stickleback *Gasterosteus aculeatus* L. (two ponds), tench (two ponds), European eel (one pond) and gudgeon (*Gobio gobio* L. (one pond).

Within our study region, crucian carp has disappeared from at least 19 ponds since the 1970s–80s (compare Figs. 1b and d). For at least six of these ponds, this was likely due to desiccation during the extreme droughts of 1976 (Ponds 24, 25) and 1988–1992 (Ponds 10, 14, 22, 29). For five ponds (Ponds 2, 11, 12, 23, 28), the cause of extinction was probably terrestrialisation, leading to a virtual loss of open water and/or to deteriorating habitat (loss of macrophytes, prolonged anoxia – see below). The disappearance of other crucian carp populations was probably due to hybridisation and/or competition with common carp (Ponds 6, 8), predation following the introduction of northern pike *Esox lucius* L. (Pond 16) and land reclamation (Ponds 26, 27). In the case of three ponds (Ponds 7, 17, 20), it was not possible to determine the likely causes of extinction, though there has been a suggestion that fish stocks in Pond 20 were decimated by Eurasian otter *Lutra lutra* (L.) (G. Catchpole, Sheringham, Norfolk, personal communication).

## 6. DISCUSSION

This is the first English study on the status of crucian carp to provide quantitative estimates of its decline over recent decades. Contrary to local perceptions (Environment Agency, 2008), crucian carp (Fig. 2a) does not appear to be close to extinction in Norfolk. Nonetheless, the species is clearly under considerable threat in our study region, with just one pond (out of 29) containing a sizeable population of crucian carp that was uncontaminated by goldfish, common carp and hybrids of these species with crucian carp. Further, the estimated 75% decline of crucian carp occurrence is well above the 25% and 50% declines stipulated in the 2$^{nd}$ and 3$^{rd}$ UK Biodiversity Action Plan (BAP) criteria.

To help initiate a future programme of conservation and restoration of crucian carp populations, it is essential to understand the reasons for the species' demise at both local and national scales. Within our study region, crucian carp has been eliminated from at least 19 ponds since the 1970s–80s. Although the precise causes of extinction contain a degree of uncertainty, there are two main factors that seem most influential: 1) the combined impacts of climatic variations and changes in land management, and 2) fish introductions. In terms of climatic variations, the most important factor appears to have been desiccation events during the droughts of 1976 and 1988–1992. Indeed, such a problem has been observed in the past: "*The smaller, silver-eyed crucian carp abounds in the ponds of east Norfolk and east Suffolk, but was exterminated in many of them by the great drought of 1921*" (p. 194, Ellis 1965). Following the drought of 1988–1992, some ponds are known to have been restocked with crucian carp (Fig. 1c), but this practice of restocking has been less prevalent during the last decade.

A compounding factor with climatic variation in the reduction or extirpation of crucian carp populations is pond terrestrialisation. Over recent decades, due to a general reduction in the intensity of tree and hedgerow management on farms (i.e. coppicing and vegetation clearance), many of the ponds in the study area have become heavily overgrown by willow (*Salix* spp.), alder (*Alnus glutinous* Gaertn.) and blackthorn (*Prunus spinosa* L.) (see Fig. 2c-d). This has contributed to substantial increases in organic matter inputs to ponds in the form of fallen leaves, branches and even entire mature trees. In a number of cases, this process has probably accelerated pond succession and infilling rendering ponds increasingly vulnerable to desiccation, such as Ponds 11 and 22, which dried up in the early 1990s.

Changes in aquatic habitat quality during terrestrialisation are also likely to affect crucian carp population dynamics (Copp *et al*., 2008a). Although there are few studies specifically on the habitat preferences of crucian carp, the species is usually associated (e.g. Tonn *et al.,* 1992; Wheeler, 1981; 2000; Copp *et al.,* 2008a) with small ponds containing significant stands of emergent (e.g. *Phragmites australis* (Cav.) Trin ex Steud., *Typha latifolia* L.) and/or rooted floating plants (e.g. *Persicaria amphibia* (L.) Gray, broad-leaved pondweed *Potamogeton natans* L., yellow water-lily *Nuphar lutea* (L.) Sm.), which provide predation refuges for 0+ fish (Tonn *et al.,* 1992) and foraging and spawning habitat (Penttinen and Holopainen, 1992; Holopainen *et al.,* 1997; Pettersson and Brönmark, 1997). A particularly important knock-on effect of pond terrestrialisation is the loss of aquatic plants due to the strong shading effect of riparian vegetation (Table 1). Additionally heavy shading, which is often associated with high densities (often 100% cover) of duckweed (least duckweed *Lemna minor* L. and American duckweed *Lemna minuta* Kunth), can lead to low dissolved oxygen levels (Morris and Baker, 1977) and a likely dominance of decomposition processes (Clare and Edwards, 1983). Indeed, a number of studies of duckweed-dominated water bodies


**Figure 2. a) crucian carp x common ("wild") carp hybrid, (b) crucian carp, (c) study pond overgrown by willow (*Salix* sp.), (d) study pond over grown by *Phragmites australis*, (e) pond in "*Lemna* year", (f) same pond in "non-*Lemna*" year.**

have reported prolonged periods of low or zero oxygen (Lewis and Bender, 1961; Pokorny and Rejmankova, 1983; Janes *et al.,* 1996).

