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Review

A review of the status and range expansion of common carp (*Cyprinus carpio* L.) in Ireland

Ross Macklin[1]*, Bill Brazier[1], Simon Harrison[1], Debbie V. Chapman[1] and Lorenzo Vilizzi[2]

[1]*School of Biological, Earth & Environmental Sciences, University College Cork, North Mall Campus, Cork, Ireland*
[2]*Faculty of Fisheries, Muğla Sıtkı Koçman University, Kötekli, Muğla, Turkey*

**Corresponding author*
E-mail: ross.macklin@gmail.com

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Abstract

Although common carp are known to have been present in Ireland since the early 17th century, historically the species' distribution was extremely localised. Owing to the popularity of carp as a sport fish in more recent times, it was suspected that the species range had expanded. Distribution maps were constructed from records in the published literature and consultations with both angling and governmental bodies, facilitating a review of the temporal changes in the range and distribution of carp from 1950 to the present day. There has been a significant increase in the range of distribution of carp, by order of 302% in the national 10 km grid-square network. The characteristic pattern of extinction and colonisation of carp in Irish water bodies clearly indicates that the species has not spread by natural dispersal but rather by human-mediated transfers, which are the mechanism for the species' range expansion. While carp has been able to establish self-sustaining populations in Ireland, these remain restricted to smaller, often land-locked, water bodies. Future climatic warming and the increasing popularity of carp as an angling quarry may facilitate further range expansion, both naturally and human mediated.

Key words: distribution, status, range, feral, domesticated

Introduction

The status of common carp (hereafter, 'carp') in Ireland remains poorly understood, despite international notoriety for its negative impacts on freshwater ecosystems (e.g. Zambrano et al. 2001; Sivakumaran et al. 2003; Lougheed et al. 2004; Nicol et al. 2004; Chumchal et al. 2005; Britton et al. 2007; Vilizzi 2012). Historically, carp (along with salmonid species) has been the most commonly introduced species to fresh waters globally (Minns and Cooley 1999) and is currently present almost worldwide (Naylor et al. 2000). In Europe, carp is considered native to the River Danube drainage system west of its piedmont zone (Balon 2004), but elsewhere it is regarded as an introduced species (Fitzmaurice 1983; Copp et al. 2005b; King et al. 2011). Additionally, in several European member states (including Ireland), carp has also been recently listed as a non-native species subject to restrictions under Regulations 49 and 50 of the EU Communities (Birds and Natural Habitats) Regulations 2011 (S.I. No. 477/ 2011).

In a recent Red List publication that describes the current status of the extant fish species of Ireland, carp and rainbow trout (*Oncorhynchus mykiss*), have been described as 'domesticated', or more precisely as species requiring human interference or input in order to maintain the viability of extant populations (King et al. 2011). Nonetheless, human-mediated transfers of carp may facilitate significant range expansion, as has been observed in the U.K. (Copp et al. 2005a; Britton et al. 2010).

Until the late 20th century, the origin and subsequent dispersal of Irish carp stocks was open to conjecture because of the absence of clearly documented evidence and, in this respect, Brazier et al. (2012) have provided the most comprehensive review to date on the historical introductions of carp into and within Ireland.

Other than limited accounts of the distribution of carp (Went 1946; 1950) and further research on its ecology, biology and distribution (McCarthy and Kennedy 1965; Fitzmaurice 1983), limited literature is available for the species in Irish waters. Fitzmaurice (1983) concluded at the time of publication that carp were a 'precarious' member of the Irish icthyofauna, as they required human intervention to prevent their extinction, given their demonstrated poor recruitment.

While the intra-specific variation in the life history traits of fish populations have been observed across geographic latitudes (Cucherousset et al. 2009), the linkage of bio-geographical areas has traditionally been used to predict the likely climatic compatibility and potential invasiveness of non-native species in a defined risk assessment area (Pauchard et al. 2004; Broennimann and Guisan 2008). Thus, Zambrano et al. (2006) used a genetic algorithm to predict that there would be high agreement with the model outputs for carp establishment in both the U.K. and Ireland. However, models can fail to predict current invaded distributional areas (Broennimann et al. 2007), but by geographically mapping the known distribution of Irish carp populations, the predictions can be supported by real distributions. By gaining an understanding of how the establishment and dispersal of carp stocks have manifested themselves, it is envisaged that such data will provide a more effective platform for the future management of the species, as has been established by other authors (e.g. Liu and Li 2009).

