APPENDIX 1: STRIPED BASS STOCKING IN COASTAL NORTH CAROLINA

STOCKING HISTORY

Striped Bass culture originated in North Carolina in the late 19th century with the inception of the Weldon Hatchery adjacent to the spawning grounds of the Roanoke River (Baird 1880; Worth 1884). The Weldon Hatchery was operated from 1884–1991 by federal fisheries agencies and state agencies, including the North Carolina Wildlife Resources Commission (NCWRC; Harrell et al. 1990). The Edenton National Fish Hatchery (ENFH), operated by the U.S. Fish and Wildlife Service (USFWS), was also heavily involved in striped bass production, and operated the Weldon Hatchery as a sub-station before it was transferred to NCWRC. Striped Bass eggs and fry (larvae) produced at the Weldon Hatchery from Roanoke River broodfish were widely distributed throughout the U.S. Although annual egg and fry production totals from the early years of the Weldon Hatchery are available for most years (1906–1947; Woodroffe 2011), little is known about fry stocking numbers and locations until NCWRC records began in 1943. Since that time, over 96 million fry have been released in North Carolina coastal systems (Table 1). A detailed overview of historical striped bass stocking in North Carolina and the southeastern U.S. can be found in Woodroffe (2011).

By the 1970s collapse of the Atlantic striped bass stock, hatchery propagation techniques had been refined to achieve grow-out to phase-I (25–50 mm; 1–2 in) and phase-II (125–200 mm; 5–8 in) sizes, providing additional opportunities for stocking. The North Carolina Division of Marine Fisheries (NCDMF) and the USFWS began a pilot project in 1979 to evaluate the restoration potential of stocking phase-II fish. In 1986, the two agencies, along with the NCWRC, developed a cooperative program to restore self-sustaining stocks of anadromous fishes in coastal North Carolina waters through a combination of fishery management techniques including stocking, regulations, and assessment (Appendix A). The cooperative agreement included plans for USFWS production of Phase-I and Phase-II fish. All sizes of striped bass (fry; phase-I; phase-II; sub-adults; adult broodfish) have been stocked into North Carolina coastal river systems since the agreement. The three agencies produce an annual workplan that details stocking strategies of multiple species including striped bass.

Albemarle Sound

The earliest record of stocking phase-II fish in the Albemarle Sound area occurred in 1978; however, the NCDMF tagging program and cooperative stockings began in January 1981 (Table 2). From 1981- 1996, over 700,000 phase-II fish were stocked in the Albemarle Sound system with nearly 54,000 fish tagged. All phase-II fish stocked in Albemarle Sound from 1991–1996 were tagged to avoid natural stock confusion. In addition, over 800,000 phase-I fish were stocked in the Albemarle Sound system from 1979–1981 and 1985. An additional 160,410 phase-I fish were stocked in the Roanoke River from 1976–1979, and 106,392 phase-I fish were stocked in 1992. Stocking in the Albemarle Sound system was discontinued in 1996 due to recovery of the stock. Poor recruitment and the overfished status of the Albemarle-Roanoke stock, however, led the NCWRC and NCDMF to develop a stocking contingency plan for the Albemarle Sound in 2021. The contingency plan outlines the decision-making process for stocking surplus phase-I fish from Roanoke River broodstock if high flow conditions are expected to limit natural recruitment. The Albemarle-Roanoke striped bass contingency plan will

be part of the annual cooperative workplan agreement, and its use will be determined each year by agreement of the agencies.

Tar-Pamlico River

Phase-II stocking began in the Tar-Pamlico River in 1977 when 4,380 fish were stocked. Phase-II fish were periodically stocked from 1982–2005, and annual stockings of phase-II fish occurred from 2007–2020 (Table 2). The change to annual stocking of phase-II fish was a recommendation in the NC Estuarine Striped Bass FMP (NCDMF 2004). Nearly 2.4 million phase-II fish have been stocked in the Tar-Pamlico River basin since 1977, and more than 2.8 million phase-I fish since 1979. Phase-I fish stocked in 1979 and 1983 were likely surplus, but in 1994 the NCWRC and ENFH began stocking phase-I fish in the Tar-Pamlico River basin with an annual stocking goal of 100,000 phase-I fish. Annual stocking of phase-I fish was discontinued in 2009 by recommendation in Amendment 1 of the NC Estuarine Striped Bass FMP (NCDMF and NCWRC 2013). Surplus phase-I fish, however, were stocked in 2013, 2014, and 2016. A portion of all phase-II fish were tagged yearly to determine migration and contribution of stocked fish to recreational and commercial fisheries. From 1998–2011, all stocked fish were marked with oxytetracycline (OTC), which leaves a chemical mark on fish otoliths (ear bone) that can be seen under fluorescent light. Parentage-based tagging (PBT) analysis using microsatellite markers was used for genetically identifying fish stocked from 2010 -2020.

Neuse River

Recent stocking history of striped bass in the Neuse River basin is similar to the Tar-Pamlico River basin. A small number of phase-II fish were stocked in the Neuse River in 1975. Phase-II fish were periodically stocked from 1981–2007, and annual stockings occurred from 2009–2020 (Table 2). More than 2.1 million phase-II fish have been stocked in the Neuse River basin. Additionally, more than 2.4 million phase-I fish have been stocked in the Neuse River basin, with an annual goal of 100,000 fish from 1993–2009. Stocking requests for phase-I fish ended with Amendment 1, but surplus fish were stocked in the Neuse River in several years following 2009. A portion of all phase-II fish were tagged each year to determine migration patterns and contribution of stocked fish to recreational and commercial fisheries. All stocked fish were marked with OTC from 1998–2011, and all striped bass stocked since 2010 are genetically traceable with PBT analysis.

Cape Fear River

The Cape Fear River was first stocked with 4,000 phase-II fish in 1968, and periodic stockings of phase-I and phase-II fish occurred from 1979–2000 (Table 2). Infrequent stockings in the Cape Fear River were due to low numbers of tag returns and complications posed by the presence of hybrid striped bass from Jordan Reservoir. Hybrid striped bass stocking was discontinued in Jordan Reservoir in 2002 in favor of striped bass (Table 3). Phase-II fish stocking was reinitiated in the Cape Fear River, with stocking in 2004, 2006, and annually since 2008. Phase-I fish were stocked annually from 2001 - 2009, and surplus phase-I fish were also stocked in 2012 and 2014. A portion of the phase-II fish were tagged. All stocked fish were marked with OTC between 1998 -2011, and all striped bass stocked since 2010 are genetically traceable with PBT analysis.

Table 1. Striped bass fry stocked into coastal systems of North Carolina, 1943–2019. Data are from NCWRC hatchery cards (1943–1971), ENFH records (1982–1990), and the NCWRC warmwater stocking database, which includes ENFH records (1994–2019).

Roanoke River		Chowan River		Albemarle Sound		Tar-Pamlico River		Neuse River		White Oak River		Northeast Cape Fear River		Cape Fear River	
Year	Fry Stocked	Year	Fry Stocked	Year	Fry Stocked	Year	Fry Stocked	Year	Fry Stocked	Year	Fry Stocked	Year	Fry Stocked	Year	Fry Stocked
1944	3,938,000	1949	171,500	1951	474,200	1943	493,000	1949	100,000	1955	330,000	1965	150,000	1968	1,830,000
1949	1,000,000	1951	359,500	1952	1,025,000	1947	250,000	1951	139,000	1957	270,000	1966	200,000	1982	399,928
1950	1,500,000	1952	750,000	1953	800,000	1948	266,000	1952	175,000	1960	33,000	1967	300,000	2002	900,000
1958	400,000	1953	400,000	1954	1,000,000	1949	475,000	1953	397,000	1964	80,000	1968	425,000	2004	900,000
1959	862,000	1954	2,030,000	1955	820,000	1950	160,000	1954	1,045,000	1983	61,772	1969	320,000	-	-
1960	4,964,000	1955	860,000	1956	150,000	1954	690,000	1955	330,000	1984	45,000	1970	187,000	-	-
1962	1,335,000	1956	300,000	1957	820,000	1955	1,126,000	1956	305,000	-	-	1971	100,000	-	-
1963	3,811,000	1959	105,000	1959	200,000	1956	200,000	1957	550,000	-	-	2000	999,999	-	-
1964	1,536,000	1961	175,000	1961	525,000	1957	420,000	1959	185,000	-	-	2002	500,000	-	-
1965	1,052,000[+]	1962	225,000	1962	677,000	1959	260,000	1960	25,000	-	-	2003	115,000	-	-
1966	1,005,000[+]	1964	69,000	1964	274,000	1961	460,000	1961	260,000	-	-	-	-	-	-
1967	1,567,500	1965	219,000	1965	375,000	1962	3,250,000	1962	360,000	-	-	-	-	-	-
1968	6,334,000	1966	350,000[+]	1966	925,000	1964	393,000	1964	90,000	-	-	-	-	-	-
1969*	2,718,000[+]	1967	297,000	1967	592,000	1965	150,000	1965	150,000	-	-	-	-	-	-
1970	1,375,000	1968	985,100	1968	2,063,250	1966	200,000[+]	1966	200,000	-	-	-	-	-	-
1971	175,000	1969	309,800	1969	619,650	1967	510,000	1967	400,000	-	-	-	-	-	-
1990	240,000	1970	63,000	1970	156,000	1968	975,000	1968	766,000	-	-	-	-	-	-
-	-	1971	250,000	1971	150,000	1969	1,943,000	1969	2,049,200	-	-	-	-	-	-
-	-	-	-	-	-	1970	6,528,000	1970	66,600	-	-	-	-	-	-
-	-	-	-	-	-	1971	1,164,000	1971	66,666	-	-	-	-	-	-
-	-	-	-	-	-	1994	1,500,000	1983	176,547	-	-	-	-	-	-
-	-	-	-	-	-	2018	608,384	1984	182,000	-	-	-	-	-	-
-	-	-	-	-	-	2019	813,000	2015	799,700	-	-	-	-	-	-
-	-	-	-	-	-	-	-	2016	1,173,000	-	-	-	-	-	-
-	-	-	-	-	-	-	-	2018	670,464	-	-	-	-	-	-
-	-	-	-	-	-	-	-	2019	1,755,000	-	-	-	-	-	-
Totals	33,812,500		7,918,900		11,646,100		22,834,384		12,416,177		819,772		3,296,999		4,029,928

