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Stock–catch analysis of carp recreational fisheries in Czech reservoirs: Insights into fish survival, water body productivity and impact of extreme events

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ABSTRACT

In culture-based fisheries, managers strive for high stocking efficiency, the ratio between the total weight of caught and stocked fish. Here we present a new time series approach to examine the dependence of reported anglers' catches on stocking and external events, using data on carp (*Cyprinus carpio* L.) from 14 reservoirs in the Czech Republic. Average stocking efficiency varied between 0.25 and 2.2, with values close to unity in most reservoirs. The lowest efficiencies occurred in three reservoirs receiving cold hypoxic water from a large upstream reservoir, while the highest efficiencies were found in two shallow, highly productive reservoirs. Analyses further indicate that stocked carp are typically caught during the year of release or the year after; but also that the mean time lag between stocking and capture increases with reservoir area. External events can be important: major floods in the years 2002 and 2006 were in many cases followed by large, up to 10-fold, increases in catches in subsequent years; we attribute the surplus catch to carp washed down from upstream aquaculture and river stretches. In contrast, the "Velvet Revolution" (demise of the communist regime in 1989) had no discernible effect on catches in subsequent years. In conclusion, the proposed method can simultaneously estimate the likely mean survival time of stocked carp and identify the impact of major environmental and societal events on recreational fisheries. The approach thus sheds light on the performance of current stocking practices at individual reservoirs, and could be used to monitor and improve stocking strategies and management of culture-based recreational fisheries.

1. Introduction

Stocking is a widespread tool in fisheries management (Cowx, 1998; Welcomme and Bartley, 1998). It is regularly used in recreational fisheries to satisfy angler expectations and demands, including increased catches and availability of multiple fish species for exploitation (Arlinghaus and Mehner, 2005; Baer et al., 2007; Britton et al., 2007). Stocking may be used to enhance or supplement natural reproduction or to create culture-based fisheries, i.e., fisheries based predominantly on the recapture of stocked fish (Lorenzen et al., 2001).

The common carp (*Cyprinus carpio* L.) in the Czech Republic provides a prime example of a culture-based fishery. Czech carp breed extremely rarely in the wild (Baruš and Oliva, 1995), yet they are the most popular target among anglers, and constitute the largest part of catches at most ponds and reservoirs (e.g., Jankovský et al., 2011). Local carp populations are actively managed by regular stocking, and long-term records of the amount of stocked and caught carp are maintained by many regional offices of the two major recreational fishing organizations, Czech Anglers' Union and the Moravian Anglers' Union. Catches of carp account for 75–80% of the total annual yield reported by anglers in the Czech Republic (e.g., Vostradovský and Mráček, 1996). During 1990–2010, the ~320,000 individual anglers registered in the two unions caught on average 3000 tonnes of carp each year; this figure excludes fish that were immediately released back and were hence not recorded.

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The participation rate of ∼3% in recreational fishing and the annual per-capita catch of ∼10 kg of carp are comparable to those in many other European countries outside Scandinavia (Aas, 2008; EIFAC, 1996; Wortley, 1995).

The relationship between annually stocked and caught fish can be used by local fisheries managers and contribute to cost-effective stocking. However, there is no established rigorous method that would be used in such assessments. Statistical analyses aimed to elucidate the dynamics of stocking have investigated general relationships between yield and stocking weight/rate, between yield per unit area and the size of the stocked system, between yield and effort, and between yield and various physico-chemical factors as proxies for habitat productivity (e.g., De Silva, 2001, 2003; Sugunan and Katiha, 2004; Welcomme and Bartley, 1998). However, these studies have been motivated mainly by the need to achieve highly productive culture-based fisheries in developing countries. The resulting relationships are based on long-term averages and comparisons across multiple systems, which limit their utility to describe more closely a stock–catch relationship in a given water body. Time series analyses could provide useful tools in this task, but are used to build predictive models in the context of freshwater fisheries only rarely (Allen et al., 2006; Loomis and Fix, 1998; Skehan and De Silva, 1998).

Managers in the Czech Republic and elsewhere often assess the return rate of stocked fish on an annual basis by comparing the total amount of caught fish (expressed in weight or numbers) to the amount of fish stocked in the same year or the year before (e.g., De Silva et al., 1992; Pivnička and Rybář, 2001). This simple approach is reasonable in the absence of better knowledge about average time to recapture. Indeed, stocking events can result in high catches shortly after the stocking because they attract increased attention and lead to temporarily higher fishing effort by the anglers and because the newly-stocked fish are often easy to catch (Baer et al., 2007; Pivnička and Čihař, 1986). Improved statistical methods, such as lag-correlation analysis, can identify most likely time lags between stocking and harvest (e.g., Quiros and Mari, 1999). Nevertheless, the drawback of correlation analyses is their inability to provide a full overview of the stock–catch relationship as they consider each of the lags separately and, furthermore, neglect any additional prominent features of the time series such as residual long-term trends. Contributions of fish stocked in different years to the catch in a given year are thus difficult to determine.