Methodology

An extensive literature review of the available published and grey literature for carp stocking records in Ireland was undertaken to construct distribution maps in order to illustrate changes in the range and density of the species over time. This included a review of Inland Fisheries Trust (IFT), Central Fisheries Board (CFB) and Inland Fisheries Ireland (IFI) stocking records. A considerable body of correspondence was also sent to the IFT, CFB and IFI staff who previously worked with carp. Communications were also made to members of Irish carp angling clubs and organisations including the Cork Carp Anglers, Abbey Anglers (now defunct), Carp Anglers Club of Ireland, the Northern Ireland Carp Anglers Society and The Coarse Fish Federation in order to acquire additional records on the current distribution of the species.

The collected data were screened and distribution maps were constructed from publications for the years 1950 (Brazier et al. 2012), post-1960 (Maitland 1972), 1989 (Fitzmaurice 1983, amended Whelan 1989), and 2014 (compiled by the authors of this paper). All maps were prepared using the distribution mapping software package DMAP version 7.2. Through mapping the existing known and historical distribution of carp, it was possible to evaluate the geo-spatial pattern of spread over time. The occupancy rate of carp distribution for each time period in each of the national 10-km^2 grid-square blocks was calculated using the formula:

No. of national 10-km^2 grid-squares containing the species/Total no. of records in national 10-km^2 grid-square network

Published records from the literature (Fitzmaurice 1983; Roche 1984; Whelan 1989; Caffrey and Coyne 2008), results of University College Cork (UCC) and Central Fisheries Board (now Inland Fisheries Ireland) fisheries assessments (CFB 1995; CFB 1996) as well as Marine Institute Fish Health Screening data were used to establish a preliminary record of how many water bodies in Ireland had evidence of recruiting populations of carp. While this list did not include a survey of all of the waters in Ireland known to contain carp, it facilitated an indication of the potential breadth of natural recruitment in the wild.

Results

Based on the occurrence of carp in the 10-km^2 grid-square network of Ireland, there has been a significant increase in its distribution between 1950 and 2014 (χ^2 = 7.84, P<0.001, df = 3, goodness of fit). According to Brazier et al. (2012) carp occupied nine national 10-km^2 grid squares in ca. 1950 with a 1.13 occupancy rate. By the 1960s the species occupied 35 national 10-km^2 grid squares (Maitland 1972), with a slight increase in the occupancy rate of 1.20 records per 10-km^2 square. By the 1980s, the species' distribution increased slightly covering 36 national, 10-km^2 grid squares (Fitzmaurice 1983, amended by Whelan 1989), with a parallel slight increase in the occupancy rate of ≈ 1.28 records per 10-km^2 square (Figure 1). The most contemporary records compiled in 2014 for the present study indicate records for the species in 135 national 10-km^2 grid squares with a parallel increase in the occupancy rate at 1.37 records per 10-km^2 grid square. This represents a 302% increase in the distribution and density of carp records in the

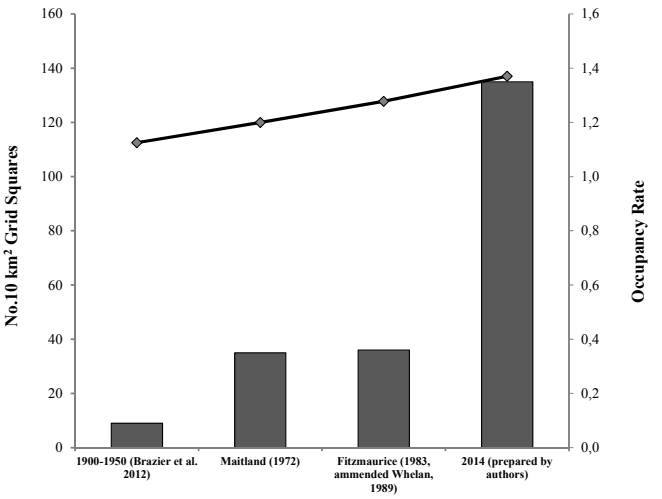

Figure 1. The number of 10-km^2 grid squares (filled bars) and occupancy rate (filled diamonds) of carp in the national 10-km^2 grid-square network from records collected in Ireland between 1950 and 2014.