*55 million eggs were also released; [+]includes records with unknown size and date of release that are assumed to be fry based on year of release and data source

Table 2. Stocking records of phase-I and phase-II fish released in coastal systems of North Carolina, 1967–2020. Note, some phase-II fish were stocked in January of the calendar year following the production year-class causing some discrepancies with tables in previous fishery management plans.

	Albemarle Sound		Roanoke River		Tar-Pamlico River		Neuse River		Northeast Cape Fear River		Cape Fear River	
Year-Class	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II
1967	-	-	-	-	-	-	-	-	-	-	-	4,000
1974	-	-	-	-	*Unknown	-	-	-	-	-	-	-
1975	-	-	-	-	-	-	-	2,124	-	-	-	-
1976	-	-	18,074	-	-	-	-	-	-	-	-	-
1977	-	-	25,000	-	-	4,380	-	-	-	-	-	-
1978	-	2,358	30,336	-	-	-	-	-	-	-	-	-
1979	100,013	-	87,000	-	104,000	-	93,480	-	-	-	3,000	14,874
1980	441,689	87,181	-	-	-	-	-	-	-	-	12,410	-
1981	215,706	-	-	-	-	-	-	47,648	-	-	-	-
1982	-	106,675	-	-	-	76,674	-	-	-	-	-	-
1983	-	67,433	-	-	28,000	-	-	-	-	-	-	13,401
1984	-	236,242	-	-	-	26,000	-	-	-	-	-	56,437
1985	45,011	45,200	-	-	-	-	-	39,769	-	-	-	-
1986	-	118,345	-	-	-	-	-	-	-	-	-	-
1987	-	15,435	-	-	-	17,993	-	-	-	-	-	-
1988	-	5,000	-	-	-	-	-	-	-	-	-	-
1989	-	3,289	-	-	-	-	-	-	-	-	-	77,242
1990	-	9,466	-	-	-	1,195	-	61,877	-	-	169,792	-
1991	-	2,994	-	-	-	30,801	-	-	-	-	-	-
1992	-	2,465	106,392	-	-	-	-	-	-	-	-	-
1993	-	2,180	-	-	-	118,600	48,000	-	-	-	-	-
1994	-	2,481	-	-	127,635	183,254	103,057	79,933	-	-	100,733	-
1995	-	2,498	-	-	100,000	140,972	99,176	-	-	-	100,000	-
1996	-	2,490	-	-	39,450	-	100,000	100,760	-	-	-	-
1997	-	-	-	-	28,022	24,031	-	-	-	-	-	-
1998	-	-	-	-	230,786	-	107,730	83,195	-	-	-	30,479
1999	-	-	-	-	100,000	17,954	100,000	-	-	10,327	-	-
2000	-	-	-	-	188,839	-	121,993	108,000	-	15,635	-	8,915

Table 2 (continued).

Year-Class	Albemarle Sound		Roanoke River		Tar-Pamlico River		Neuse River		Northeast Cape Fear River		Cape Fear River	
	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II
2001	-	-	-	-	171,000	37,000	103,000	-	94,083	-	90,149	-
2002	-	-	-	-	39,110	-	-	147,654	50,000	-	50,000	-
2003	-	-	-	-	100,000	159,996	100,000	-	151,873	-	104,775	-
2004	-	-	-	-	100,000	-	100,000	168,011	50,000	-	50,000	172,055
2005	-	-	-	-	114,000	267,376	114,000	-	54,500	-	54,500	-
2006	-	-	-	-	134,100	-	146,340	99,595	84,125	-	80,450	102,283
2007	-	-	-	-	160,995	69,871	172,882	69,953	79,690	-	80,376	-
2008	-	-	-	-	331,202	91,962	314,298	-	190,460	-	395,226	92,580
2009	-	-	-	-	99,730	61,054	100,228	104,061	51,750	-	166,812	112,674
2010	-	-	-	-	-	114,012	-	107,142	-	-	-	210,105
2011	-	-	-	-	-	107,767	-	102,089	-	-	-	130,665
2012	-	-	-	-	-	45,667	50,180	91,985	12,384	-	45,000	127,070
2013	-	-	-	-	257,404	123,416	181,327	113,784	-	-	-	195,882
2014	-	-	-	-	138,889	92,727	79,864	78,866	-	-	211,726	141,752
2015	-	-	-	-	-	52,922	-	109,107	-	-	-	116,011
2016	-	-	-	-	234,718	121,190	80,910	134,559	-	-	-	70,734
2017	-	-	-	-	-	101,987	-	14,203	-	-	-	154,024
2018	-	-	-	-	-	120,668	96,900	86,556	-	-	-	101,254
2019	-	-	-	-	-	97,920	-	85,694	-	-	-	105,405
2020	-	-	-	-	-	90,614	-	96,933	-	-	-	73,038
Totals	802,419	711,732	266,802	0	2,827,880	2,398,003	2,413,365	2,133,498	818,865	25,962	1,714,949	2,110,880

*NCDMF report indicates Phase-I fish were stocked in the Tar-Pamlico in 1974, but records have not been located.

Table 3. Striped bass and hybrid striped bass stocked by the NC Wildlife Resources Commission in B. Everett Jordan Reservoir located in the Cape Fear River basin, 1988–2020.

	Striped bass	Hybrid striped bass			
Year-class	Phase-I	Fry	Phase-I	Phase-II	Total
1988			42,517		42,517
1989			30,000	96	30,096
1990			12,114		12,114
1991			96,887		96,887
1993			214,710	21,447	236,157
1994		600,000			600,000
1995	21,780		50,600		50,600
1996	15,867		29,000		29,000
1997	35,000		35,000		35,000
1998	37,766		13,692		13,692
1999	51,567		37,330		37,330
2000	42,150		42,118		42,118
2001	35,000		35,000		35,000
2002	70,000				
2003	70,000				
2004	70,000				
2005	70,000				
2006	70,000				
2007	70,000				
2008	70,000				
2009	70,000				
2010	70,000				
2011	70,000				
2012	100,000				
2013	100,000				
2014	100,000				
2015	78,000				
2016	78,000				
2017	100,000				
2018	128,164				
2019	120,000				
2020	120,000				
Totals	1,863,294	600,000	638,968	21,543	1,260,511

Northeast Cape Fear River

The NCWRC stocked approximately 26,000 phase-II fish in the Northeast Cape Fear River in 1999 and 2000 (Table 2). The NCWRC also stocked phase-I fish annually during 2001–2009. A final stocking of phase-I fish in the Northeast Cape Fear River occurred in 2012. Approximately 818,000 phase-I fish were stocked in the Northeast Cape Fear River (Table 2). All stocked fish, except for those stocked in 2012, were marked with OTC, and the 2012 year-class is genetically traceable with PBT analysis.

Broodstock source

Striped bass originating from the Roanoke River have provided most fish used for stocking in North Carolina waters, but many broodstock sources have been used throughout the state. Early fry stockings from the Weldon Hatchery were entirely from Roanoke River broodfish. Phase-II

fish stocked in the Albemarle Sound region were supplied by the ENFH and the USFWS McKinney Lake National Fish Hatchery in NC, with supplemental fish produced in South Carolina, Georgia, Alabama, and Texas, all of which used various broodstock sources. During most years, phase-I fish stocked by NCWRC originated from Roanoke River broodstock. Broodstock from Roanoke River; Monks Corner, SC; and Weldon/Monks Corner crosses were artificially spawned at the hatcheries to provide fish for grow-out to phase-II. When WSFH began striped bass production in 1994, nearly all striped bass broodstock used for all coastal river stockings were collected from the Roanoke River and Dan River (Roanoke River basin) each year (Jeff Evans, NCWRC hatchery manager, personal communication). In 2010, however, local broodstock were used for producing phase-II fish for stocking in the Cape Fear River, and local broodstock have been used for stocking the Tar-Pamlico and Neuse rivers since 2012.

