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Signs of Recovery of American Shad in the James River, Virginia

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Abstract.—Abrupt increases in the prevalence of hatchery-released adult American shad *Alosa sapidissima* on the James River, Virginia, coincided with higher catch rates by staked gill nets at the river mouth in spring 2000 and 2001. Furthermore, the age composition of the hatchery-released adults corresponded to the ages that were expected to return to the river in appreciable numbers following the first large releases of marked fry in 1995 and 1996. These observations represent a hopeful sign of recovery for a severely depressed stock that has been under a fishing moratorium since 1994. To determine current status of American shad, we have monitored catch rates by a commercial fisherman who authored historic logbook data on the James River. The fisherman was paid to fish in a historic location using historic methods, and his catches in 1998–2001 are compared to his historic records in 1980–1992. Otoliths from the entire catch were scanned for hatchery marks, and scales were used to estimate age. Catch indexes in 1998–1999 were low and near the level of the historic data when a fishing moratorium was imposed in 1994. However, catch indexes in 2000 and 2001 rose above those in 1998 and 1999. Concurrently, the prevalence of hatchery-marked fish rose to more than 40%, well above the level of hatchery contribution (3–8%) in 1998 and 1999. The increase in catch indexes in 2000 and 2001 was due to the first large-scale influx of mature age-4 and age-5 hatchery fish since the restoration program began in 1992. We believe that a continuation of hatchery-based restoration efforts for American shad on the James River in combination with the current in-river moratorium on fishing is essential for recovery of the stock.

Introduction

The current moratorium on the taking of American shad *Alosa sapidissima* in Virginia's portion of the Chesapeake Bay and its tributaries was established by the Virginia Marine Resources Commission (VMRC) beginning 1 January 1994. The prohibition applies to both recreational and commercial fishers and was imposed at a time when commercial landings and catch rates of American shad in Virginia's rivers were experiencing severe declines. At the time, data from the commercial fishery in Virginia were the best available for assessing the status of individual stocks. Catch-per-unit-effort data were compiled from commercial logbooks that recorded landings by fishers using staked gill nets at various locations throughout the middle reaches of the James, York, and Rappahannock rivers. The logbooks were voluntarily provided to the Virginia Institute of Marine Science (VIMS) during the period 1980–1992 and were subsequently used in an assessment of the status of American shad stocks along the Atlantic coast by the American Shad and River Herring Technical Committee of the Atlantic States Marine Fisheries Commission (ASMFC 1999). More recently, these logbooks and other archived data have become the primary source of historical information for a monitoring

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and research program designed to determine stock abundance, set appropriate target catch-rate levels for restoration, and develop new assessment methods (Olney and Hoenig 2001).

On the James River, the voluntary logbooks of the Brown family (Rescue, Virginia) recorded the total daily catch of staked gill nets in weight of females for each year from 1980 through 1991. Prior to the moratorium, the Brown family fished their staked gill nets near the entrance to the James River, downstream of most of the historic fishing effort (Figure 1). To compare contemporary catch rates of American shad directly with these historical data, VIMS contracted Marc Brown (who, with his father, had supplied the voluntary logbooks) to fish the same type of net used historically at one of his family's traditional sites. Since the spring of 1998, VIMS scientists have monitored the spawning run of American shad at this James River location, compiling data on the magnitude and biological attributes of the catch (see Olney and Hoenig 2001 for additional discussion of the monitoring and research program).

Through a cooperative agreement with the U.S. Fish and Wildlife Service and the VMRC, the Virginia Department of Game and Inland Fisheries (VDGIF) began a restoration program for American shad in the James River in spring 1992. Each year, VDGIF scientists collect gametes from wild American shad in the Pamunkey River (part of the York River system, Virginia), rear fry in a local hatchery, mark their otoliths with river-specific tags using antibiotic immersions, and release fry in a variety of locations in the upper James River (approximately 93% of all releases occur above Bosher Dam at Richmond, Virginia). Some methodological details of the hatchery and marking procedures and the relative success of similar restoration efforts in the Susquehanna River, Pennsylvania, are reported by Hendricks (1995).

