Recruitment of Two Non-native River-Spawning Fishes in Lake Texoma, Oklahoma and Texas

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Abstract: The impoundment of a river alters environmental conditions to the extent that some important life history requirements of lotic-adapted fishes are disrupted; changes in requisite conditions for reproduction can interfere with spawning and recruitment. Water movement stimulates spawning migration as well as providing buoyancy to maintain eggs in suspension during development. These requirements can be met for reservoir populations if the fish can access adequate flowing water conditions in tributaries. Two non-native river-spawning fishes, Grass Carp (*Ctenopharyngodon idella*) and Striped Bass (*Morone saxatilis*) have become established in Lake Texoma; both have spawned in the Red and Washita Rivers and have been recruiting in the lake environment. Based on relative abundance of each species in the 2017 samples, we consider that both produced a strong year class. Successful reproduction for the exotic Grass Carp might be expected in some of the other 10 inland reservoirs where Striped Bass spawning occurs.

Introduction

Reproduction and survival of a non-native fish determines whether a population will be naturalized in the new aquatic habitat. Requisite physico-chemical conditions for lotic spawners are not present within reservoirs, however, some in-flowing tributaries can provide suitable habitat for reproduction. The anadromous Striped Bass (*Morone saxatilis*) has been widely stocked in large impoundments of North America since 1965 following the development of artificial propagation techniques (Stevens 1984); however, natural reproduction and recruitment have occurred in only about ten of the over 450 stocked reservoirs. Setzler et al. (1980) provide a biological review for the Striped Bass including reproductive biology and Bonn et al. (1976) and Harrell et al. (1990) published details of hatchery-based propagation.

Grass Carp (*Ctenopharyngodon idella*) were imported from Asia in 1963 and hatchery spawned in 1966; they were first collected in open waters within the U.S. in 1971 (Kelly et al. 2011), becoming widespread and common by 1974-1976 (Pflieger 1978). Stanley et al. (1978) summarized the reproductive requirements of this river-spawning cyprinid and speculated on the likelihood of recruitment in North America. Yolk-sac larvae were reported at water temperatures from 23-28^{0}C (Brown and Coon 1991; Zimpfer et al. 1987). Naturalization was widely established by 1990 (Raibley et al. 1995). Shireman and Smith (1983) and Chilton and Muoneke (1992) review the biology of the Grass Carp and summarize the reproductive requirements and Opuszynski and Shireman (1995) describe important details of artificial propagation.

Grass Carp stocking in Oklahoma is permitted only in private waters, but collection from public waters tributary to Lake Texoma has been reported (Wagner et al. 1983). While Grass Carp have spawned and have become naturalized in North America and natural spawning of Striped Bass is known from only a few of the stocked reservoirs, reproduction and recruitment within the same system has not been reported. Here, the reproductive requirements for these two rheophilic species are compared within the context of known recruitment in Lake Texoma.

Striped bass were introduced into Lake Texoma between 1965 and 1974 through stocking over 1 million juveniles; they established a self-sustaining population through natural reproduction, which was reported in 1973 and 1975 and continues to the present (Mauck 1991; Harper and Namminga 1986; Lamprecht et al. 2013). The specific localities of Striped Bass spawning in both major tributaries in 2001-2004 were identified by Baker et al. (2009) and Ryan (2004).

Striped Bass are anadromous in their Atlantic Coast range; they migrate far enough up the coastal rivers so that the current will suspend the semi-buoyant eggs throughout incubation and early larval development. The reproductive biology for Grass Carp, although totally occurring in freshwater, is quite similar relative to upstream spawning migration. Both seek suitable environmental conditions to stimulate spawning and the eggs of both must have sufficient flowing water conditions to maintain the developing eggs in the water column until hatching and until the swimbladder develops in larvae (Table 1).

Both species migrate upstream comparable distances to spawn at similar temperatures. The current velocity to maintain water-hardened eggs in suspension is similar, however, spawning in Lake Texoma presents conditions which are quite different from their native spawning habitats. Both the Red and Washita Rivers have high total dissolved solids (TDS) from natural sources; this high salinity reduces the post-fertilization swelling of the eggs which results in smaller eggs with greater density (Combs 1980). In contrast, eggs swell to a proportionately greater size in water with low dissolved solids (Bergey et al. 2003). Various studies present confounding information on the relationship of water quality and the extent of post-spawning egg swelling (Gonzal et al. 1987; Spade and Bristow 1999); is it a factor of the components of Total Hardness (Calcium & Magnesium) or Alkalinity (Carbonates & Bicarbonates) or the total array relative to osmolality (Total Dissolved Solids - Conductivity)? Water hardened eggs of grass carp in water of low TDS (ca 40 µmhos/cm) have 16-18 eggs/mL (W. Shelton, Unpublished data, Auburn University) compared to about 65/mL at 800-1,000 µmhos/cm (Rothbard et al. 2000). Both Grass Carp and Striped Bass eggs have a relatively thin non-adhesive limiting membrane which are similar in initial diameter, and developmental periods are very similar at comparable temperatures and further, both are similarly affected by the ionic level of water relative to the extent of swelling during water hardening (Table 1). Consequentially, smaller eggs will require a greater minimum velocity to keep them in suspension, thus, will travel further prior to hatching at any particular temperature.