Broodstock collection

Striped bass broodstock are collected during annual electrofishing surveys conducted by NCWRC on the spawning grounds of the Roanoke, Tar-Pamlico, Neuse, and Cape Fear rivers. NCWRC biologists coordinate broodstock collections with hatcheries staff. Gravid (egg laden) females and three to four males per female are collected and transported to hatcheries. The number of females collected annually varies based on stocking goals and hatchery needs. Broodstock for Tar-Pamlico and Neuse rivers phase-II production are typically delivered to ENFH, whereas broodstock for phase-I production for the Cape Fear and the Roanoke rivers and inland reservoirs are delivered to WSFH. Prior to 2014, WSFH transferred fry to ENFH for grow-out to phase-II.

Fry production

North Carolina hatcheries use established striped bass culture techniques adapted from Harrell et al. (1990). At the hatchery, male and female striped bass are injected with human chorionic gonadotropin (hCG) hormone to induce spawning. One female to three or four males are placed in a circular spawning tank and allowed to spawn. Eggs are collected by gravity and flow in a secondary circular tank equipped with an extra fine mesh egg retention screen equipped with a bubble curtain to prevent eggs from contacting the screen. Water-hardened eggs are transferred to McDonald style hatching jars at a density of 75,000 to 125,000 eggs per jar and supplied with flow-through well water to keep eggs in suspension. Incubation typically takes 48 hours, and as eggs hatch, fry are collected in aquaria. At 2 days post-hatch, fry are transferred to circular tanks and inventoried. During the period of 4 - 7 days post-hatch, fry are fed brine shrimp A*rtemia nauplii* through an automated feeding system for first feeding. Fry are then transferred to earthen production ponds for phase-I fingerling production.

Fingerling production

Fry are stocked into fertilized production ponds where they feed on naturally produced zooplankton. Supplemental feeding begins 15 days after stocking. Harvest of phase-I fingerling ponds is scheduled after a 35 - 45-day pond culture period. Phase-I fingerlings are then cultured inside in raceways for 30- 45 days. They are then graded to similar size, and advanced fingerlings are pond-stocked at a rate of 15,000–20,000 fingerlings/acre for a final pond grow-out period. Advanced fingerlings are fed sinking pellet food, and phase-II production ponds are typically treated to control algae and aquatic vegetation and to offer protection from birds. Harvest of phase-II fingerling ponds is scheduled after a 120–130-day pond culture period.

Harvested fingerlings range from 5–8 fingerlings/lb. Stocking of phase-II fingerlings typically occurs from October - December yearly.

EARLY STOCKING EVALUATIONS

The NCDMF striped bass tagging program provided an opportunity to evaluate the contribution of stocked fish to commercial and recreational fisheries. Prior to 1980, however, striped bass stockings in coastal North Carolina systems were not formally evaluated. Winslow (2010) analyzed tag-return data for phase-II fish stocked from 1981–2008 and found stocked phase-II fish contributed to the commercial and recreational fisheries as well as the spawning stock in the Tar-Pamlico and Neuse rivers.

Studies evaluating OTC marks were conducted by NCWRC to estimate the contribution of stocked phase-I and phase-II fish to the spawning stocks in the Tar-Pamlico and Neuse rivers in the early 2000s. Otoliths from adult striped bass from 2000–2004 in the Neuse River and from 2002–2004 in the Tar-Pamlico River were analyzed for the presence of an OTC mark (Barwick et al. 2008). Results suggested striped bass stocked in the Tar-Pamlico and Neuse rivers contributed little to the spawning stocks in these systems. In the Tar-Pamlico River in 2004 and Neuse River from 2000–2002, no stocked juveniles were recaptured as spawning adults. Fewer than three stocked fish were recaptured as adults in other years. However, results from this study may have been impacted by low mark retention.

With low abundance of stocked striped bass documented on the spawning grounds, NCWRC research efforts shifted to evaluating the contribution of stocked phase-I fish to seine and electrofishing samples conducted in the Neuse River. During the summers of 2006 and 2007, beach seining and electrofishing was conducted at estuarine and inland sampling locations (Barwick and Homan 2008). No juvenile striped bass were collected in 2006 and only five were collected in 2007. Three were collected close to the stocking location near New Bern, N.C. and two without OTC marks were collected upstream, all were hatchery fish. Results from this project suggested limited benefit of phase-I stocking as a management option to supplement striped bass populations in the Neuse River. In addition, the overall low number of juveniles indicated poor reproductive success, poor survival, or a combination of these two factors (Barwick and Homan 2008).

In response to a research need identified in Amendment 1 to determine factors impacting survivability of stocked fish in each system (NCDMF and NCWRC 2013), Bradley et al. (2018) acoustically tagged 100 hatchery-reared phase-II juveniles stocked in the Neuse River to estimate mortality and monitor movement and seasonal distribution. Annual discrete total mortality of phase-II stocked striped bass juveniles was 66.3% and was not related to seasonal variation in dissolved oxygen, temperature, or salinity. High observed mortality could be related to inadequate feeding or lack of predator avoidance. Future research should address whether changes in hatchery protocols could improve survival of stocked fish.

PARENTAGE-BASED TAGGING STOCKING EVALUATION

In 2010, NCWRC began using PBT to evaluate contributions of stocked striped bass to the populations in the Tar-Pamlico, Neuse, and Cape Fear rivers. PBT method uses genetic microsatellite markers to match stocked fish with broodfish used in hatchery production (Denson et al. 2012). Evaluating stocking with PBT is non-lethal as it requires a small fin clip. Fish are permanently marked with PBT without the issues of poor mark retention seen with OTC and without having to physically tag every fish with external tags. However, PBT cannot distinguish the origin of non-hatchery striped bass. Fish determined to not be of hatchery origin could be the result of wild reproduction in any system. Additionally, striped bass stocked prior to 2010 are not identifiable using this technique.

The NCWRC and NCDMF began collecting striped bass fin clip samples for PBT analysis in 2011. Fin clips are processed and analyzed by the South Carolina Department of Natural Resources Hollings Marine Laboratory. Samples in the early years focused on small fish, but as more PBT year-classes became available, fin clip samples were analyzed from all size-classes of striped bass. PBT analysis of samples collected on the spawning grounds and internal coastal fishing waters of the Tar-Pamlico, Neuse, and Cape Fear rivers revealed stocked striped bass can make up greater than 90% of the fish sampled some years (O'Donnell and Farrae 2017); however, results from 2017 and 2018 indicated a noticeable decrease in contribution of hatchery-stocked fish in the Tar-Pamlico and Neuse rivers (Farrae and Darden 2018).

Tar-Pamlico River

In 2012, NCWRC began collecting fin clips in the Tar-Pamlico River during annual spawning area surveys for PBT evaluation. NCDMF began collecting additional samples from adult striped bass in lower portions of the Tar-Pamlico River in 2016. Annual hatchery contribution from 2012–2019 ranged between 38% - 94% (Table 4) and were similar between NCWRC and NCDMF samples (Table 5). Non-PBT fish overlapped with size-classes of 2010 and 2011 stocked cohorts (Figure 1 and 2). These results indicate stocked fish heavily contribute to the Tar-Pamlico striped bass population, but there is some evidence of natural recruitment, particularly in 2014 and 2015 (Figure 2). It is possible these recruits were migrants from the Albemarle-Roanoke stock or some other source as a NCDMF telemetry study indicated non-PBT fish tagged in the Tar-Pamlico River migrated to the Albemarle Sound, suggesting mixing in the systems (NCDMF unpublished data). Continued sampling to document young-of-the-year production will be required to verify natural recruitment in the Tar-Pamlico River.

Table 4. Parentage-based tagging results for Tar-Pamlico, Neuse, and Cape Fear River at-large striped bass samples collected by NCWRC and NCDMF, 2011–2019. Data presented here do not include results for hybrids, broodfish, duplicates, and errors.

