Fisheries Management and Ecology

461-F

Fisheries Management and Ecology, 2008, **15**, 85–91

First year growth and survival of common carp in two glacial lakes

Q. E. PHELPS, B. D. S. GRAEB & D. W. WILLIS

Department of Wildlife and Fisheries Sciences, South Dakota State University, Brookings, SD, USA

Abstract Cohorts of common carp, *Cyprinus carpio* Linnaeus, were monitored from hatch through the next spring in two South Dakota, USA lakes to identify factors affecting year-class strength. Hatching occurred over 37- and 47-day periods in the two lakes. Common carp that hatched earlier achieved greater total lengths at the end of the first growing season (Brant Lake: $r = -0.84$, d.f. = 77, $P < 0.001$; Campbell Lake: $r = -0.87$, d.f. = 78, $P < 0.001$). Mean daily growth rates were approximately 1.0 mm day^{-1} and similar between lakes. Total length was positively related to daily growth rate in the two lakes, indicating that members of the cohort that grew faster achieved greater total lengths by time of capture. Hatch date was inversely related to daily growth (fish hatched earlier grew faster) in one lake ($r = -0.44$, d.f. = 77, $P < 0.001$) but not the other ($r = -0.04$, d.f. = 78, $P = 0.678$), suggesting that length at the end of the growing season can be affected by length of growing season and growth rate. Overwinter survival of age-0 fish appeared to be size dependent because age-1 common carp length–frequency distributions from both lakes comprised only of the larger cohort members present the previous autumn.

KEYWORDS: Common carp, *Cyprinus carpio,* overwinter survival, recruitment.

Introduction

Management strategies for common carp, *Cyprinus carpio* Linnaeus, tend to differ for native and introduced populations. In Europe, the common carp is a highly desired sport and food fish (e.g. Vacha 1998), and most management practices involve population enhancement (Panek 1987; Wedekind, Hilge & Steffens 2001). In contrast, the common carp typically is viewed as a nuisance in North America where it has been introduced, and most carp management efforts involve population elimination or control (Cahn 1929; Wydoski & Wiley 1999). For example, a substantial body of evidence indicates that common carp can reduce the abundance of aquatic plants (e.g. Threinen & Helm 1954; Tryon 1954; King & Hunt 1967; Crivelli 1983; Fletcher, Morrison & Hume 1985; Engel 1995), which in turn adversely affects fish community dynamics (e.g. Cahn 1929) and waterfowl (e.g. Chamberlain 1948; Robel 1961). Whether desirable or undesirable, information concerning common carp recruitment is important for effective management.

Because year-class strength is determined during the early life stages in most fishes (Rice, Crowder & Holey 1987; Sammons & Bettoli 2000), evaluating population parameters during this critical time period could provide insight into the complex mechanisms that affect common carp recruitment. Few studies have described common carp recruitment and subsequent year-class strength (Starrett & Fritz 1965; Wichers 1976; Mueller & Downen 2000). Survival during early life stages often is size dependent (Rice *et al*. 1987); thus, recruitment may be related to growth rates of age-0 common carp. Hence, the purposes of this study were to determine hatch dates, measure daily growth rates, and compare autumnal size structure of age-0 common carp to that for age-1 carp the following spring as means to understand recruitment better.

Materials and methods

Common carp sampling was conducted on two natural lakes in eastern South Dakota, USA. Brant Lake (latitude 43º55′16.87, longitude 96º56′47.87) has a surface area of 405 ha, a maximum depth of 4.3 m, a shoreline development index of 1.40, and a fish community consisting of 13 species. Campbell Lake (latitude 44º12′23.45, longitude 96º50′51.21) has a

Correspondence: David W. Willis, Department of Wildlife and Fisheries Sciences, South Dakota State University, Brookings, SD 57007-1696, USA (e-mail: david.willis@sdstate.edu)

doi: 10.1111/j.1365-2400.2007.00568.x

surface area of 322 ha, a maximum depth of 2.1 m, a shoreline development index of 1.82, and a fish community consisting of 12 species. Both lakes are considered hypereutrophic based on trophic state indices and do not thermally stratify during summer (Stueven & Stewart 1996).