Methods

Natural spawning and recruitment for each species in Lake Texoma have been previously reported, however, the present report documents reproduction and high survival for both within the same year, suggesting similar environmental conditions were effective. The two sampling efforts had different objectives; the ODWC program was directed toward documenting survival of recently stocked age-0 Alligator Gar (*Atractosteus spatula*) in the river-reservoir interface section of the Red River arm of Lake Texoma during the summer of 2017. Alligator gar are native to the Red River drainage, but have not been common since the impoundment of Lake Texoma. Sampling has been designed to evaluate the effectiveness of stocking to supplement natural spawning. Mini-fyke nets (0.6 m x 6.35 m; with 3.18-mm mesh, 0.6 m x 1.92-m rectangular cab, 510-mm metal throat and with a 9.14-m lead) were deployed perpendicular to the shoreline in water less than 1- m deep and surrounded by aquatic or terrestrial vegetation and woody debris (per protocol referenced in Snow et al. 2016). Grass Carp and Striped Bass juveniles were captured incidentally. Secondly, fish were collected during the Freshwater Fish Ecology

Table 1. Characteristics of spawning-related parameters for grass carp and striped bass.

Parameter	Grass Carp	Literature	Striped Bass	Literature
Temperature (^{0}C)				
Migration:	15-17	1,2	13-15	7,8
Spawning:	18-22	1,3,16	14-18	7,8
Current Velocity (m/s)	0.2-1.8	1,2,3	0.3-2.0	7,8,13
			0.5-0.8*	11
Egg Size				
Initial (#/mL)	800-1000	1,5,14	900-1000	7,9,10,15
Initial diameter (mm)	1.2-2.0	1,5	1.2-1.8	9
*Water hardened (mm)	4.2-5.3 (+1-2h)	1,5,17	2.9-4.6 (+1.0-1.5h)	6,9,10
			1.7-2.0; 1.5-1.8	11,12
*Water hardened (#/mL)	16-18 to 65-85	5,14	117	15
Incubation Period (h)	23-33 @ 21-25°C	1,5	26-40 @ 20-25°C	9,10
**Drift Distance (km)	28-100	1-4,6	30-150	7,8
			60-160	11,12,13
Yolk-sac larvae –Swim-up	+ 3d; ca 5 mm TL	1,5	+ 4 d; ca 6 mm TL	7,8

* Smaller eggs have greater specific gravity, therefore greater current is required to maintain buoyancy; swelled size (water hardened) is affected by total dissolved solids [smaller in water with high conductivity e.g. **Striped Bass** - Red River @ 2380-5460 µmho/cm (1.55 mm); Washita @ 449-1811 µmho/cm (1.7 mm); larger in low conductivity water e.g. **Striped Bass** - Santee-Cooper @ 100-120 µmho/cm (2.0-3.0 mm), **Grass Carp** – 16-18 eggs/mL (4-5 mm) @ ca. 40 µmho/cm vs. 65-85/mL (4.0-mm) @ 800 µmho/cm (11, 12, 13, 14).

**drift distance depends on temperature and current velocity.

1)Shireman & Smith 1983; 2) Chilton & Muoneke 1992); 3). Stanley et al. 1978; 4) Leslie et al. 1982; 5) Opuszynski and Shireman 1995; 6) Bergey et al. 2003; 7) Setzler et al. 1980; 8) Crance 1984; 9) Bonn et al. 1976; 10) Harrell et al. 1990; 11) Combs 1980; 12) Baker et al. 2009; 13)Lamprecht et al. 2013; 14) Rothbard et al. 2000; 15) Spade and Bristow 1999; 16) George & Chapman 2015; 17) Rach et al. 2010.

(BIOL 4433/5533) course at the University of Oklahoma Biological Station (UOBS) in May of 2014 and August of 2017. The objectives of these efforts were intended to demonstrate the usefulness of seine-sampling reservoir fishes. Juvenile fishes were collected by seining along the south perimeter of the biological station. Multiple daytime and nighttime seine samples were made with standard 3-m seines, a 6-m bag seine and a 30-m seine.