		Hatchery Cohort											
River Basin	Sample Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	Unknown	Total	Hatchery Percentage
Tar-Pamlico	2012	19	12								14	45	69%
	2013	99	41								23	163	86%
	2014	55	112	5							29	201	86%
	2015	22	79	56	34						12	203	94%
	2016	28	102	101	98	6					51	386	87%
	2017	7	35	17	86	24	1	1			78	249	69%
	2018	4	11	6	38	43	3	21	9		225	360	38%
	2019		7	1	7	9	4	57	11	4	85	185	54%
Neuse	2011	36									0	36	100%
	2012	24	8								1	33	97%
	2013	123	5	2	1						69	200	66%
	2014	96	77	20	99						55	347	84%
	2015	31	53	34	11						55	184	70%
	2016	20	25	42	83	22	1				42	235	82%
	2017	16	30	35	70	65	5	1			78	300	74%
	2018	14	19	26	35	67	76	39			117	393	70%
	2019	3	10	5	19	21	42	158	6	9	57	330	83%
Cape Fear	2011	55									0	55	100%
	2012	72	35								3	110	97%
	2013	109	27	14							92	242	62%
	2014	39	42	75	67						65	288	77%
	2015	45	31	32	41	10					66	225	71%
	2016	18	24	59	84	25					28	238	88%
	2017	17	9	37	46	51	18	1			17	196	91%
	2018	12	8	26	50	38	34	13	10		24	215	89%
	2019	6	2	10	10	7	7	25	85	115	31	298	90%

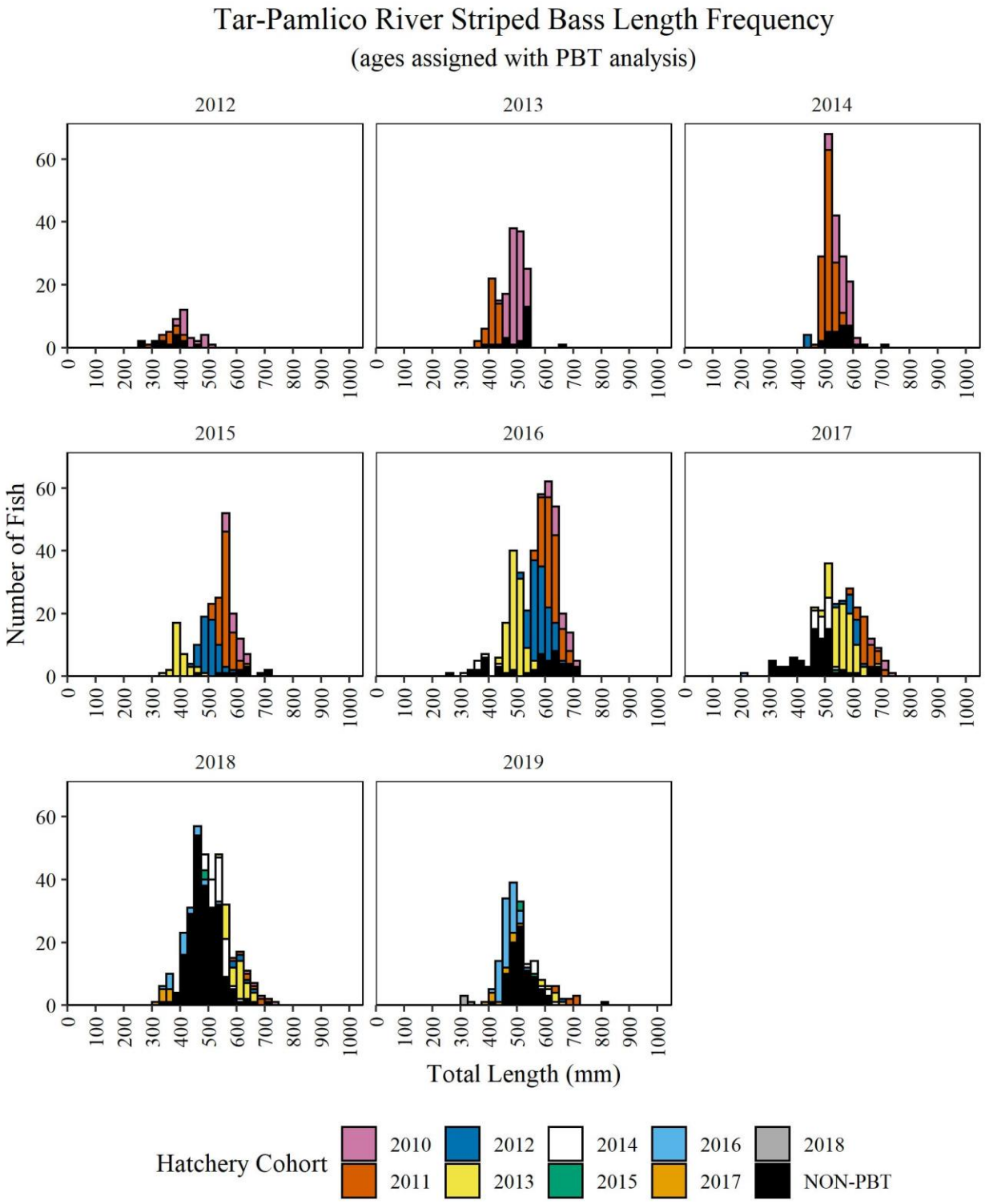

Figure 1. Length-frequency histograms for at-large striped bass collected in the Tar-Pamlico River by NCWRC and NCDMF, 2012–2019. Hatchery cohorts identified by parentage-based tagging analysis (PBT) are plotted within each 25-mm length group. Fish identified as non-PBT were not assigned to a hatchery cohort because they did not match to a broodstock pair.

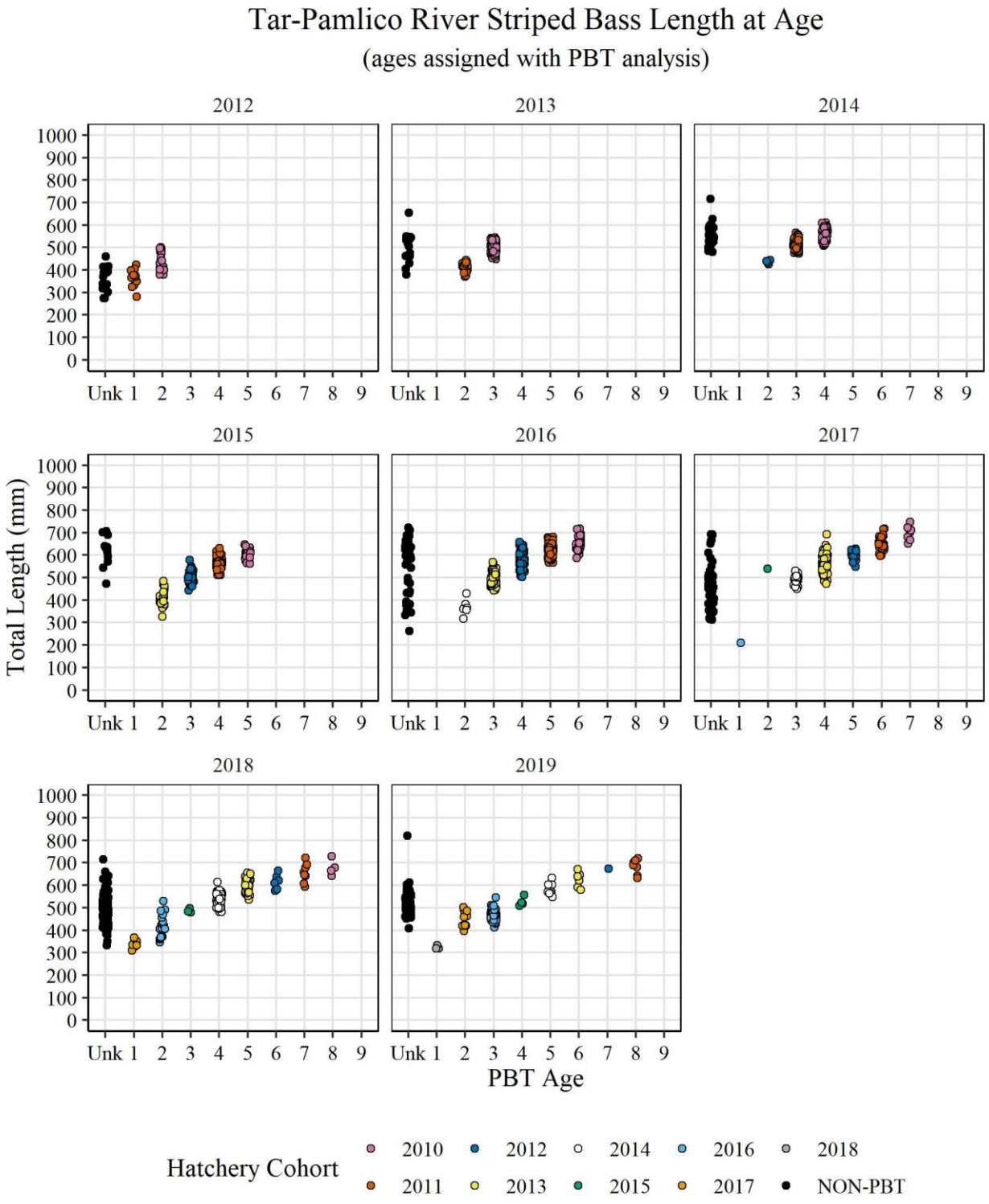

Figure 2. Length at age for at-large Tar-Pamlico River striped bass collected by NCWRC and NCDMF, 2012–2019. Ages were identified using parentage-based tagging (PBT) analysis. Those fish with an unknown age (Unk) each year were not identified as hatchery cohorts by PBT analysis and could not be assigned an age. Points are jittered about each age column to clarify overlapping data points. Outliers were removed before plotting.