Age-0 common carp were sampled in Brant and Campbell lakes by diurnal electric fishing at 2-week intervals beginning the second week of July 2004 and continuing through the end of growing season (second week of September) in 2004. Age-1 (2004 year class) common carp were then sampled the following spring (May) 2005 using the same methods. Electric fishing was continued until 75 age-0 common carp were collected or, when fewer fish were collected, until all potential habitats had been sampled. All fish were measured to the nearest millimetre total length (TL). Relative abundance was indexed for each sampling period by calculating the number of individuals captured per hour of electric fishing.

Lapilli otoliths were removed from age-0 common carp and analysed to estimate hatch date and daily growth rate. Unlike many other species commonly aged with saggital or asteriscus otoliths, Vilizzi (1998) reported that the lapillus otolith was the only structure that had distinguishable microincrements. Otoliths were examined using transmitted light and a dissecting microscope at low magnification (10-50×); each translucent zone and distal opaque band was considered a daily ring (Vilizzi 1998). For each otolith, three separate daily ring counts were made by two individual readers and average daily ring counts were used to estimate hatch dates.

Hatching dates were determined from age-0 common carp captured 27 July at Brant Lake and 15 July at Campbell Lake because no newly hatched fish were collected on subsequent dates. Hatch date was estimated by subtracting mean daily ring count from collection date because ring formation is assumed to occur at onset of hatch (Vilizzi 1998). Daily growth rates from hatch until time of capture in July were calculated as (TL at capture – TL at hatch)·(average daily ring count)$^{-1}$. Panek (1987) and McCrimmon (1968) reported that total length of common carp at hatch was approximately 6 mm. Finally, to determine if overwinter survival was size dependent length–frequency distributions of autumn age-0 and spring age-1 population samples were compared using a Kolmogorov–Smirnov test by lake. The relationships between hatching date and both fish total length and daily growth were evaluated using regression analysis. Relations between total length and daily growth were qualitatively evaluated using bivariate plots.

Results

Mean total length of age-0 common carp cohorts increased throughout the growing season in both lakes (Figs 1 and 2). The relative abundance substantially declined in both lakes from autumn to spring, and survival appeared to be size specific. Comparisons between age-0 common carp length distributions at the end of the first growing season and distributions of those sampled the following spring indicated larger individuals experienced greater survival than smaller members of the age-0 carp cohort (Brant: Kolmogorov–Smirnov test, $Ksa = 2.25$, $P < 0.001$; and Campbell; $Ksa = 3.26$, $P < 0.001$). Specifically, age-1 common carp longer than 78 mm in Brant Lake and longer than 114 mm in Campbell Lake apparently had greater overwinter survival than smaller members of the same cohorts.

Hatching of common carp in Brant Lake during 2004 occurred during at least a 47-day period beginning on May 17 (day of year 137) and continuing until July 3 (day 183). Hatching duration in Campbell Lake in 2004 occurred during a 37-day period from May 9 (day 129) to June 14 (day 134). Hatch date was negatively related to fish total length at time of capture in both Brant Lake ($r = -0.84$, d.f. = 77, $P < 0.001$) and Campbell Lake ($r = -0.87$, d.f. = 78, $P < 0.001$) (Fig. 3). Age-0 common carp in Brant Lake grew approximately 0.96 mm day^{-1} (range = 0.56-1.37, $n = 78$, SE = 0.02) while those in Campbell Lake grew 1.03 mm day^{-1} (range = 0.73-1.30, $n = 79$, SE = 0.01). Daily growth appeared to be positively related to total length at time of capture in both lakes (Fig. 4). Daily growth was not related to hatch date in Campbell Lake ($r = -0.04$, d.f. = 78, $P = 0.678$, Fig. 5) but negatively related to hatch date in Brant Lake ($r = -0.44$, d.f. = 77, $P < 0.001$).