American shad migrate annually from mixed stock assemblages at sea to their natal freshwater streams and rivers to spawn (Talbot and Sykes 1958; Walburg 1960; Carscadden and Leggett 1975; Glebe and Leggett 1981). Spawning-river fidelity is believed to be high, and spawning populations are genetically distinct (Bentzen et al. 1989; Nolan et al. 1991; Epifanio et al. 1995). After hatching, young fish reside in riverine nursery areas and then migrate to sea in their first year of life where they

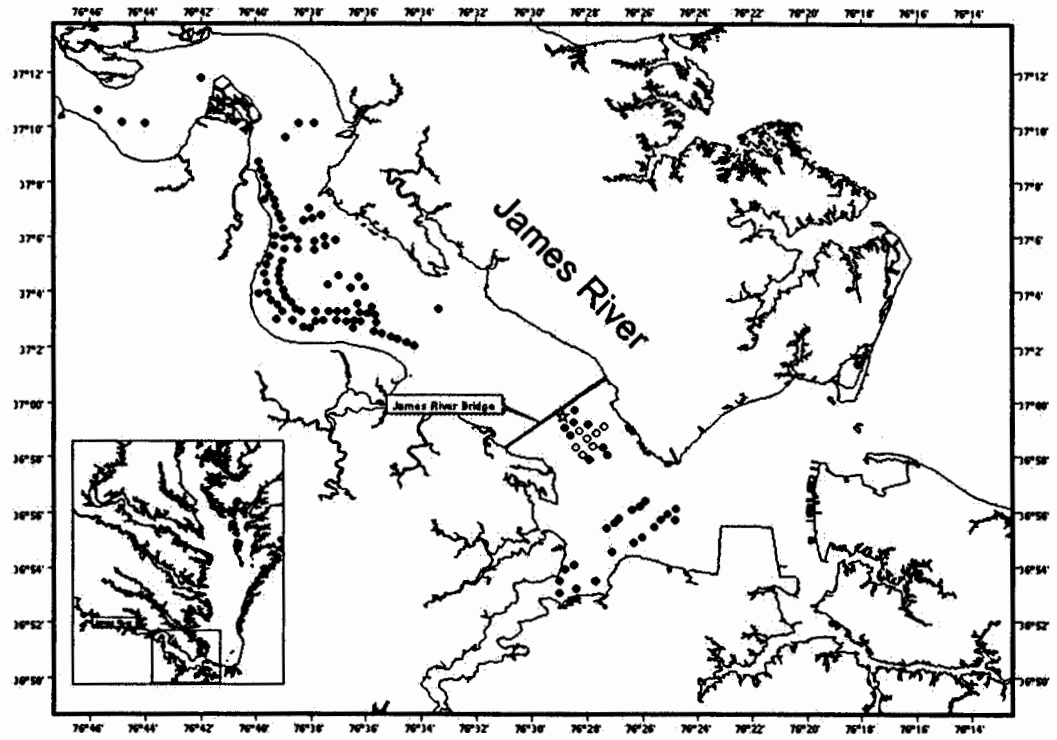

Figure 1.—Historic locations of staked gill nets on the James River in 1983 (black circles), locations of nets used historically by the Brown family (open circles), and the current monitoring location (star).

remain until maturity. Adults first spawn at ages 3–7, with approximately 80% mature by age five (Maki et al. 2001). Given this maturity schedule and the first release of marked fry in 1992, Virginia scientists and managers seeking information on the effectiveness of the restoration program in the James River have been anticipating the return of mature female hatchery fish beginning in 1996 or 1997.

One measure of the success and contribution of the restoration program in the James River would be the simultaneous observation of increased catch rates and increased ratios of hatchery versus wild fish in the ongoing monitoring program for age classes corresponding to large releases of hatchery-raised fish. In this study, we provide such evidence and provide a preliminary report on the status of the James River stock of American shad relative to levels occurring in the decade prior to the moratorium.

Study Area and Methods

One 273-m staked gill net was set on the lower James River near the James River Bridge at river mile 10 (36.0°50.0′N, 76°28.8′W, Figure 1). Historical catch-rate data on the James River came from nets constructed of 12.4-cm (4.875-in) stretched-mesh monofilament netting with 30 panels, each 9.14 m (30 ft) in length. To ensure that catch rates in the current monitoring program were comparable to logbook records, the monitoring net was similarly constructed. The in-river shad fishery in Virginia was primarily a roe fishery; thus, the mesh size is highly selective for mature females. Each week, the net was fished on two succeeding days (two 24-h sets) and then hung in a nonfishing position until the next week. Occasionally, high winds prevented the regularly scheduled sampling, and sampling was either postponed or canceled. For each year, sampling occurred for the following durations and dates: 8 weeks, 16 March–4 May 1998; 11 weeks, 24 February–5 May 1999; 13 weeks, 20 February–15 May 2000; and 14 weeks, 18 February–14 May 2001.