Table 5. Parentage-based tagging hatchery contribution for at-large samples (excluding hybrids, broodfish, duplicates, and errors) collected by NCWRC during the Tar-Pamlico River spawning area survey and by NCDMF in downstream portions of the Tar-Pamlico River basin.

	NCWRC Samples			NCDMF Samples		
Year	Non-PBT	Total	Hatchery Percentage	Non-PBT	Total	Hatchery Percentage
2016	25	196	87%	26	190	86%
2017	31	100	69%	47	149	68%
2018	93	154	40%	132	206	36%
2019	26	78	67%	59	107	45%

Neuse River

NCWRC began collecting fin clips from the Neuse River spawning area survey in 2011. NCDMF began collecting additional samples in lower portions of the Neuse River basin in 2016. Annual hatchery contribution from 2011–2019 ranged between 66% - 100% (Table 4; Figure 3-4). Non-PBT contribution estimated in early years of this study may have fish from age classes before 2010. Results from 2019 are more likely to accurately reflect actual hatchery contribution for the Neuse River striped bass population and indicate non-PBT recruitment in 2014 and 2015 is contributing to the Neuse River striped bass population. The non-hatchery fish from the 2014 and 2015 year-classes could be wild-spawned fish from the Neuse River or another system. Telemetry studies conducted by NCDMF documented that striped bass tagged in the lower Neuse River migrated to the Albemarle Sound (NCDMF unpublished data), suggesting mixing in these populations. Additionally, hatchery contribution was much higher for NCWRC samples collected on the Neuse River spawning grounds compared to NCDMF samples collected in the lower Neuse River in 2017–2019 (Table 6). The lower hatchery contribution for the downstream samples could indicate striped bass from the Albemarle-Roanoke population mix with the Neuse River population. Nevertheless, results indicate some non-PBT fish from the 2015 year-class are participating in the upstream spawning migration.

Table 6. Parentage-based tagging hatchery contribution for at-large samples (excluding hybrids, broodfish, duplicates, and errors) collected by NCWRC during the Neuse River spawning area survey and by NCDMF in downstream portions of the Neuse River basin.

	NCWRC Samples			NCDMF Samples		
Year	Non-PBT	Total	Hatchery Percentage	Non-PBT	Total	Hatchery Percentage
2016	34	85	60%	8	150	95%
2017	26	182	86%	52	118	56%
2018	77	307	75%	40	86	53%
2019	23	228	90%	34	102	67%

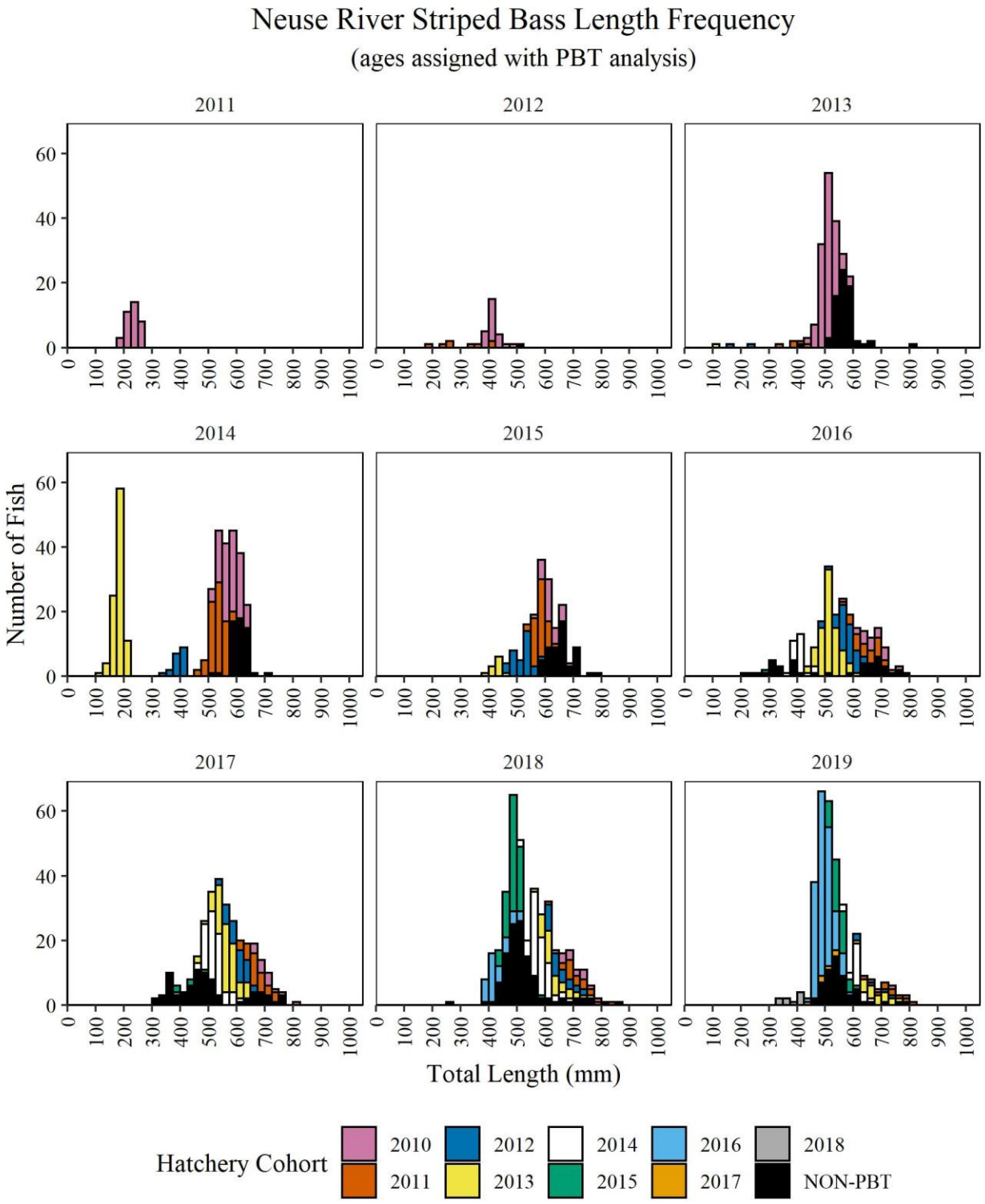

Figure 3. Length-frequency histograms for at-large striped bass collected in the Neuse River basin by NCWRC and NCDMF, 2011–2019. Hatchery cohorts identified by parentage-based tagging analysis (PBT) are plotted within each 25-mm length group. Fish identified as non-PBT were not assigned to a hatchery cohort because they did not match to a broodstock pair.