The aim of this paper is to propose a relatively simple time series analysis that can reconcile the aforementioned problems and, in addition, help identify attributes of each reservoir that are of high relevance to fisheries managers. In particular, we ask the following questions: can linear models capture long-term relationships between stocked and caught fish in culture-based fisheries? Do such models imply any differences between individual water bodies? Can we use long-term data to indirectly estimate survival patterns of the stocked fish, assess the reservoir productivity, and identify the impact of extreme events, such as large floods, on the catches? The questions are framed in the context of carp recreational fisheries in the Czech Republic, but the methods developed here are general and applicable to any other culture-based fishery.

2. Materials and methods

2.1. Data sources

We use time series of stocked and caught carp from 14 reservoirs (Table 1), collated from annual reports provided by regional offices of the Czech Anglers' Union and Moravian Anglers' Union. The reservoirs vary greatly in age (ca. 20–80 years old) and surface area (14–4870 ha) and represent four distinct groups: relatively small urban reservoirs (from the smallest to the largest: Papež, Džbán and Hostivař), canyon-shaped and relatively cold, moderately productive reservoirs on the Vltava River (Kořensko, Hněvkovice, Slapy, Orlík and Lipno) and three productive reservoirs on the Dyje River (Mušov, Vranov and Nové Mlýny). Finally, three of the reservoirs on the Vltava River (Štěchovice, Kamýk and Vrané) are located immediately downstream of a large and deep reservoir (Orlík or Slapy; see Table 1) and receive cold hypoxic water from their hypolimnion, causing low productivity (referred to as a "cascade effect"). Draštík et al. (2004), Kubečka (1993) and Lusk and Krčál (1983) provide maps and further details on the reservoirs.

Data for each reservoir cover a period of 16–52 years (Table 1). The variables available from all reservoirs are the total weight and number of stocked carp and the total weight and number of caught carp. We use only weight in the analyses because it is the primary variable in stocking statistics; to our knowledge, only a subset of the stocked carp is weighed individually to obtain an estimate of the numbers of stocked carp. On the other hand, both total weight and total number of caught carp is calculated directly from the anglers' catches and thus represent relatively precise (bar any errors in reporting) primary data. Stocking usually consists of 2-year-old carp, which are largely invulnerable to local piscivorous fish (pike, pikeperch and wels catfish). Younger fish were sometimes stocked in 1960s and early 1970s, and older fish have sometimes been stocked in recent years. We combine only the

Table 1
Summary of available data for carp in selected Czech and Moravian reservoirs. Stock/catch data = period with available stock and catch data; effort data = period with available effort data. Stock/catch data available as total weight; effort available as total number of reported fishing trips. Cascade effect = reservoir receiving cold water with low oxygen concentrations from another large and deep upstream reservoir.

Reservoir	Area (ha)	Main characteristics	Year built	Stock/catch data	Effort data
Papež	14	Small urban reservoir (pond)	1987*	1987–2009	
Džbán	18	Small urban reservoir (pond)	1971	1982–2007	
Hostivař	44	Small urban reservoir	1963	1980–2009	
Štěchovice	115	Reservoir on the Vltava River (river km 84), cascade effect	1944	1971–2009[a]	
Kořensko	120	Reservoir on the Vltava River (river km 200)	1991	1994–2009	
Kamýk	195	Reservoir on the Vltava River (river km 135), cascade effect	1962	1993–2009	
Vrané	251	Reservoir on the Vltava River (river km 71), cascade effect	1936	1971–2009[a]	
Hněvkovice	268	Reservoir on the Vltava River (river km 210)	1991	1991–2009	
Slapy	1392	Remote reservoir on the Vltava River (river km 92)	1955	1971–2009[a]	
Orlík	2730	Remote reservoir on the Vltava River (river km 145)	1961	1990–2009	
Lipno	4870	Remote reservoir on the Vltava River (river km 330)	1960	1958–2009[b]	
Mušov	530	Shallow reservoir on the Dyje River (river km 56), highly productive	1978	1991–2007	1991–2007
Vranov	761	Reservoir on the Dyje River (river km 162), productive	1934	1991–2008	1996–2008
Nové Mlýny	1668	Shallow reservoir on the Dyje River (river km 41.5), highly productive	1988	1991–2008	1991–2008

[a] Missing 1976 and 1979 stocking data.
[b] Missing 1999 stocking data.
* The pond was last emptied in 1987 or before.