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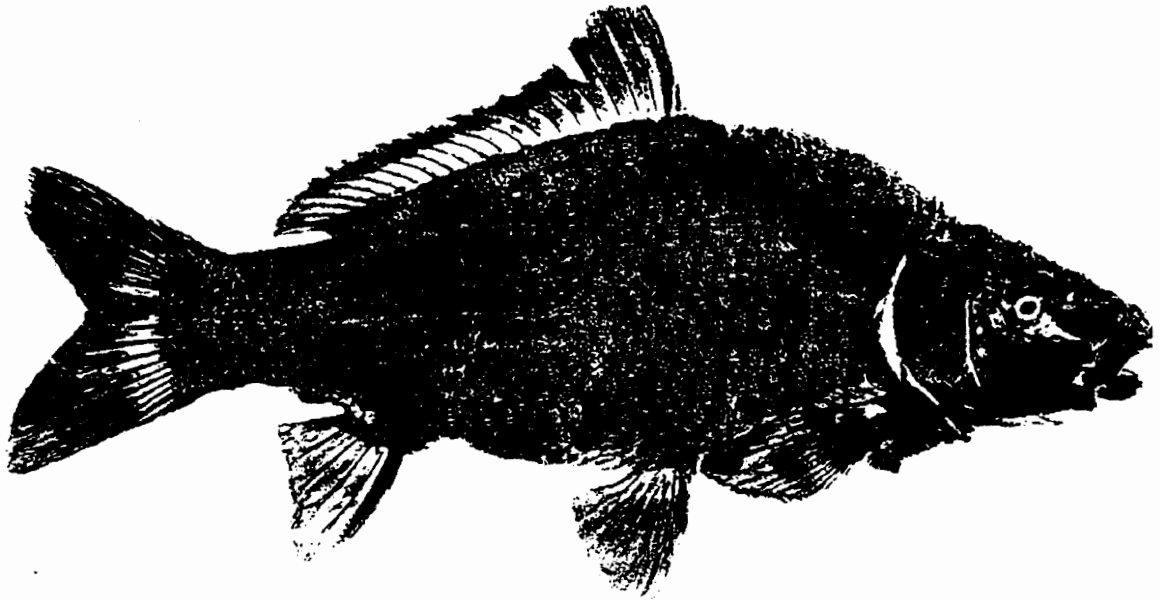
Carp (*Cyprinus carpio* L.) spawning dynamics and early growth in the lower River Murray, South Australia

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A Ph.D. 'Thesis by Publication' submitted to The University of Adelaide
for the degree of Doctor of Philosophy

- August 2004 -



Common carp (*Cyprinus carpio* L.)

Gyotaku (*gyo* = fish, *taku* = rubbing; ghee-yo-tah-koo): *'is the ancient Japanese folk art of printing trophy fish. The concept stemmed from fishermen wanting to prove and preserve the bragging rights of their trophy catch. An original fish print never lies...'*

(DeRyan 2004).

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SYNOPSIS

This thesis extends and summarises Australian data on carp (*Cyprinus carpio* L.) reproductive biology and early growth. Specifically, it (1) validates the aging of larval and early-juveniles via daily otolith increment counts, (2) provides regression equations to account for shrinkage that occurs upon preservation of young-of-the-year (YOY) carp in 70 and 95% ethanol, (3-4) investigates the timing, frequency and duration of spawning via gonad staging *and* via a combination of gonad staging and YOY sampling, and (5) investigates relationships between YOY recruitment and nine hydro-climatic parameters, and examines spatial and temporal variation in YOY growth. Each of the first four topics constitutes a chapter in this thesis (Chapters 4-7) and each chapter represents a paper that has been published in a refereed, scientific journal. Accordingly, this thesis has been submitted as a PhD 'Thesis by Publication', as outlined in Section 9.3 of the 2004 University of Adelaide 'PhD Rules and Specifications for Thesis'. The fifth topic (Appendix 1) represents additional work that was also completed during candidature.

Chapters 1-2 detail the Introduction and Literature Review. Chapter 3 explains the linkages between research topics in Chapters 4-7 and Appendix 1: the key findings are outlined below. Finally, in Chapter 8, there is a general discussion outlining the overall significance of the work, problems encountered and prospectus for future carp research.