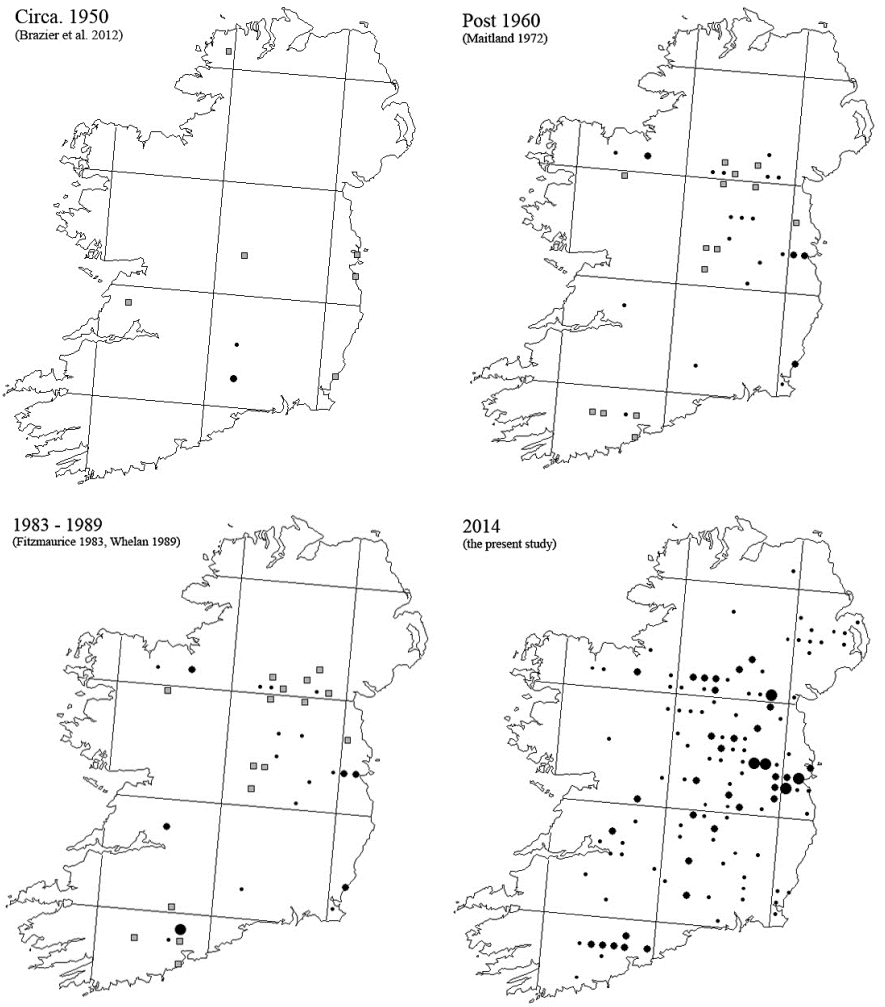

Figure 2. The distribution of carp in Ireland between 1950 and 2014 (filled square = population extinction following stocking; filled dots of increasing density (records per 10-km^2 grid square): Low [1 record], medium [2–4 records], high [5–10 records]).

national 10-km^2 grid square network from the 1980s to present (2014). Of the national inventory of waters that are known to contain carp, 15% are known to have self recruiting populations based on stock surveys and reviews of available literature on the species (see Supplementary material Table S1).

Discussion

The distribution of carp in Ireland has increased substantially since the year 1950. Prior to the 21st century, the early global expansion of carp was driven primarily by ornamental demand and the species' use as a food source (Balon 1995; Hoffman 1995), and this also applied to Ireland (Brazier et al. 2012). As such, the resilience of carp as a species tolerant to hypoxia (Billard 1999) and food rations (Jhingran and Pullin 1985) made their transportation across Europe between the 17th and 20th centuries more feasible than other more intolerant fish species (Balon 1995; Copp et al. 2005b). Unlike the U.K., introductions of common carp to Ireland did not include the crucian carp *Carassius carassius,* which is believed by some (e.g. Maitland 1972) to have been introduced to England with consignments of common carp.

In more recent times an increase in the production of carp by aquaculture for deliberate stocking to fisheries in the wild (Environment Agency 2004; Britton et al. 2010) or through accidental release, (Shearer and Mulley 1978; Coates and Ulaiwi 1995; Britton et al. 2007; Rowe 2007) have both contributed to the expansion of carp worldwide (Tapio and Zambrano 2003; Ribeiro et al. 2009; Vilizzi 2012).