Discussion

Age-0 common carp overwinter survival appeared size dependent in these two South Dakota lakes in 2004. Common carp hatching occurred during at least 37 days in our two study lakes. The earlier-hatched members of the cohort in each lake achieved greater total lengths by time of capture in July. Consequently, these earlier hatched fish may have achieved greater total lengths by the end of the first growing season and may have experienced greater overwinter survival, as previously documented for other fishes such as bluegill, *Lepomis macrochirus* Rafinesque (Cargnelli & Gross 1996), largemouth bass, *Micropterus salmoides* (Lacepède) (Goodgame & Miranda 1993; Miranda &

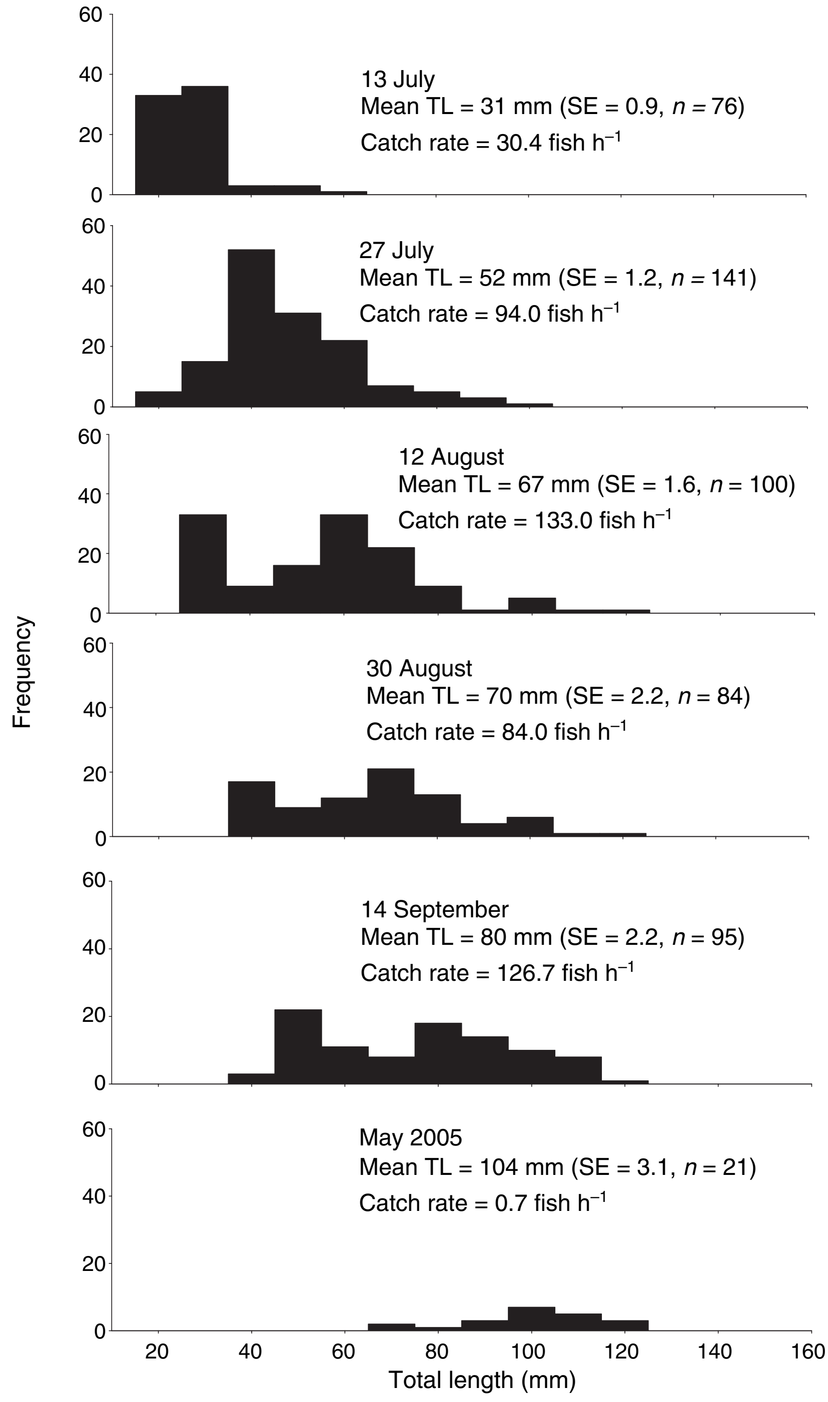


Figure 1. Length distribution for common carp captured throughout the first growing season in 2004 and the following spring in 2005 from Brant Lake, South Dakota.