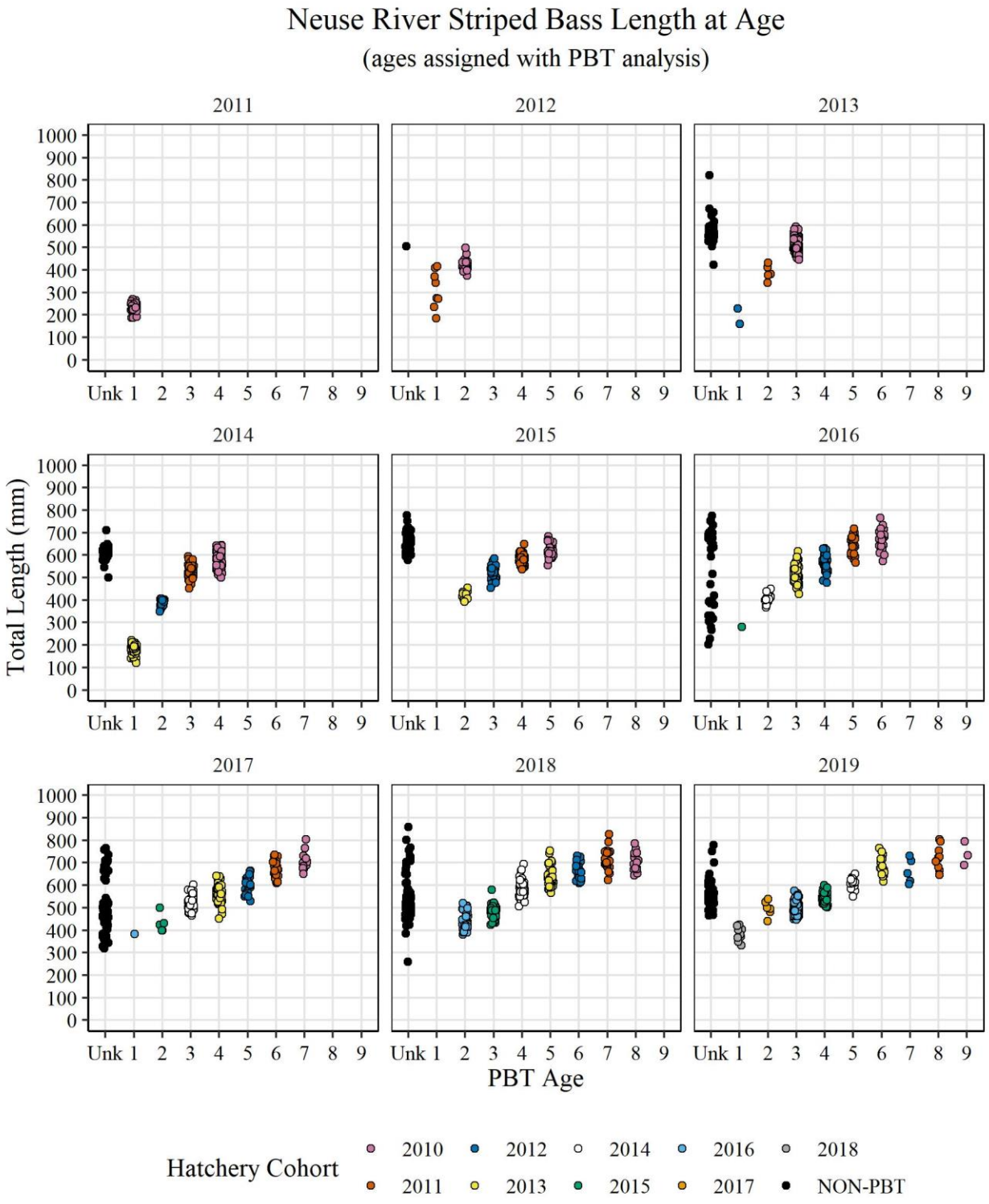

Figure 4. Length at age for at-large Neuse River striped bass collected by NCWRC and NCDMF, 2011–2019. Ages were identified using parentage-based tagging (PBT) analysis. Those fish with an unknown age (Unk) each year were not identified as hatchery cohorts by PBT analysis and could not be assigned an age. Points are jittered about each age column to clarify overlapping data points. Outliers were removed before plotting.

Cape Fear River

In 2011, NCWRC began annual PBT analysis of striped bass captured in the Cape Fear spawning survey. NCDMF provided samples from the lower Cape Fear River in 2011 and 2012. Starting in 2017, NCDMF began collecting additional samples from adult fish in the lower portion of the Cape Fear River during winter months. Additionally, NCDMF tested fin clips from five young-of-the-year striped bass collected in the Northeast Cape Fear River during 2018. Results of PBT analysis from both agencies combined show hatchery-origin fish comprise between 62% - 100% of the fish tested annually with increasing percentage of hatchery-origin fish each year since 2013 (Table 4). Despite the high hatchery contribution in 2019, there was evidence of wild recruitment in the 2018 year-class (Figures 5 and 6). Juveniles collected in the Northeast Cape Fear River in 2018 were not of hatchery origin suggesting limited natural reproduction

Escapement of striped bass stocked in Jordan Reservoir is the source of most striped bass found in the Cape Fear River upstream of the locks and dams. PBT analysis revealed an increasing proportion of fish stocked in upriver reservoirs in later year-classes, increasing as sites move upriver (Figure 7). The Jordan Reservoir striped bass fishery is entirely hatchery supported to provide recreational fishing opportunities in the reservoir. Due to low survival and low angler participation, NCWRC fisheries biologists stopped striped bass stocking in Jordan Reservoir in 2021 (C. Oakley, NCWRC, personal communication). Future striped bass stock enhancement decisions in the Cape Fear River need to account for the loss in contribution from striped bass escapement from Jordan Reservoir. Additionally, stocking decisions regarding hybrid striped bass in Jordan Reservoir should consider escapement potential and effects on the Cape Fear River.

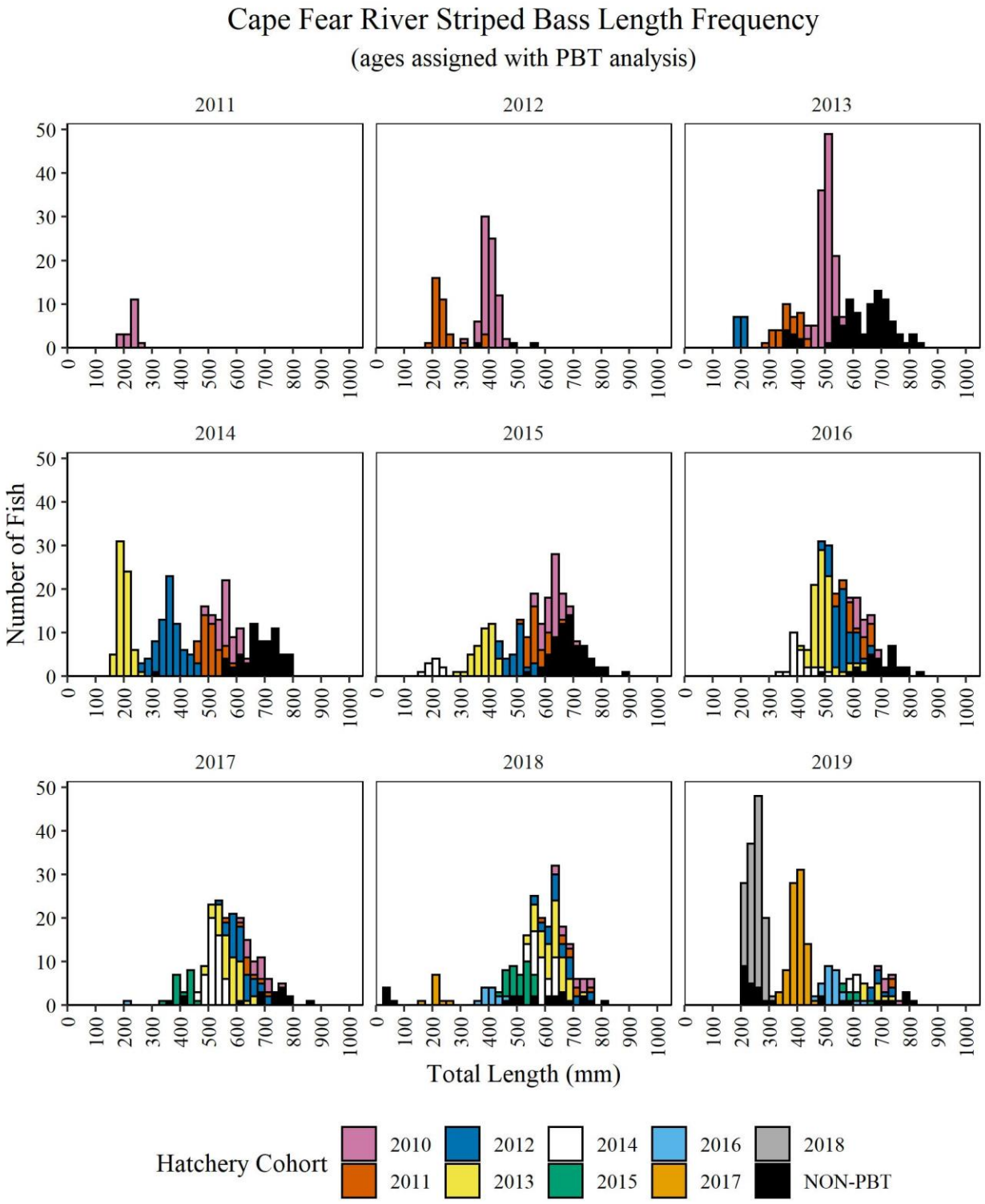

Figure 5. Length-frequency histograms for at-large striped bass collected in the Cape Fear River basin by NCWRC and NCDMF, 2011–2019. Hatchery cohorts identified by parentage-based tagging analysis (PBT) are plotted within each 25-mm length group. Fish identified as non-PBT were not assigned to a hatchery cohort because they did not match to a broodstock pair.