The most recent account of the distribution and biology of carp in Ireland was undertaken by Fitzmaurice (1983), who compiled an annex of all of the Irish lakes officially stocked with carp between 1950 and 1978. At the time of publication the author concluded that carp would have become extinct in Ireland after 1950 if it were not for the stockings undertaken by the Inland Fisheries Trust. However, because of the prolonged lag period between the arrival and later establishment of non-native species (Sakai et al. 2001), past performance can be a poor predictor of future range expansion and associated ecological impacts (Crooks and Soulé 1999; Rilov et al. 2004; Stohlgren and Schnase 2006). In this respect, cultural changes that influence the demand for a species can be a catalyst for their expansion. In the England for example, carp has been present for at least 500 years and were once scarce because of intermittent spawning success, poor demand as a food item and unpopularity as a sporting fish (Bucke 2000). This contrasts with recent reports by the Environment Agency (2004) in the U.K., who state that carp and trout accounted for 25% and 45% respectively of the total proportion of their consented stocking records, supporting a trend of the proliferation of non-native sport fisheries over game fisheries (e.g. Hickley and Chare 2004). Indeed six million carp were authorised for stocking into water bodies in England and Wales between 1998 and 2008 (Britton et al. 2010). Cultural changes can therefore drive the expansion of a species (Vilizzi 2012).

Understanding the dynamic of dispersal pathways of a propagule is best achieved through early detection (Hulme 2006), but in reality the mechanisms by which non-native species colonise geographical areas are often disregarded, while records of distribution are typically unconsolidated (Ribeiro et al. 2009). This can make inherent lag periods in the establishment of the non-native species difficult to detect. To this end, Crooks and Soulé (1999) discuss three types of lag periods in the expansion of non-native species, namely; inherent lags, genetic factors and environmental factors. All of these, to varying degrees, may have played a part in the expansion of Irish carp stocks in Ireland.

Smaller propagules typically lead to demographic stochasticity because of heterogeneity in the environment, thereby making establishment dependent on the ability of a species to colonise suitable patches through movement patterns (Schreiber and Lloyd Smith 2009). In U.K. waters, the survival of young-of-year (age-0) carp is known to be especially low (Seagrave 2001) and evidence from Irish stocking records suggest that low density of age-0 carp used in early trials likely resulted in many of the documented extinctions (Fitzmaurice 1983; Whelan 1989). The historical mapping of the distribution of carp clearly illustrates that the species continued to expand their range despite known population extinctions (Figure 2). Indeed, further artificial stocking must have occurred to facilitate the observed range expansion (Figure 1). The current distribution of carp suggests that stocking rates have been greatly increased over the last 60 years (Figure 2). Records further suggest that unofficial movements of the species have also increased in this period (Kelly 1985; Whelan 1989; Warner 2009; King et al. 2011). Therefore, the unofficial stocking of carp to new waters has most probably accounted for a large proportion of the observed range expansion.

Other means of propagation have been through fish farming. In 2001, the Central Fisheries Board (now Inland Fisheries Ireland) set up a carp breeding facility at Roscrea Fish Farm, Co. Tipperary that facilitated the increased availability of adult and juvenile carp for stocking and angling purposes (CFB 2001). This included the stocking of 100000 age-0 individuals into selected waters during the first year. However, this facility is no longer in operation and there remains no commercial carp breeder in the Republic of Ireland. This is in stark contrast with the U.K., where there is in excess of 100 fish farms that primarily breeding carp (Environment Agency 2004). Effectively when more individuals from an introduced population are released in one event, 'propagule pressure' is increased, whereby the chances of establishment increase as a consequence (Kolar and Lodge 2001; Lockwood et al. 2005; Copp et al. 2007; Hayes and Barry 2008). Interestingly, in the U.K. and Ireland the movement of propagules has not been through poly-vectic (i.e. multiple vectors) transfer but primarily by means of human mediated stocking for recreational angling (e.g. Copp et al. 2010). Following the closure of the coarse fish breeding unit at Roscrea (April 2008), the importation of carp increased substantially to accommodate the increasing demand from the recreational angling market. Carp were imported to a number of private fisheries from Neil Hardy Aquatica Ltd. (2008 to present) because of the absence of any national supplier. Carp were also imported to Northern Ireland for the first time in 2000 (from Heather Fisheries, U.K.) following a change in government policy issued under a draft proposal issued by the Northern Ireland assembly government Department of Culture Arts and Leisure (DCAL) (M. McGivern, pers. comm.). In addition, a consignment of 2.2 tonnes of carp was unofficially imported from Pisciculture Horton, France in 2003, and stocked into two private Irish fisheries (Brazier et al. 2012).

