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Distribution of common carp in a Spanish reservoir in relation to thermal loading from a nuclear power plant

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ABSTRACT

Arrocampo Reservoir is used as a cooling basin for a nuclear power plant located in southern Europe. Its annual mean temperature is about 30 °C with maxims that achieved 41.5 °C near the hot water effluent. Common carp (*Cyprinus carpio*, Linnaeus 1758) is the dominant pelagic fish species in this reservoir. Hydroacoustic surveys were conducted bimonthly over 9 years to characterize common carp abundance and distribution in the reservoir on an annual and seasonal temporal scale. Mean fish density during the period was 0.029 fish m^{-3}, varying from a maximum of 0.038 in 2003 to a minimum of 0.012 in 1998. There were no significant differences in the mean fish density among years. Each year, fish distribution showed significant seasonal variation. Carp were homogeneously distributed during autumn and spring; in winter carp occupied warmer outfall areas, whereas in summer, fish were distributed in the coldest area of the reservoir (dam area) but avoided the warm outfall area. These seasonal tendencies of carp distribution was repeated every years. Behavioural reaction appears to be particularly important in explain carp distribution in this reservoir.

1. Introduction

A wealth of experimental evidence demonstrates that environmental temperature is a key abiotic factor, particularly for ectotherms, such as fish (Coutant, 1970, 1977; Crawshaw, 1977, 1979; Beitinger and Fitzpatrick, 1979; Brett, 1997; McKinley et al., 2000; Schreer and Cooke, 2002; Cooke and Schreer, 2003; Das et al., 2004). Due to a variety of anthropogenic influences, many fish populations experience altered thermal regimes. One of the most extreme examples of thermally altered environments are thermal effluents associated with power plants. Studies investigating the ecological effects of heated effluent condenser cooling systems at power-generating stations were common in the early 1970s, but declined through the 1980s and 1990s. In recent years, these investigations have become relevant again due to the continuous increment of the energy supply (Cooke et al., 2004). In addition, studies on thermal loading have also begun to place an increased focus on the impacts of climate change on freshwater fish species (Tyedmers and Ward, 2001). Ecological studies of fish in habitats heated by power plants can be useful to provide information on the response of aquatic organisms to thermal loading in wild conditions. Specially, long-term studies are needed as direct effects of waste heat discharges of fish depend upon both the duration and intensity of thermal exposure.

Animal's distribution can be difficult to assess, particularly for mobile species occupying environments that prevent direct visual observation as fish. Technological advances have permit more detailed assessments of how fish respond to dynamic thermal regimens. Hydroacoustics is a well-established and recognized technique for assessment of fishery resources (MacLennan and Simmonds, 1992; Kubecka et al., 1994; Horne, 2000; Mehner and Schulz, 2002) and for assessing the distribution of fish in relation to thermal effluents (Minns et al., 1978). This technique avoids many of the biases of traditional sampling gears, and it can reveal the variability in the fish distribution at relevant spatial and temporal scales (Schael et al., 1995; Rakowitz and Zweimüller, 2000, Robinson et al., 2000; Encina and Rodríguez-Ruiz, 2002).

The purpose of this study was to examine the behavioural response of fish to dynamic environmental and operating conditions within the Arrocampo Reservoir (south Spain). Arrocampo is 770 ha (35.5 hm^3) and was created in 1980 on the Arrocampo River (CNA, 1996). The reservoir provides water for cooling the 930 MW generated by the Almaraz-Trillo Nuclear Power Plant. The 3,17,106 Kcal h^{-1} of heat transmitted from the power plant into the Arrocampo Reservoir is dissipated due to the forced circulation of the water through a 25 km labyrinthic run (CNA, 1991). Arrocampo is a warm and eutrophic reservoir. It is also shallow, with a maximun depth of 22 m in the dam and a mean depth of 4.6 m. The water level is maintained constant throughout all year.

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Only the dam area shows summer water stratification with anoxia in the hipolimnetic strata. Mean water temperature is higher than 30 °C all year, became greater than 40 °C during summer in the area closer the hot water effluent (outfall area).

Fish fauna assemblage of the reservoir is former by common carp (*Cyprinus carpio* Linnaeus 1758), pumpkinseed (*Lepomis gibbossus* Linnaeus 1758) and largemouth bass (*Micropterus salmoides* Lacépède 1802). In Arrocampo, the centrarchid species inhabit only the littoral area where a dense macrophyte vegetation is developed with common carp dominating the pelagic zone (CNA, 1996). The study revealed the seasonal distribution of fish in relation to thermal loading of the water in the reservoir.