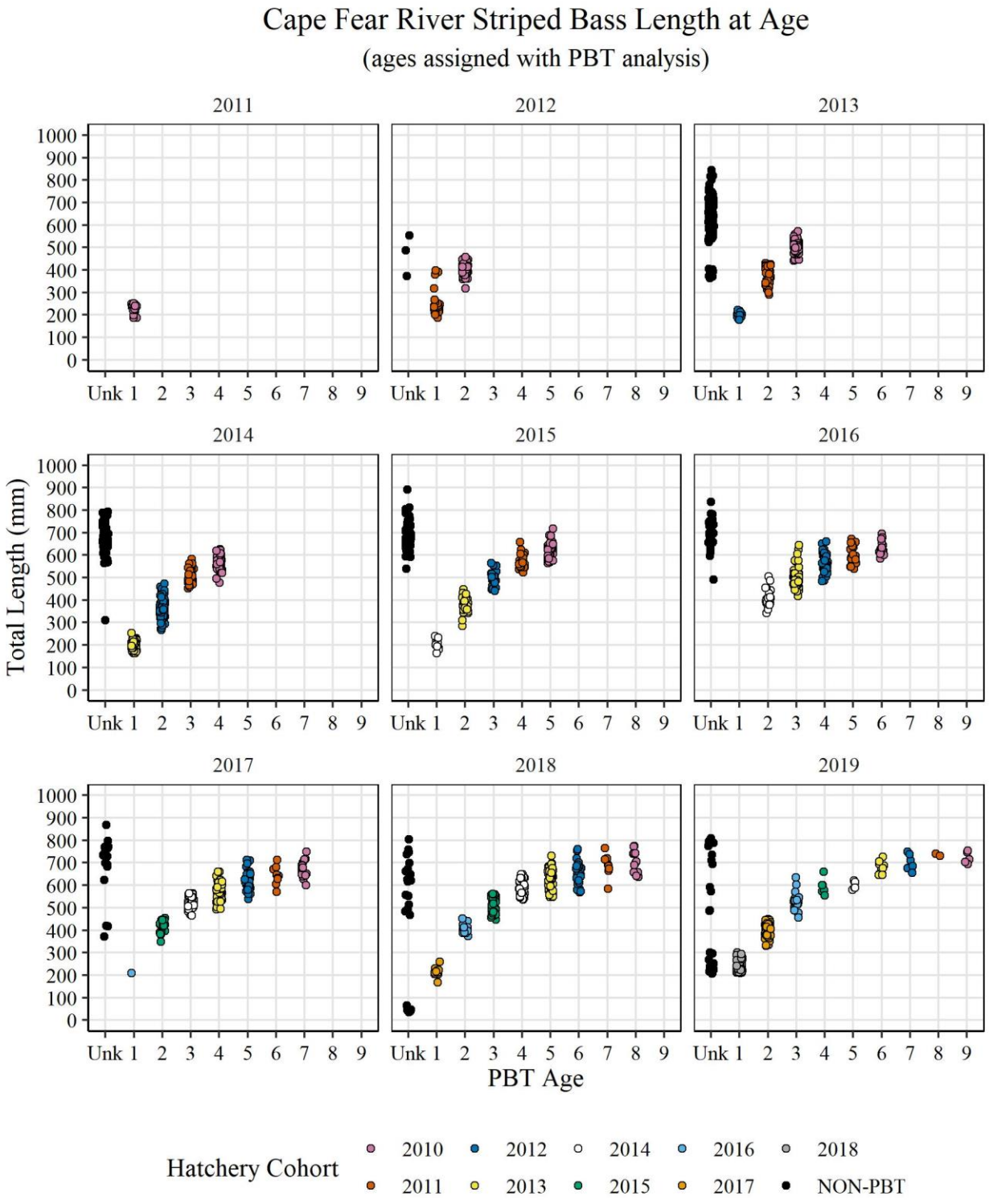

Figure 6. Length at age for at-large Cape Fear River striped bass collected by NCWRC and NCDMF, 2011–2019. Ages were identified using parentage-based tagging (PBT) analysis. Those fish with an unknown age (Unk) each year were not identified as hatchery cohorts by PBT analysis and could not be assigned an age. Points are jittered about each age column to clarify overlapping data points. Outliers were removed before plotting.

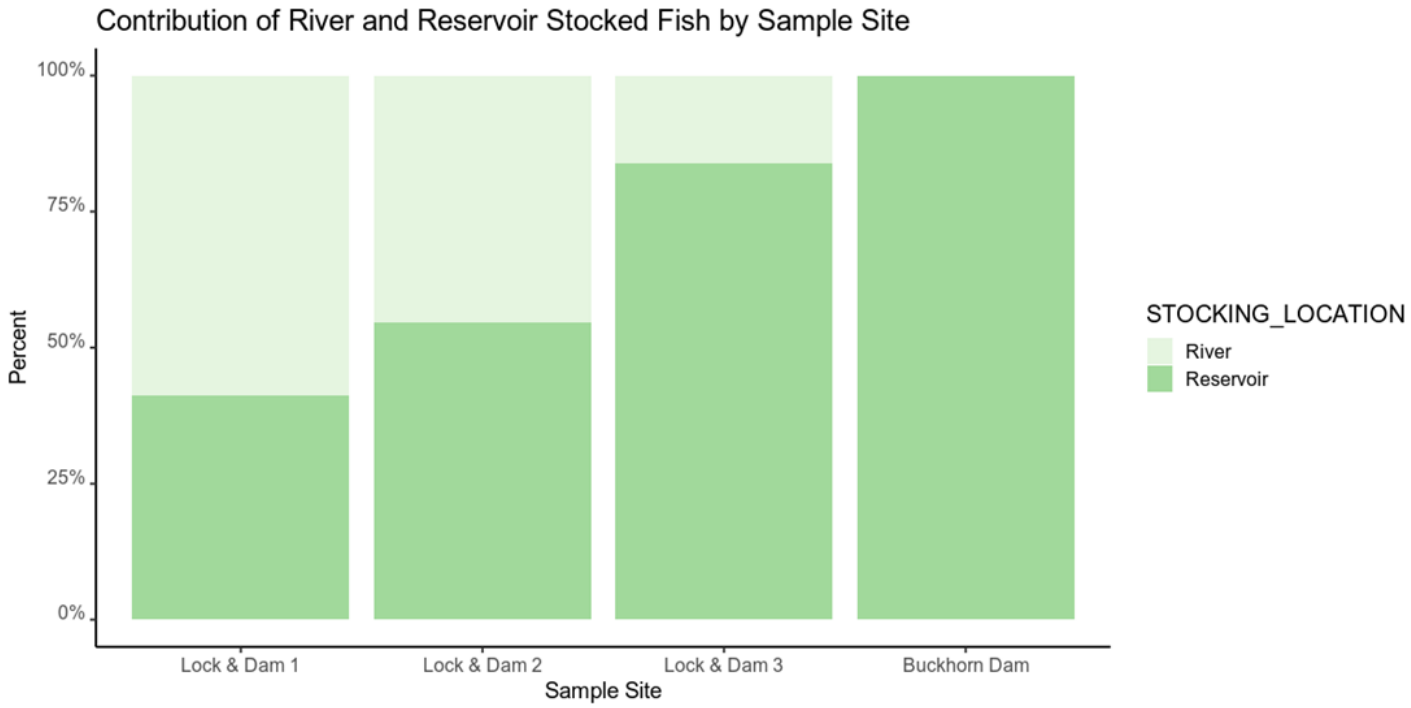

Figure 7. Relative contribution of hatchery-origin striped bass by stocking location to each NCWRC electrofishing sample site in the Cape Fear River, 2015–2019.

MANAGEMENT CONSIDERATIONS

Historically, many hatchery programs have operated as harvest augmentation or production hatcheries with the primary goal of producing as many fish as possible for put-grow-take fisheries (Trushenski et al. 2015, 2018). Conversely, supplementation hatchery programs compensate for poor recruitment caused by limitations related to habitat quantity or quality, environmental quality, or intense harvest pressure (Trushenski et al. 2015). Many anadromous fish stocking programs have experienced a shift since 2000 (Trushenski et al. 2018), using a hatchery model with increased emphasis on producing fish genetically equivalent to wild fish with a long-term goal of producing a self-sustaining, naturally spawning population. The Amendment 1 objective of the striped bass stocking program in North Carolina coastal rivers (NCDMF and NCWRC 2013) employs an integrated hatchery program model "to increase spawning stock abundance while promoting self-sustaining population levels appropriate for various habitats and ecosystems."

Hatchery rearing, stocking, and stocking evaluation methods vary depending upon stocking program goals. Lorenzen et al. (2010) identified that lack of clear fishery management objectives, lack of stock assessments, ignoring the need for a structured decision-making process, lack of stakeholder involvement, and failure to integrate flexible and adaptive management into the stocking plan are weaknesses of hatchery programs. When implementing a stocking program, Lorenzen et al. (2010) recommended managers should set goals used to

evaluate the potential for stocking, establish appropriate rearing protocols to ensure the genetic and physiological integrity of stocked fish, and define and implement management plans with metrics that can be used to evaluate program success/failure. The cooperative agreement between the USFWS, NCDMF, and NCWRC established the current striped bass stocking program in coastal North Carolina. This agreement should be revisited annually to provide adaptive management and reaffirm program goals and objectives, integrate evaluation results, and update future needs for stocking in each specific system. The contingency plan created for outlining the decision-making process for stocking surplus phase-I fish in the Albemarle Sound provides a template for stocking decisions in other North Carolina coastal river systems, though the process for each system will be unique based on local challenges.