Hubbard 1994; Ludsin & DeVries 1997), smallmouth bass, *Micropterus dolomieu* Lacepède (Oliver, Holeton & Chua 1979; Post, Kitchell & Hodgson 1998; Curry, Currie, Arndt & Bielak 2005), walleye, *Sander vitreus* (Mitchill) (Toneys & Coble 1979), white crappie, *Pomoxis annularis* Rafinesque (Sammons, Bettoli & Grear 2001) and yellow perch, *Perca flavescens* (Mitchill) (Post & Evans 1989). Additionally, age-0 common carp in both lakes grew approximately 1.0 mm day^{-1}, but direct comparisons of daily growth

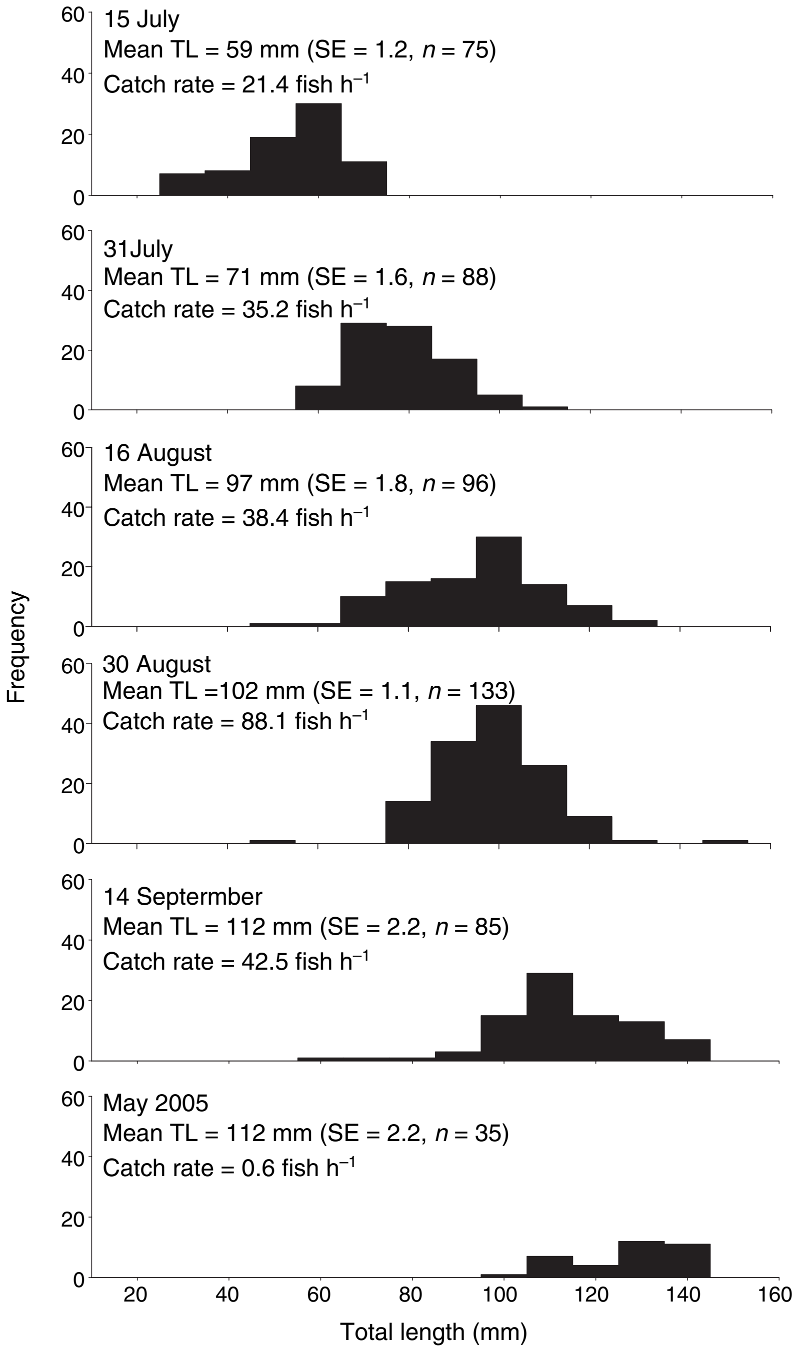


Figure 2. Length distribution for common carp captured throughout the first growing season in 2004 and the following spring in 2005 from Campbell Lake, South Dakota.

rates for common carp across their range was not possible because of an apparent lack of studies describing age-0 carp growth.