Although crucian carp are able to tolerant prolonged periods of anoxia, due to a remarkable ability to utilise glycogen stores in the brain (Vornanen and Paajanen, 2006), this tolerance is unlikely to save the species under the extreme circumstances of advanced pond terrestrialisation (e.g. Pond 2). It does, however, explain the persistence of crucian carp as a sole species in several of the study ponds (Table 1). For example, Pond 1 is moderately overgrown and has undergone phases (e.g. 1999–2005) of

*Lemna*-dominance (variously *L. minor* and *L. minuta* at 90–100% cover) interspersed by phases (e.g. 1994–1999, 2006–2009) of abundant submerged vegetation (including *P. natans*, soft hornwort *Ceratophyllum submersum* L. and curled pondweed *Potamogeton crispus* L.) (see Figs 2e-f). In the non-duckweed phase of 1994–1999, crucian carp were extremely abundant (albeit of small size; Sayer, personal observations), but observed at a low density (CPUE 0.3–0.5; Table 1) in the present study. Clearly, therefore, a substantial decline in crucian carp population size was induced by anoxia beneath the duckweed mats. By contrast, other native species observed prior to duckweed dominance (C. Sayer, personal observation), including perch, roach and rudd, did not survive.

Pond populations of crucian carp appear to be particularly sensitive to the potential impacts of fish introductions. For example, Pond 16 appears to be an ideal habitat for crucian carp (occurrence of good stands of emergent vegetation and yellow water-lily) but this fish species disappeared in the late 1990s following the introduction of northern pike, an action aimed at removing two large goldfish that were released into the pond (note in Table 1 that two large goldfish were observed in this pond). Of greater concern than such cases of native predator releases are the introductions of non-native species, such as goldfish and common carp (and varieties thereof). Indeed, the threat of goldfish hybridization to crucian carp has been raised at local government levels (London Councils, 2007). Similar to a study of ponds in Epping Forest, Essex (Copp *et al.,* 2005), goldfish and their hybrids with crucian carp were observed in a number of the study ponds (Table 1), the majority being easily accessible by the general public.

The hybridisation of crucian carp with non-native species appears to be a long-standing problem in the study area, as evidenced by a passage in Doubleday and Page (1901) "*Mr. Gurney informs me that it* [crucian carp] *is common in the ponds of East Norfolk and he says it is well known to hybridise freely with the common carp*" (p. 210). Hybridisation with introduced goldfish and common carp has been linked to the decline and/or elimination of crucian carp (Wheeler, 1998, 2000; Hänfling *et al*., 2005), and this may be the case for Ponds 6 and 7, where crucian carp was observed only as a hybrid of common carp (Table 1). Indeed, crucian carp hybrids with goldfish and common carp were generally observed in ponds where these pairs of species co-existed (Fig. 2a), and in some cases the fish assemblage was dominated by the hybrids (Table 1), suggesting the crucian carp population is in the process of being eliminated. While any fish movement that involves non-native fishes is likely to have had negative consequences for crucian carp populations, where crucian carp has been moved, and the recipient pond did not contain either goldfish or common carp, the conservation of crucian carp has been promoted. For example, Pond 3 was de-silted in 1988 (when few fish are thought to have been present) and subsequently re-stocked with crucian carp and roach taken from Pond 17 (Fig. 1c). This resulted in Pond 3 maintaining a good population of crucian carp with no hybrids present (Table 1), even though the source crucian population in Pond 17 subsequently disappeared for some unknown reason.

To halt the decline of crucian carp demonstrated in the present study, an active programme of conservation is needed, providing protection of ponds that contain the species and enhancement of those in which the species was known previously to occur. This will be best effected by making landowners, anglers and the general public aware of the threats to crucian carp populations posed by non-native fish introductions (see Copp *et al.,* 2005) and through the provision of information on how best to manage small pond habitats for crucian carp (e.g. Copp *et al.,* 2008a). The present study suggests that pond (land) management interventions are also likely to benefit the conservation of crucian carp, in particular through the reduction of riparian shading, which should promote submerged and floating-leaved aquatic macrophyte development. As a consequence of the present study, crucian carp was designated in 2009 as a BAP species for the county of Norfolk (Copp & Sayer, 2010), its first formal conservation protection in the UK.

## 7. ACKNOWLEDGEMENTS

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