Striped bass stocking practices have likely altered natural population genetics in North Carolina's coastal rivers. Patrick and Stellwag (2001) identified six distinct lineages among striped bass from the Roanoke, Tar-Pamlico, and Neuse rivers; the Tar-Pamlico and Roanoke rivers populations were similar but were significantly different from the Neuse River population. The researchers concluded that stocking practices could potentially affect the natural genetic distribution in these populations and suggested that broodstock should be taken from each specific population, especially when stocking the Neuse River. LeBlanc et al. (2020) showed that Cape Fear River striped bass were genetically similar to the Roanoke River population; and although North Carolina rivers, including the Tar-Pamlico and Neuse rivers, may have once supported genetically distinct populations, evidence suggests there is currently little genetic differentiation between populations (Reading 2020). While maintaining native population genetics is often a goal of restoration stocking programs (Lorenzen et al. 2010), introducing different genetic strains may be beneficial especially if native population genetics have been altered. Potential benefits, consequences, feasibility, and utility of alternative broodstock sources from systems outside coastal North Carolina systems should be thoroughly evaluated before introducing new genetic strains of striped bass.

The effectiveness of the striped bass stocking program in coastal North Carolina river systems has changed throughout the evaluation period of 1980–2019. Initial evaluations indicated limited contribution of stocked fish to commercial and recreational fisheries and little contribution to fish collected during spawning grounds surveys. Results of new evaluation methods indicated striped bass stocks in the Tar-Pamlico, Neuse, and Cape Fear rivers are maintained by phase-II stocking. Natural recruitment is low in these systems, and striped bass stocking has yet to produce self-sustaining populations. Stocking remains a necessary tool for persistence of striped bass populations in the Tar-Pamlico, Neuse, and Cape Fear river systems (Mathes et al. 2020). Stocking strategies should complement management measures that promote natural reproduction and recruitment to sustain the populations.

ADDITIONAL RESEARCH NEEDS

Parentage-based tagging analysis allows for precise investigation of multiple stocking treatments when using genetically distinct broodstock families. Various stocking treatments, including fry, phase-I, phase-II and different stocking locations, have been attempted in the Tar-Pamlico, Neuse, and Cape Fear rivers. Results from multiple treatments should be analyzed in the future to provide more precise guidance of future stocking decisions.

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APPENDIX A. Cooperative agreement between USFWS, NCDMF, and NCWRC that established the current version of the North Carolina Coastal Striped Bass Stocking Program, 1986.

AGREEMENT NO. 14-16-0004-87-904

COOPERATIVE AGREEMENT

for Anadromous Species Restoration in Historically Significant

Coastal River Basins

Between

U.S. Fish and Wildlife Service

and

Department of Natural Resources and Community Development

and

North Carolina Wildlife Resources Commission

I. Purpose

THIS AGREEMENT is made and entered into by and between the Fish and Wildlife Service, United States Department of the Interior--hereinafter referred to as the "Service," and the Department of Natural Resources and Community Development and the North Carolina Wildlife Resources Commission--hereinafter referred to as the "State," to establish by mutual agreement the restoration of self-sustaining stocks of anadromous species in North Carolina coastal river basins. For the purposes of this agreement, anadromous species shall include striped bass, American shad, hickory shad, blueback herring, and alewife. Principal emphasis shall be on the restoration of self-sustaining stocks of striped bass. The State's authority to engage in this agreement is set forth in Gen. Stat. of NC §§ 113-181 (a) and NC §§ 113-224. The Government of the United States has expressed a national interest in maintaining our fishery resources and has authorized the Service through the Fish and Wildlife Coordination Act (16 U.S.C. 661-666c, as amended) and other related legislation to provide assistance and cooperate with other Federal agencies and the States in the maintenance and development of fishery resources, and has further expressed a particular interest in restoration of anadromous species such as striped bass on the east coast as demonstrated by the Chafee amendment to the Anadromous Fish Conservation Act (16 U.S.C. 757g, as amended) and the Atlantic Striped Bass Conservation Act (P.L. 98-613). The Service, through its Fishery Resources Program's Statement of Responsibilities and Role document, seeks to foster strong and mutually supportive linkages with the States and other Federal agencies to restore and protect depleted nationally significant interjurisdictional fishery resources, with particular emphasis on Atlantic and Gulf anadromous striped bass as well as other anadromous and migratory intercoastal/estuarine fishes.

This agreement also complements an intrastate agreement between the North Carolina Wildlife Resources Commission and the Department of Natural Resources and Community Development concerning regulations and management of striped bass in Albemarle Sound and the Roanoke River.

II. Mutual Agreement

North Carolina waters are recognized as historically providing major contributions to the coastal stocks of anadromous fishes on the east coast.

River herring (blueback herring and alewife) stocks have declined drastically since the early 1970s, and recovery has been very slow, probably due to poor water quality in the Albemarle Sound spawning areas. Stocks of American shad are much below the levels of the 1960s and earlier throughout the south Atlantic coastal area. Striped bass stocks in North Carolina coastal waters have declined since the mid-1970s and are currently at extremely low levels. The Albemarle Sound stock, which has historically supported important recreational and commercial fisheries, is exceptionally depressed and has shown no ability to rebound.

The State and the Service entered into a pilot program in October 1979 to evaluate the potential for hatchery Phase II striped bass production and stocking to determine (1) effects on the commercial and recreational fisheries, and (2) contributions of stocked fish to spawning runs. Tagging returns, to date, have conclusively shown that these stocked fish have contributed to spawning runs and have recruited into the recreational and commercial fisheries.

The State has the responsibility to manage the fishery resources within its boundaries, including the mixed species fisheries which harvest anadromous fishes along with other species in coastal waters. The State has expressed a desire to continue to stock hatchery-reared striped bass fingerlings as a management tool in the restoration of this species, and the Service has the hatchery capability with which to assist the State in the production of striped bass.

It is the joint desire of the State and the Service to enter into a cooperative program to restore self-sustaining stocks of anadromous fishes in coastal North Carolina waters through a combination of fishery management techniques including stocking, regulations, and assessment.

Therefore, it is mutually agreed that:

1. The Service will produce Phase I and Phase II striped bass fingerlings based on restoration objectives established by the Service and the State for specific rivers in North Carolina.

2. The Service will provide facilities for holding and tagging striped bass, a hatchery truck to transport the fish to the release site(s), appropriate supervision in handling the fish to minimize mortality, and advisory personnel for the tagging project and related technical assistance efforts.

3. The State will provide personnel, tags and equipment for tagging the fish prior to release from hatcheries, tag rewards, and publicity on the cooperative program.

4. The State will evaluate survival and contribution of the hatchery fish to the population and spawning stocks and provide a report annually to the Service.

5. News releases on the cooperative restoration program initiated by the Service will receive prior approval from the State, and news releases initiated by the State will receive prior approval from the Service.

6. As an initial action, the cooperators will jointly develop a Striped Bass Restoration Plan for coastal North Carolina waters including goals, objectives, and milestones reflecting both the restoration as well as the maintenance of stocks. Restoration plans for other anadromous species such as American shad will be developed at a later date.

7. The Service will establish a Project Coordinator in North Carolina to provide liaison with the State for restoration purposes.

8. The principal signatory parties shall meet annually to review project progress and plan future activities.

9. A technical committee with representation from each signatory of this agreement shall meet quarterly and oversee the development of restoration plans and their implementation. Chairmanship of the technical committee will be rotated among the three cooperating agencies. Term of the chairman will be one year.

This agreement shall be contingent upon the availability of funds for the expenditures contemplated herein. The liability of the parties to this agreement, to each other, and to third persons shall be governed by applicable laws and regulations, now and hereafter in force.

The Equal Opportunity clause prescribed in 1-12.803-2 of the Federal Procurement Regulations is hereby incorporated into this agreement by reference and made a part thereof. No members of or delegate to Congress or Resident Commissioner shall be admitted to any share or part of this agreement, or to any benefit that may arise therefrom.

This agreement will become effective upon the date subscribed by the last signatory and shall continue in force from year to year until cancelled by any signatory party on 30 days' written notice to the other parties. The agreement and its addenda may be amended by mutual consent of all parties.

Date: 11/19/86

By: _____
for S. Thomas Rhodes, Secretary
North Carolina Department of Natural Resources and Community Development

Date 12/1/86

By: Charles R. Fullwood
Charles R. Fullwood, Jr.
Executive Director
North Carolina Wildlife Resources Commission

Date 12/12/86

By: _____
James W. Pulliam, Jr.
Regional Director
U.S. Fish and Wildlife Service
Region 4, Atlanta, GA