Individual American shad were measured (fork length, FL, to the nearest mm) and weighed (total weight to the nearest g). Sagittal otoliths were removed, placed in numbered tissue culture trays, and stored for subsequent aging and screening for oxytetracycline (OTC) marks. Whole otoliths were cleaned by immersion in warm distilled water. One otolith from each otolith pair was scanned for hatchery marks using epifluorescent microscopy. To do this, otoliths were mounted on slides, ground to the core, and polished with wet 600-grit and 800-grit sandpaper mounted on a scientific-grade polishing machine. Otoliths of American shad are small and fragile. We were unable to screen for hatchery marks on some specimens because otoliths were lost in dissection or were broken during processing. The numbers (and percentages of total specimens) of these undetermined specimens in each sampling year were as follows: 1998, 35 (17%); 1999, 16 (8%); 2000, 35 (9%); and 2001, 31 (11%). From 1993–2000, VDGIF scientists tagged hatchery-reared fry using six sequences of OTC marks as follows (numbers are days posthatch of immersion in OTC, and marks show in sequences on daily rings of otoliths): 3-13-17-21 (1993); 3-7-15-19 (1994); 5 (1995); 6 (1996); and 9 (1997–2000).

Scales were removed from a mid-lateral area 2–3 cm below the middle of the dorsal fin on the left side of each fish. Scales were cleaned with a less than 3% hydrogen peroxide solution, mounted and pressed on acetate sheets, and read on a microfilm projector using the methods of Cating (1953) that were later validated by Judy (1961).

Annual catch data are reported as a catch index computed as the area under the curve of catch rate versus day of the year for each year. In the historical data, catches were reported daily through the commercial season with occasional instances of skipped days due to inclement weather or damaged fishing gear. In the current monitoring data, catches on two successive days are separated by up to five days (usually Tuesday–Saturday) in each week of sampling. To compute the catch index, we estimated catches on skipped days using linear interpolation between the weekend averages of two days' sampling.

Results

The total number, total weight, and catch rates (both maximum and mean catch per unit effort) of hatchery-reared adult American shad that were released into the James River as fry were low in 1998 and 1999 and increased by one to two orders of magnitude in 2000 and 2001 (Table 1). In 2001, the maximum daily catch rate observed for hatchery-reared fish exceeded that of wild fish, although mean seasonal catch rates of wild American shad were higher. The catch index on the James River was low in 1998 (2.57) and 1999 (2.99) and near the level of the historic data when the fishing moratorium was imposed (Figure 2). The index approximately doubled in 2000 (6.61) and dropped in 2001 (5.01).

The prevalence of hatchery-reared fish was low in spring 1998 (8.2%; 14 of 170 adults) and 1999

Table 1.—Summary of recent catch and effort (total effort is $\times 10^3$ m/year) data of wild and hatchery-reared American shad taken in a 273-m staked gill net in the James River, Virginia. Catch rates (CPUE) are expressed as kg/m (both sexes combined). Hatchery fish that were strays (captured but not released in the James River) are excluded.

		Hatchery fish				Wild fish			
				CPUE				CPUE	
Year	Total effort	Total number	Total weight (kg)	Peak daily	Mean seasonal	Total number	Total weight (kg)	Peak daily	Mean seasonal
1998	4.6	14	18.6	0.012	0.004	156	205.8	0.212	0.045
1999	6.0	7	8.8	0.010	0.001	169	205.8	0.176	0.039
2000	7.2	156	216.9	0.126	0.030	224	313.1	0.161	0.043
2001	7.3	103	140.2	0.130	0.019	150	213.8	0.124	0.029

(3.6%; 7 of 177 adults) (Table 1; Figure 2). Prevalence rose abruptly in spring 2000 (40.3%; 156 of 387 adults) and remained near that level in 2001 (40.2%; 103 of 256). In most years, fish with hatchery tags from rivers other than the James River were among those counted. These strays were not included in the estimates of hatchery prevalence (or the data summary in Table 1) and are as follows (year captured as an adult, number, river of release): 1999, $n = 1$, Patuxent River, Maryland; 2000, $n = 7$, Pamunkey River, Virginia, and Juniata River, Pennsylvania; and 2001, $n = 3$, Pamunkey River, Juniata River, and the western branch of the Susquehanna River, Pennsylvania. There were few differences in the time of appearance of hatchery and wild fish in the monitoring gear in the spring of 2000 and 2001 (Figure 3).