Earlier hatched common carp in Campbell Lake likely were larger by the end of the growing season primarily because they had a longer growing season than later hatched fish. In contrast, earlier hatched fish in Brant Lake likely were larger by the end of the growing season because they had a longer growing season and a faster growth rate than later spawned fish. The inverse relationship between growth rate and hatching date was based only on growth during the

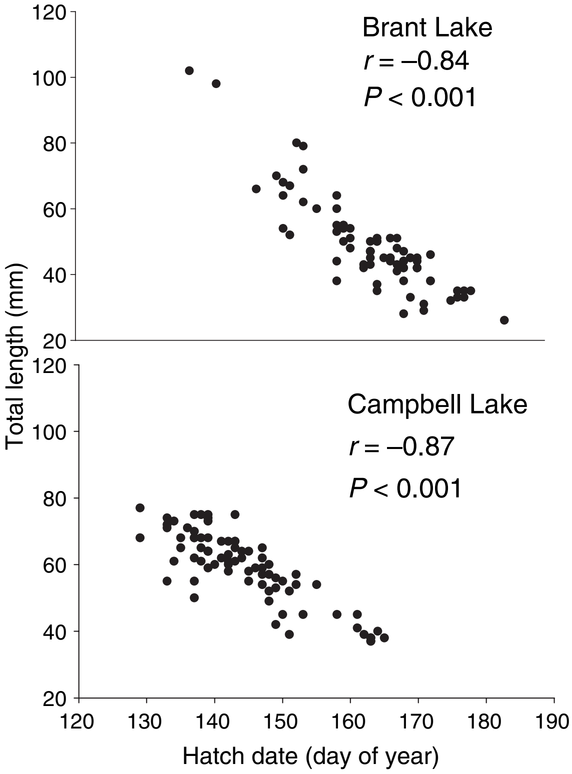


Figure 3. Relation between total length at time of capture and hatch date for age-0 common carp collected on 27 July at Brant Lake, South Dakota and 15 July at Campbell Lake, South Dakota. Day of year 130 = 9 May 2004.

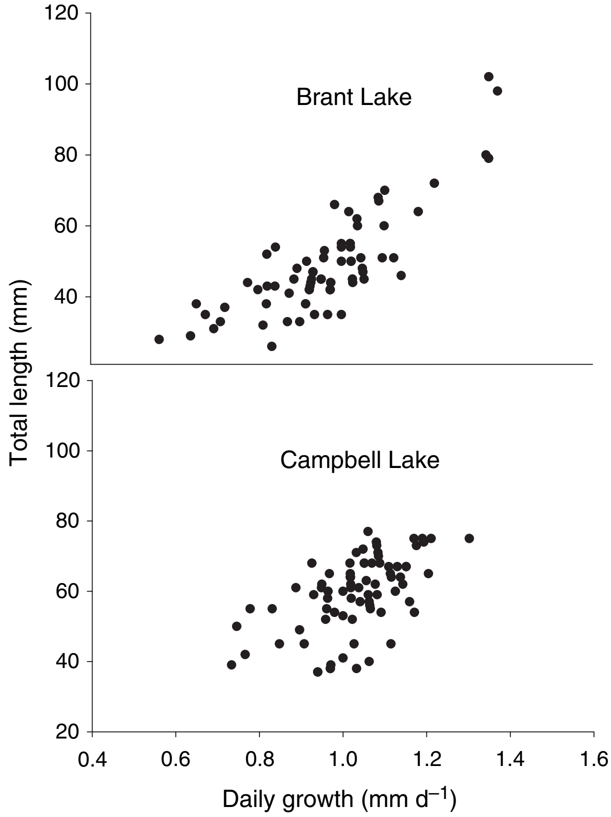


Figure 4. Relation between total length at time of capture and daily growth for age-0 common carp collected on 27 July 2004 at Brant Lake, South Dakota and 15 July 2004 at Campbell Lake, South Dakota.