Thus elevated frequencies of carp stocking events after the millennium and the stocking of adult carp at higher densities, both officially and unofficially, have been the key drivers in the expansion of carp stocks in Ireland. Carp are known to possess the ability to revert from domesticated forms into feral forms within a short evolutionary period, as a result of the high plasticity in their ability to adapt to wild aquatic habitats following release (Balon 1995; Matsuzaki et al. 2009). Lockwood et al. (2007) described the mechanism of an 'altered vector' that may increase population fitness through the deposition of better adapted or larger propagules. It is therefore critical to determine whether or not the more recently introduced domesticated carp varieties can adapt to the Irish climate and recruit more successfully than pre-existing less domesticated forms given their more recent importations.

Despite evidence of extant breeding populations of carp at multiple sites in Ireland, successful recruitment appears to be restricted to small shallow lakes and ponds that are isolated from larger water courses (Table S1). There is no current evidence to support naturally-recruiting populations of carp in lakes > 5 ha given that the species has not been recorded in national surveys undertaken as part of fish surveillance for the Water Framework Directive in over 95 large lake catchments surveyed between 2007 and 2011 (Kelly et al. 2011; Kelly et al. 2012). It has been the policy of government agencies to restrict the potential natural dispersal of carp by stocking water bodies that are not connected to larger catchments via interconnected river channels. This has resulted in a reduction of the potential for the species to disperse naturally, should they have the capability to recruit successfully in a given water body. The thermal characteristics of larger and deeper lakes would typically be cooler in summer in contrast to small and shallow lakes or ponds that warm more rapidly because of their morphometric and hydrodynamic characteristics (Ambrosetti and Barbanti 1999; Van Burren et al. 2000). These shallow water bodies are more likely to reach temperatures of between 18 and 20°C, which are considered necessary thresholds for carp to commence spawning activity (Billard 1999). As such they are considered a more suitable habitat for carp in cool temperate climates. This is supported by evidence from the lakes with spawning populations of carp that are typically small (< 2ha) and shallow (< 3.0m) (Table S1). It is known that carp have recruited successfully in 15% of the water bodies surveyed given the presence of juvenile cohorts of fish and this illustrates that carp can successfully reproduce in some Irish waters. However, the analysis of selected carp populations suggests that carp breeding is not an annual event in Ireland, even where seemingly optimal breeding sites exist (e.g. Cork Lough, Decoy Lake and Gorteen Lake) (R. Macklin and B. Brazier, unpublished data). This has identified that only a fraction of the Irish carp populations are self sustainable and that range expansion has been human-induced. Therefore, irrespective of the nature of propagation,

unforeseen range expansion may occur even if the species capability to reproduce naturally is restricted. Furthermore, despite known sporadic spawning in Ireland (Fitmaurice 1983), the longevity of carp means the species does not need to recruit annually to sustain populations and thus it is possible for the latter to persist, albeit at low densities and in sub-optimal spawning environments (Seagrave et al. 2001).

There is evidence to suggest that the current status of carp in Irish waters may shift in the future to fit the description of a naturalised species (*sensu* Richardson et al. 2000, p. 98) as that of a naturalised species i.e. "that reproduce consistently and sustains populations over many life cycles without intervention by humans (or in spite of human intervention); that often recruits offspring freely […] and do not necessarily invade natural, semi-natural or human-made ecosystems". However, this definition would contrast with the current status of carp in Ireland as 'domesticated' (King et al. 2011), indicating a species requiring human interference and management in order to maintain their viability (Kelly et al. 2008). Should the current trends of expansion continue, the status of carp will likely shift from the domesticated species category to the feral, non-benign category: "an introduced species that may pose a threat to native species, but it is also considered important for recreational fisheries" (King et al. 2011, p. 6).

Conclusions

The distribution of carp has expanded significantly in Ireland between the 1980s and present. To date, it is known that the vast majority of water bodies in Ireland that contain carp are small, shallow and eutrophic, and there is currently an absence of any evidence supporting widespread successful spawning and recruitment in large open lakes or in river systems. While internationally the species has been studied in detail, very little is known about the functional ecology, reproductive success and growth in the wild of carp in the temperate maritime climate of Ireland. Ultimately, by understanding the ecology of carp in an Irish context, which represents the western periphery of the species' European range, a species-specific management plan can be formulated. Given that carp could be considered an established species in Ireland, the implementation of a management plan will prevent unwarranted expansion (Britton et al. 2011), minimise ecological risk, and accommodate recreational angling where ecological impacts can be avoided (Cowx et al. 2010).

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The following supplementary material is available for this article:

Table S1. Preliminary list of Irish Lakes with evidence of naturally recruiting populations of common carp, *Cyprinus carpio* (L.)

This material is available as part of online article from:
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