Results and Discussion

A fresh specimen of an adult Grass Carp (ca. 50 cm TL) was found in 2014 during a class field trip; it appeared to have been killed by a bow hunter. Presence of adult Grass Carp indicated the potential for reproduction. In fact, juvenile Grass Carp had been reported from collections in 1999 and 2000 in both the Red River and Washita River areas, respectively (Hargrave and

Gido 2004); no other published reports have been made. Grass Carp were not collected during class sampling in May of 2014, but juvenile Striped Bass were abundant. On 7 August 2017, the class seine sampled for about two hours along the shoreline area south of UOBS. In one seine series, 40-50 Striped Bass fingerlings (5 to 12-cm TL) and 20-30 Grass Carp fingerlings (8.5 to 10-cm TL) were collected using a 6-m bag seine. A second seine series was repeated on 8 August using both a 6-m and a 30-m bag seine; multiple hauls were made during the day and after dark. Striped Bass juveniles were again common as well as a few juvenile White Bass (*Morone chrysops*), however, no grass carp juveniles were collected. These young-of-the-year Striped Bass and Grass Carp presumably were spawned in the Red River based on the netting in that region of the reservoir.

The mini-fyke netting by Oklahoma Department of Wildlife Conservation (ODWC) personnel in the river-reservoir interface section of the Red River arm collected 66 juvenile Grass Carp during 216 net-nights of effort (Table 2). Most Grass Carp (92.4%) were captured from 19 June through 14 July 2017. Only five individuals were captured after 14 July. No juvenile Grass Carp were captured at the end of June 2017 within the mid-lake reservoir proper during seine sampling by ODWC personnel of the Southcentral Management Region (Cliff Sager, ODWC, Personal Communication). The five Grass Carp collected from 31 July through 4 August were of two distinct size groups, one individual was 113 mm TL and the other four averaged 44 mm (Table 2). During the post-nursing period, larger juveniles probably disperse into the reservoir; we speculate that by the time Grass Carp have reached about 100 mm TL, they will have left the nursery habitat in the river-reservoir interface and moved down lake to alternative habitat and/or food sources. This transition could account for the size of Grass Carp collected by the class at UOBS, about one month after frequent capture of smaller fish in the upper reaches of the reservoir. Daily age estimation of individual otoliths for these four Grass Carp will need to be completed before any conclusive results are made.

Previous ODWC mini-fyke netting from May through June of 2012 and June through July of 2013, captured 8 and 12 juvenile Grass Carp, respectively (ODWC unpublished data); no juvenile Grass Carp were collected during 2015 netting (Porter and Snow 2016). Regarding Striped Bass year-class recruitment, average year class sizes were produced in both 2012 and 2013, but 2015 and 2017 year classes were considered strong (Cliff Sager, ODWC, Personal Communication). Even though a good year class of Striped Bass was formed in 2015, no Grass Carp were collected; however, sampling was in August through September (Porter and Snow 2016), so the juvenile Grass Carp may have already moved down lake,

Analyzing otolith daily growth increments for both Grass Carp and Striped Bass will allow management biologist to better understand environmental factors influencing recruitment. Proper daily growth increment estimates will allow managers to back-calculate fish ages at hatching, and possibly correlate the environmental variables (river flows, water

Table 2. Summary of age-0 Grass Carp capture (N) for each sample date, net-nights, CPUE with standard error (S.E.), coefficient of variation (CV$\bar{x}$), mean total length (mm) and mean weight (g) from the river-reservoir interface section of the Red River arm of Lake Texoma.

Year	Date	Net Nights	*N*	CPUE (S.E.)	CV$\bar{x}$	Total Length (mm)	Weight (g)
2017	June 19-23	48	24	0.52 (0.17)	0.43	52 (1.7)	1.6 (0.16)
2017	July 10-14	64	37	0.63 (0.18)	0.47	76 (1.2)	5.2 (0.3)
2017	July 31- Aug 4	64	5	0.08 (0.05)	0.82	58 (13.8)	3.9 (0.3)
2017	Aug 21-25	40	0	0 (0)	0	None	None

temperatures, etc.) associated with those hatch dates. A better understanding of these factors could allow management biologist to use one species as a proxy to understand whether any specific impoundment could be suitable for the natural reproduction of the other species. Thus, a reservoir with successful recruitment of Striped Bass might suggest the potential for naturalization of Grass Carp. The capability for a manager to predict recruitment potential of either Grass Carp or Striped Bass in a reservoir based on the level of recruitment success of the other species is a novel idea that is in need of further research. For example, Lake Keystone on the Arkansas River has similar chemico-physical conditions to Lake Texoma and also has a self-sustaining Striped Bass population (Combs 1978); therefore, based on the comparable reproductive requirements of Grass Carp and Striped Bass, we should expect that spawning of Grass Carp will occur in this impoundment and possibly some of the other ten inland reservoirs where Striped Bass spawn.

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