first half of the growing season and should be interpreted cautiously. Estimating growth rate from fish collected in July was necessary because accurate enumeration of daily increments became more problematic as fish age. The inverse relationship between growth rate and hatching date at Brant Lake but not at Campbell Lake may be related to interspecific competition for available resources. The fish community in Brant Lake includes several species of centrarchids in addition to the percids and esocids that are present there and in Campbell Lake. The later-appearing age-0 centrarchids in Brant Lake may provide the basis for interspecific competition for food resources with later-hatching members of the age-0 common carp. In contrast, the percids and esocids in Lake Campbell hatch earlier and thus have already peaked in abundance prior to appearance of the age-0 common carp. Further research is needed to verify this speculation.

If overwinter survival of age-0 common carp is size dependent, as suggested by these two populations, then fish that hatch earlier or grow faster may achieve greater sizes prior to winter, thereby increasing their probability of survival. Furthermore, the minimum length that appeared to be required to survive winter in these two study lakes was considerably different (78 mm in Brant; 114 mm in Campbell). These differences could be attributed to dissimilarities in amount of available overwinter habitat, food availability or predator density; but these data were not measured or available.

This study documents size selective overwinter mortality of age-0 common carp, which subsequently affects recruitment to age 1. This insight into overwinter survival of age-0 common carp should allow ecologists and managers to better predict population changes of common carp. Research is needed to identify the causes of overwinter mortality (e.g. overwinter habitat, starvation or predation), as well as to identify factors affecting the magnitude of inter-annual recruitment variability. A secondary contribution is that mechanisms driving size attained by age-0 common carp may vary by water body. Given that this study was based on only two waters, such a conclusion is tenuous. Future research should

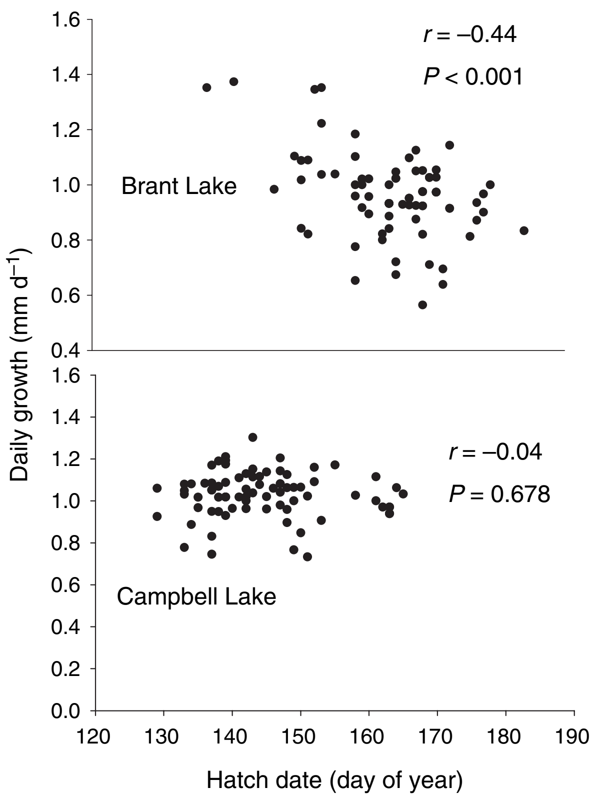


Figure 5. Relation between daily growth and hatch date age-0 common carp collected on 27 July at Brant Lake, South Dakota and 15 July at Campbell Lake, South Dakota. Day of year 130 = 9 May 2004.

examine intra-cohort common carp growth rate and hatch timing at weekly time intervals throughout the first growing season to understand the relative importance of these factors better and how they influence overwinter survival and eventual recruitment. Additionally, multiple waters and multiple years should be evaluated to determine potential mechanisms (such as hatching date and growth rate as determined in this study) that may drive the resulting autumn size structure and overwinter survival of the age-0 fish.

Acknowledgments

Partial funding for this study was provided by the South Dakota Department of Game, Fish and Parks through Federal Aid in Sport Fish Restoration Project F-15-R Study 1596. Special thanks to numerous technicians and graduate students at South Dakota State University for assisting with the study, especially Kris Edwards and Nathan Gosch for both field and laboratory assistance.