Most hatchery-reared adults taken in 2000 and 2001 had OTC marks on either daily ring 5 or daily ring 6, indicating that these specimens were released in 1995 or 1996. These tags cannot be easily differentiated microscopically, however. Because of this, we determined the year of release of hatchery fish using scale-determined ages (Figure 4; Tables 2, 3). In 1998, hatchery-reared fish captured in our monitoring gear ($n = 14$) were ages 4 or 5 (released

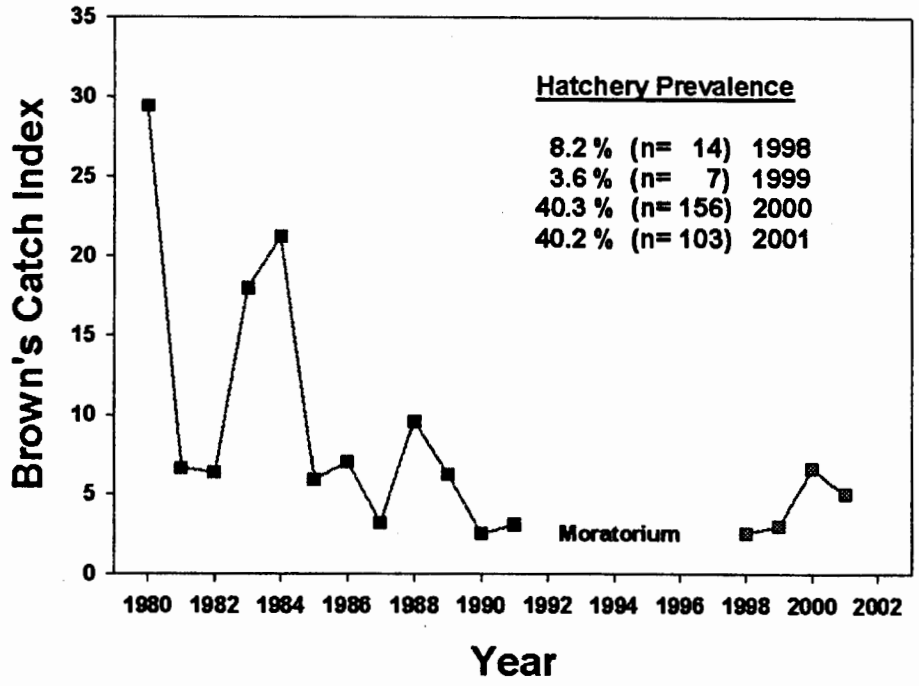

Figure 2.—Recent (1998–2001) and historical values (1980–1991) of the catch index of female American shad on the James River, Virginia. Hatchery prevalence for each year of recent monitoring are reported as percentages of the total number of both sexes that had hatchery marks on their otoliths.