KEY FINDINGS

CHAPTER 4: VALIDATION OF THE AGING OF 0+ CARP. Forty carp larvae were reared from eggs spawned in the Torrens River, Adelaide, South Australia, and their otoliths were examined at hatch or at 6, 10, 15 or 20 days after hatching (post-hatch). Using light- and scanning electron microscopy (SEM), otolith increments were counted and compared with known post-hatch ages. Typically, the counts were one day (range 0-2 days) more than the known post-hatch age, but increment formation was daily to at least age 20 days. Thus, age estimates derived from otolith increment counts of wild-caught 0+ carp should be reduced by one day. Comparison with SEM data showed that light microscopy alone offers sufficient resolution for aging 0+ carp.

CHAPTER 5: SHRINKAGE OF 0+ CARP AFTER PRESERVATION IN ETHANOL: Changes in the length and weight of 240 larval and juvenile carp (10-45 mm SL) were monitored over 180 days after preservation in 70% and 95% ethanol. Shrinkage varied with initial (pre-preservation) size and ethanol concentration, but was stable after 1 day. Absolute shrinkage was directly proportional to initial body size, but per cent shrinkage was inversely proportional to initial size. Length shrinkage peaked at about 14% and weight shrinkage peaked at about 75%. Weight loss in 95% ethanol was almost twice that in 70% ethanol. Regression equations are provided to calculate initial (pre-preservation) measurements of body size (length/weight) from measurements made after preservation.

CHAPTER 6: SPAWNING DYNAMICS OF COMMON CARP IN THE RIVER MURRAY, SOUTH AUSTRALIA, SHOWN BY MACROSCOPIC AND HISTOLOGICAL STAGING OF GONADS. Gonadosomatic indices and macroscopic and histological changes to gonads were monitored in an aggregate sample of 231 male and female carp (359-755 mm total length TL) from the River Murray in South Australia between November 2001 and October 2002. Histological inspection was most accurate and macroscopic inspection was not possible for males, as discrete reproductive stages could not be distinguished. Histological photographs and descriptions are provided for each stage of ovary, testis and oocyte development. Only one (female) fish >350 mm TL was classified as immature. Spawning occurred initially over at least 7 months, from mid-November 2001 to mid-May 2002, and it began again in mid-September 2002. Spawning was asynchronous within the population and each female may have spawned up to three discrete batches of eggs. These data have implications for the control of carp populations and environmental flow management in the region.

CHAPTER 7: REPRODUCTION OF COMMON CARP IN SOUTH AUSTRALIA, SHOWN BY YOUNG-OF-THE-YEAR SAMPLES, GONADSOMATIC INDEX AND THE HISTOLOGICAL STAGING OF OVARIES. Young-of-the-year (YOY) samples, gonadosomatic index (GSI) and the histological staging of ovaries were used to monitor the reproduction of carp in the lower River Murray, from August 2001 to December 2002. Spawning occurred initially over 9 months from late September 2001 to May 2002, the longest period recorded in Australia. It recommenced in September 2002 and continued until at least December, when sampling ended. Contrary to previous reports, hatch-dates estimated from otolith analyses revealed that in each year, spawning was continuous from onset until completion, and that there were two peaks in YOY production between mid-October and December 2001 and mid-January and mid-March 2002. Over the entire period, there were at

least 29 discrete spawning events at two locations about 30 river-km apart, most of them synchronous. GSI and histological evidence indicated spawning over seven months, including two months where the hatch-date data failed to identify any reproductive activity. Thus, the benefits of combining analyses of YOY and ovary samples are apparent here, where reproduction is protracted and there is potentially low YOY survivorship in some months, and where the local ecology of the target species is not well-understood.

APPENDIX 1. RECRUITMENT, AGE AND GROWTH OF YOUNG-OF-THE-YEAR CARP IN SOUTH AUSTRALIA. Young-of-the-year (YOY) carp were monitored in two backwaters of the River Murray, South Australia, during August 2001-2003. The post-hatch age was estimated from daily increments in thin-sectioned otoliths (lapilli). Otolith length and width proved to be better predictors of age ($r^2 = 0.76 - 0.93$) than body length or body weight ($r^2 = 0.64 - 0.85$). Growth rates varied between sites and years, and in 2001-2002, accelerated as the spawning season progressed. Spawning was continuous from onset to completion each year, but the estimated production of YOY carp varied daily. YOY carp were most abundant when there were stable flows and stable atmospheric conditions during the periods of spawning, egg-incubation and larval development. Complex interactions between environmental variables, however, precluded development of a simple model to predict the timing of spawning