References

Cahn A.R. (1929) The effect of carp on a small lake: the carp as a dominant. *Ecology* **10,** 271–274.

Cargnelli L.M. & Gross M.R. (1996) The temporal dimension in fish recruitment: birth date, body size, and size-dependent survival in a sunfish (bluegill: *Lepomis macrochirus*). *Canadian Journal of Fisheries and Aquatic Sciences* **53,** 360–367.

Chamberlain E.B. (1948) Ecological factors influencing the growth and management of certain waterfowl food plants on Back Bay National Wildlife Refuge. *Transactions North American Wildlife Conference* **13,** 347–356.

Crivelli A.J. (1983) The destruction of aquatic vegetation by carp. *Hydrobiologia* **106,** 37–41.

Curry R., Currie S., Arndt S. & Bielak A. (2005) Winter survival of age-0 smallmouth bass, *Micropterus dolomieu*, in northeastern lakes. *Environmental Biology of Fishes* **72,** 111–122.

Engel S. (1995) Eurasian watermilfoil as a fishery management tool. *Fisheries* **20**(3) , 20–27.

Fletcher A.R., Morrison A.K. & Hume D.J. (1985) Effects of carp, *Cyprinus carpio* L., on communities of aquatic vegetation and turbidity of waterbodies in the lower Goulburn River Basin. *Australian Journal of Marine and Freshwater Research* **36,** 311–327.

Goodgame L.S. & Miranda L.E. (1993) Early growth and survival of age-0 largemouth bass in relation to parental size and swim-up time. *Transactions of the American Fisheries Society* **122,** 131–138.

King D.R. & Hunt G.S. (1967) Effect of carp on vegetation in a Lake Erie marsh. *Journal of Wildlife Management* **31,** 181–188.

Ludsin S.A. & DeVries D.R. (1997) First-year recruitment of largemouth bass: the interdependency of early life stages. *Ecological Applications* **7,** 1024–1038.

McCrimmon H.R. (1968) Carp in Canada. *Bulletin of the Fisheries Research Board of Canada* **165,** 1–93.

Miranda L.E. & Hubbard W.D. (1994) Winter survival of age-0 largemouth bass relative to size, predators, and shelter. *North American Journal of Fisheries Management* **14,** 790–796.

Mueller K.W. & Downen M.R. (2000) *1999 Green Lake Surveys: Aspects of the Biology of Common Carp with Notes on the Warmwater Fish Community*. Olympia, WA: Washington Department of Fish and Wildlife, Warmwater Enhancement Program Report, 41 pp.

Oliver J.D., Holeton G.F. & Chua K.E. (1979) Overwinter mortality of fingerling smallmouth bass in relation to size, relative energy stores, and environmental temperature. *Transactions of the American Fisheries Society* **108,** 130–136.

Panek F.M. (1987) Biology and ecology of carp. In: E.L. Cooper (ed.) *Carp in North America*. Bethesda, MD: American Fisheries Society, pp. 1–15.

Post J.R. & Evans D.O. (1989) Size-dependent overwinter mortality of young-of-the-year yellow perch (*Perca flavescens*): laboratory, in situ enclosure, and field experiments. *Canadian Journal of Fisheries and Aquatic Sciences* **46,** 1958–1968.

Post D.M., Kitchell J.F. & Hodgson J.R. (1998) Interactions among adult demography, spawning date, growth rate, predation, overwinter mortality, and recruitment of largemouth bass in a northern lake. *Canadian Journal of Fisheries and Aquatic Sciences* **55,** 2588–2600.

Rice J.A., Crowder L.B. & Holey M.E. (1987) Exploration of mechanisms regulating larval survival in Lake Michigan bloater: a recruitment analysis based on characteristics of individual larvae. *Transactions of the American Fisheries Society* **116,** 703–718.

Robel R.J. (1961) The effect of carp populations on the production of waterfowl plant foods on a western waterfowl marsh. *Transactions North American Wildlife Conference* **26,** 147–159.

Sammons S. M. & Bettoli P.W. (2000) Population dynamics of a reservoir sport fish community in response to hydrology. *North American Journal of Fisheries Management* **20,** 791–800.