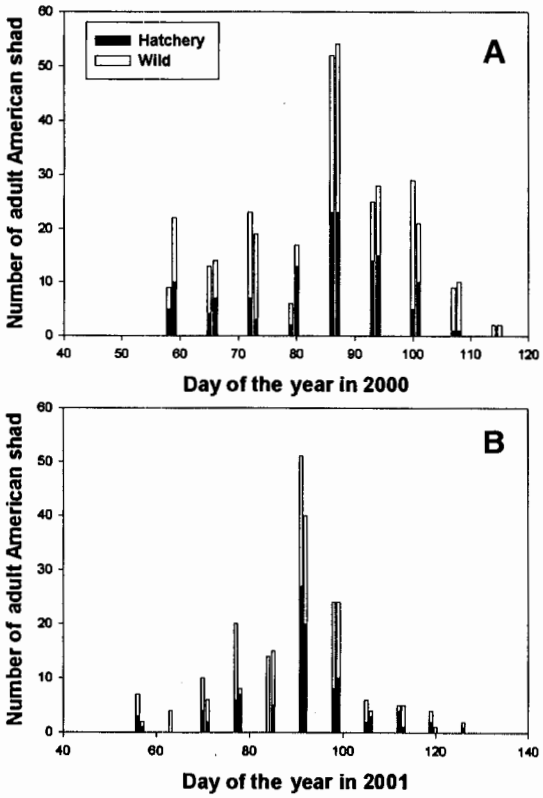

Figure 3.—Daily catches of hatchery-reared and wild American shad in a staked gill net on the James River, Virginia, in (A) spring 2000 and (B) spring 2001.

as fry in 1993 or 1994). In 1999, hatchery-reared fish (n = 7) were ages 5, 6, or 7 (released as fry in 1992, 1993, or 1994). In these years (1992–1994), hatchery production was below 2 million fry annually. In our 2000 and 2001 staked gill net catches, hatchery-reared fish were ages 3–7 (released as fry in 1992–1998), with the highest numbers released in 1995–1997 (Figure 4). During 1995–1997, hatchery production exceeded 5 million fry released annually. The 1996 year-class of hatchery-reared American shad was well represented in both 2000 and 2001. The 1995 year-class was abundant in 2000, but its numbers decreased in 2001. The 1997 year-class first appeared in moderate numbers in 2001, suggesting that additional recruitment might be expected in succeeding years (Figure 4).

Most hatchery fish captured in 2000 and 2001 were virgins (no spawning marks on the scales) that had matured at age 4 or 5 (Tables 2, 3). Almost 34% of all fish in the combined sample from the 2 years were repeat spawners (2000, 28.2%; 2001, 39.8%). The oldest hatchery-reared fish collected was released in 1993, captured in 2000, and had three spawning marks on its scales (Table 2).

Discussion

The coincident observations of abrupt increases in the prevalence of hatchery-released adult American shad and higher catch indexes in our monitor-

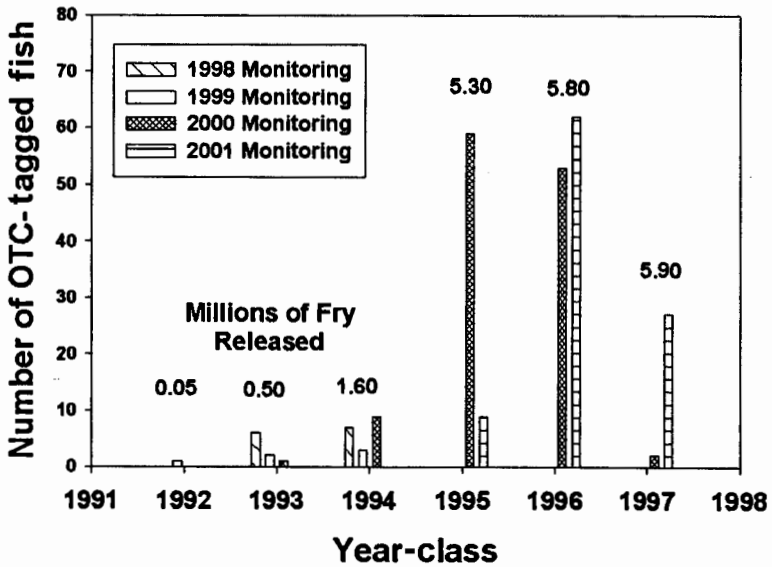

Figure 4.—Numbers and years of release of adult American shad with hatchery marks. Year-class designations are based on scale ages. Numbers above bars are millions of hatchery-reared fry released each year on the James River. OTC = oxytetracycline.

Table 2.—Spawning histories of American shad collected in the James River in spring 2000. Table entries are numbers of fish (n = 380) for which ages could be determined by scale analysis. Numbers in bold italics are virgins in year-class. Numbers in parentheses are the numbers of fish with hatchery tags (n = 124). Blank cells indicate that age at maturity of individuals in some year-classes is yet to be determined. The table truncates at age 7 because American shad are mature by that age (Maki et al. 2001).