2. Material and methods

Reservoir was divided into three study areas: the outfall area, the central area and the dam area (Fig. 1). Echo surveys were conducted in each study area bimonthly from 1998 to 2006 to characterize common carp abundance and distribution on a seasonal time scale. Temperature-depth data of the water column were collected using a field DO/BDO meter (YSI, model 58). A scientific portable echosounder (SIMRAD EY200) working at 200 kHz was used for echo surveys. The complete system was calibrated with a 13.7 mm diameter copper sphere standard target with a target strength (TS) of −36 dB. Surveys were conducted mainly at sunset and spanned nearly the entire width of the reservoir. Shallow littoral areas (less than 2 m deep) were excluded from the transects to avoid largemouth bass and pumpkinseed in the acoustic samples. Thus, pelagic fish distribution corresponds mainly to common carp distribution. Twenty-four transects per survey were conducted covering all basins of the reservoir. Data were processed using the post processing program HADAS (Lindem, 1992). Each transect was analysed for the whole water column sampled and taking to account two deep layers: <5 and >5 m. Fish density was estimated as fish m^{-3}.

Analysis of variance (ANOVA; one-way and two-way with Bonferroni univariate contrasts) was used to test differences in

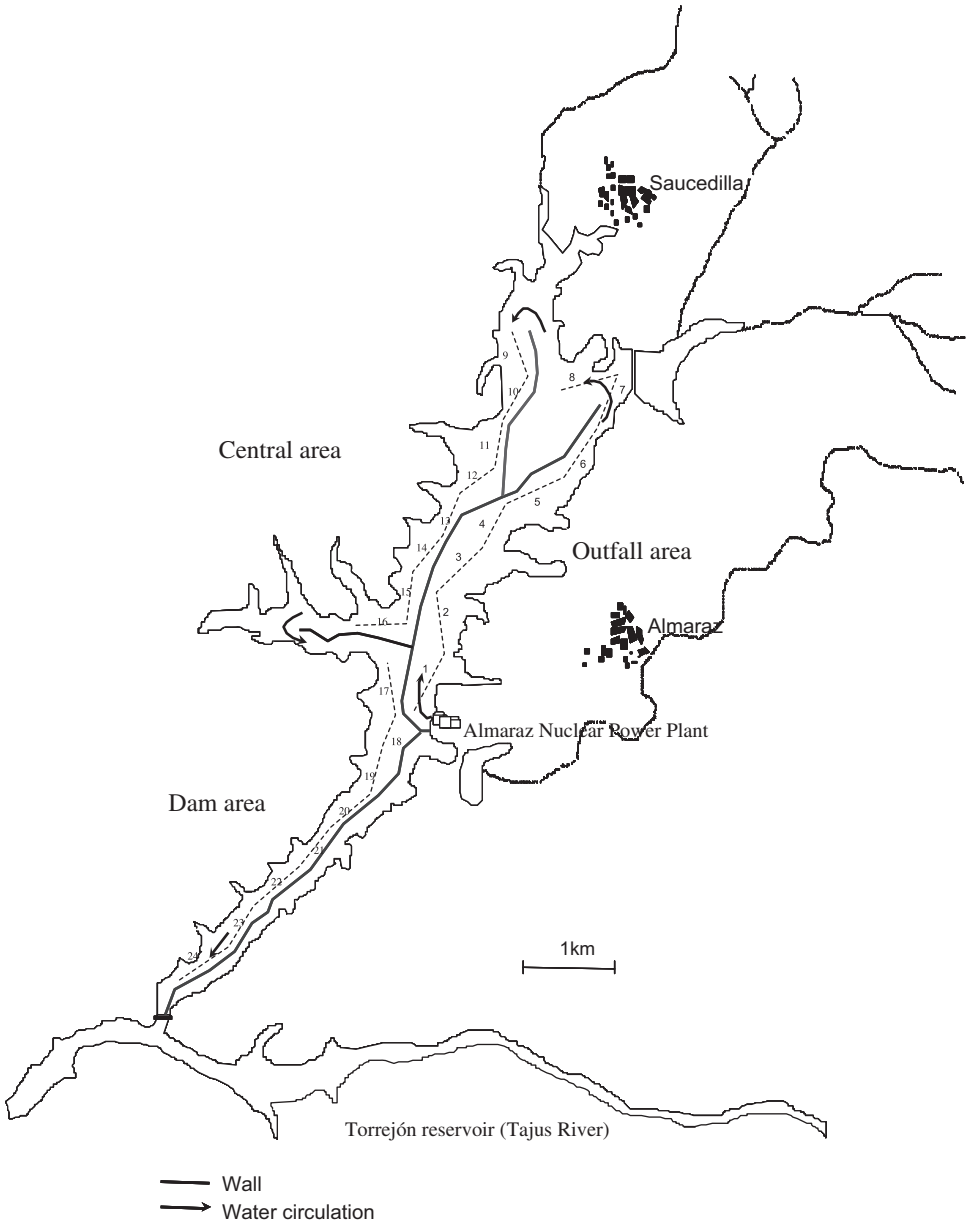

Fig. 1. Study area and locations of the echosurvey transects.