Sammons S.M., Bettoli P.W. & Grear V.A. (2001) Early life history characteristics of age-0 white crappies in response to hydrology and zooplankton densities in Normandy Reservoir, Tennessee. *Transactions of the American Fisheries Society* **130,** 442–449.

Starrett W.C. & Fritz A.W. (1965) A Biological Investigation of the Fishes of Lake Chautauqua, Illinois. *Illinois Natural History Survey Bulletin* No. 29(1) 104pp.

Stueven E. & Stewart W.C. (1996) *1995 South Dakota Lakes Assessment Final Report*. Pierre, SD: South Dakota Department of Environmental and Natural Resources, 760 pp.

Threinen C.W. & Helm W.T. (1954) Experiments and observations designed to show carp destruction of aquatic vegetation. *Journal of Wildlife Management* **18,** 247–254.

Toneys M.L. & Coble D.W. (1979) Size related, first winter mortality of freshwater fishes. *Transactions of the American Fisheries Society* **108,** 415–419.

Tryon C.A. Jr (1954) The effect of carp exclosures on growth of submerged aquatic vegetation in Pymatuning Lake, Pennsylvania. *Journal of Wildlife Management* **18,** 251–254.

Vacha F. (1998) Information on Czech Republic fisheries. In: P. Hickley & H. Tompkins (eds) *Recreational Fisheries: Social, Economic and Management Aspects*. Oxford, UK: Fishing News Books, pp. 48–57.

Vilizzi L. (1998) Age, growth and cohort composition of 0+ carp in the River Murray, Australia. *Journal of Fish Biology* **52,** 997–1013.

Wedekind H., Hilge V. & Steffens W. (2001) Present status, and social and economic significance of inland fisheries in Germany. *Fisheries Management and Ecology* **8,** 405–414.

Wichers W.F. (1976) *Age and Growth of Carp (Cyprinus carpio) from Pathfinder Reservoir, Wyoming, 1974 and 1975*. MSc thesis, Laramie, WY: Department of Zoology and Physiology, University of Wyoming, 69 pp.

Wydoski R.S. & Wiley R.W. (1999) Management of undesirable fish species. In: C.C. Kohler & W.A. Hubert (eds) *Inland Fisheries Management in North America*. Bethesda, MD: American Fisheries Society, pp. 403–430.

Erratum

In Phelps, Graeb & Willis (2008), the sixth length-frequency histogram in figure 2 on p. 88 was published with errors.

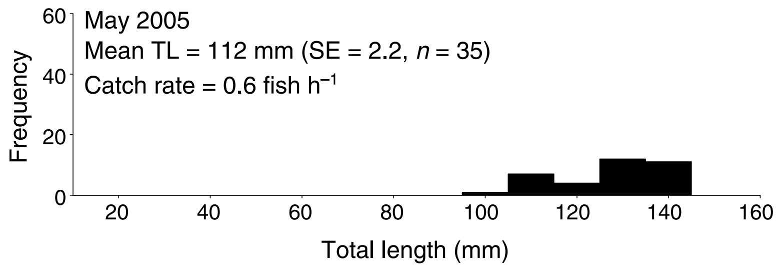
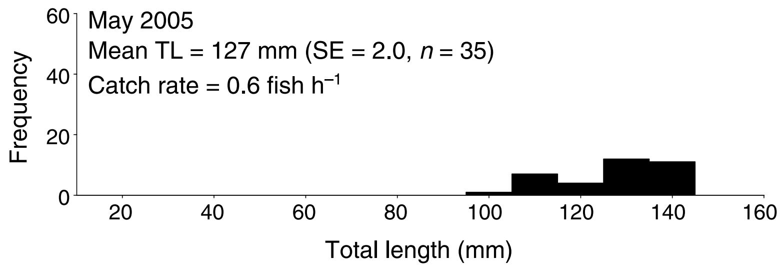


Figure 2. Length distribution for common carp captured throughout the first growing season in 2004 and the following spring in 2005 from Campbell Lake, South Dakota.

The sixth length-frequency histogram in this figure should have read:



We apologise for this error.

Reference

Phelps Q.E., Graeb B.D.S. & Willis D.W. (2008) First year growth and survival of common carp in two glacial lakes. *Fisheries Management and Ecology* **15,** 85–91.

 doi: 10.1111/j.1365-2400.2008.00613.x