Year-class	Age at capture	Age at maturity				
		3	4	5	6	7
1997	3	***13 (2)***				
1996	4	2 (0)	***165 (53)***			
1995	5	4 (0)	63 (25)	***89 (34)***		
1994	6	3 (0)	26 (7)	5 (2)	***4 (0)***	
1993	7	0 (0)	4 (1)	1 (0)	0	***0 (0)***
1992	8	0	1	0	0	0

Table 3.—Spawning histories of American shad collected in the James River in spring 2001. Table entries are numbers of fish (n = 260) for which ages could be determined by scale analysis. Numbers in bold italics are virgins in year-class. Numbers in parentheses are the numbers of fish with hatchery tags (n = 98). Blank cells indicate that age at maturity of individuals in some year-classes is yet to be determined. The table truncates at age 7 because American shad are mature by that age (Maki et al. 2001).

Year-class	Age at capture	Age at maturity				
		3	4	5	6	7
1998	3	***1 (0)***				
1997	4	0 (0)	***92 (27)***			
1996	5	1 (0)	53 (31)	***76 (31)***		
1995	6	0 (0)	13 (4)	13 (4)	***3 (1)***	
1994	7	0 (0)	5 (0)	1 (0)	0 (0)	***0 (0)***
1993	8	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)
1992	9	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)

ing gear suggest the first large scale influx of mature virgin hatchery fish since the James River restoration program began in 1992. Furthermore, the age composition of the monitoring catch is consistent with the timing of releases of large numbers of hatchery-released fish.

While catches of wild American shad remained relatively constant during the 4 years of monitoring (200–300 kg annually), the catches of hatchery fish increased dramatically by two orders of magnitude. Thus, the increase in spawning biomass cannot be attributed to natural production of wild fish. The time series is short (1998–2001), but the data represent a hopeful sign of recovery for a severely depressed stock that has been under a fishing moratorium since 1994.

Although the 2000–2001 catch indexes on the James River are nearly double those in 1998–1999, the current monitoring indexes are still well below the peak historic levels (1980, 1983, 1984, and 1988; see Figure 2). Overall, the mean catch index in 1998–2001 (4.29) is below the historical mean catch index from 1980 to 1991 (10.19) on the James River. Interstate (ASMFC 1999) and Chesapeake Bay fishery management plans mandate the establishment of targets for restoration of American shad in all stocks under moratorium, and historic catch rates by staked gill nets appear to be the best approach available for the James River (Olney and Hoenig 2001). Compared to the maximum catch index observed in the 1980–1991 record of the Brown family (29.20; Figure 2), current monitoring suggests that the James River stock remains severely depressed.

Patterns of maturation observed in hatchery-reared American shad in our 2000 and 2001 samples reflect maturity schedules predicted for wild fish (Maki et al. 2001). Most hatchery fish recruited to the monitoring gear at ages 4–5. Annual hatchery releases have remained high since 1995 (10, 7.3, 8.9, and 9.3 × 10^6 fry were released respectively in 1998, 1999, 2000 and 2001) and portions of only three cohorts (1995–1997) have matured thus far (Figure 4). Given this maturity schedule and assuming constant immature survival, we expect to see a continuation of strong levels of recruitment of virgin hatchery fish into the James River spawning stock, with the first strong appearance of the 1998 hatchery year-class in the 2002 monitoring.[1] Furthermore, if these strong cohorts of mature hatchery fish produce viable young that survive at constant rates, then we should see enhanced catches of wild fish (including the unmarked progeny of hatchery cohorts) beginning in 2004–2005. Our data suggest that a continuation of the hatchery program at present levels of production in com-

[1] After this manuscript appeared in proof, data became available from 2002 sampling on the James River. Prevalence of hatchery-marked fish was higher in spring 2002 (42.8%; 139 of 325 adults) and the catch index increased to 5.62. There were three strays (one from the Pamunkey River and two unknown tags). Proportions of repeat spawners increased in 2002. Of 142 aged fish, 65 were virgin spawners and 77 had previously spawned. As expected, the 1998 year-class appeared in 2002, but the catch of hatchery-marked fish was dominated by age-5 and age-6 individuals. The following age structure of hatchery fish was observed: age 4 (1998 year-class), n = 13 or 9.2%; age 5 (1997 year-class), n = 78 or 54.9%; age 6 (1996 year-class), n = 43 or 30.3%; age 7 (1995 year-class), n = 8 or 5.6%.

bination with fishing moratoria are effective components of a recovery program for this stock.

Acknowledgments

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