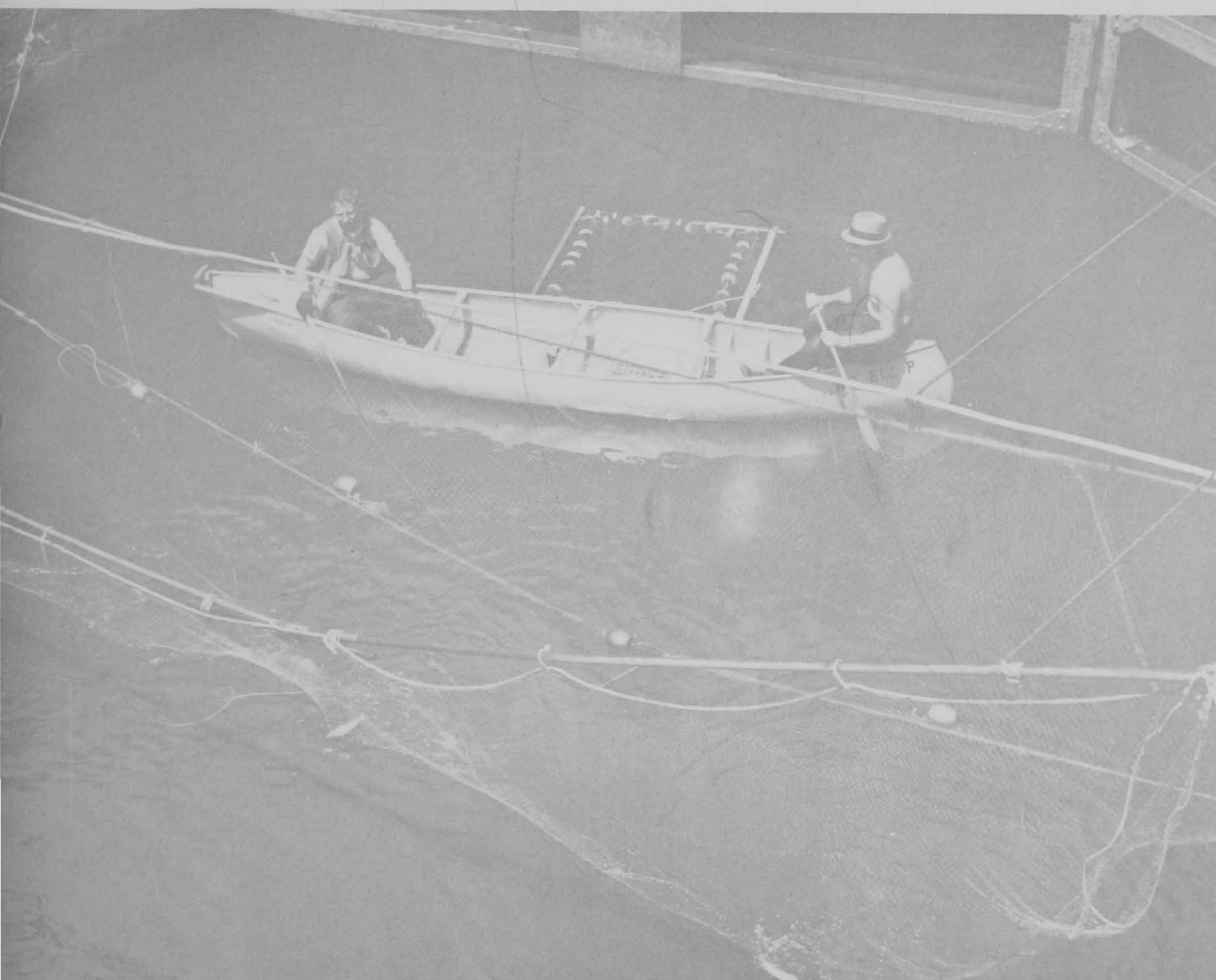
U.S. Fish Wildl. Serv. Circ.

Upstream Passage of Anadromous Fish hrough Navigation Locks and Use of the Stream for Spawning and Nursery Habitat Cape Fear River, N.C., 1962-66



UNITED STATES DEPARTMENT OF THE INTERIOR
U.S. FISH AND WILDLIFE SERVICE
BUREAU OF COMMERCIAL FISHERIES

Circular 352

Cover Photograph.—Brailing fish from haul seine into live car.

UNITED STATES DEPARTMENT OF THE INTERIOR
Walter J. Hickel, *Secretary*
Fred J. Russell, *Under Secretary*
Leslie L. Glasgow, *Assistant Secretary for Fish and Wildlife and Parks*
U.S. FISH AND WILDLIFE SERVICE
Charles H. Meacham, *Commissioner*
BUREAU OF COMMERCIAL FISHERIES
Philip M. Roedel, *Director*

Upstream Passage of Anadromous Fish Through Navigation Locks and Use of the Stream for Spawning and Nursery Habitat Cape Fear River, N.C., 1962-66

By

PAUL R. NICHOLS and DARRELL E. LOUDER

Circular No. 352

Washington, D.C.
October, 1970

CONTENTS

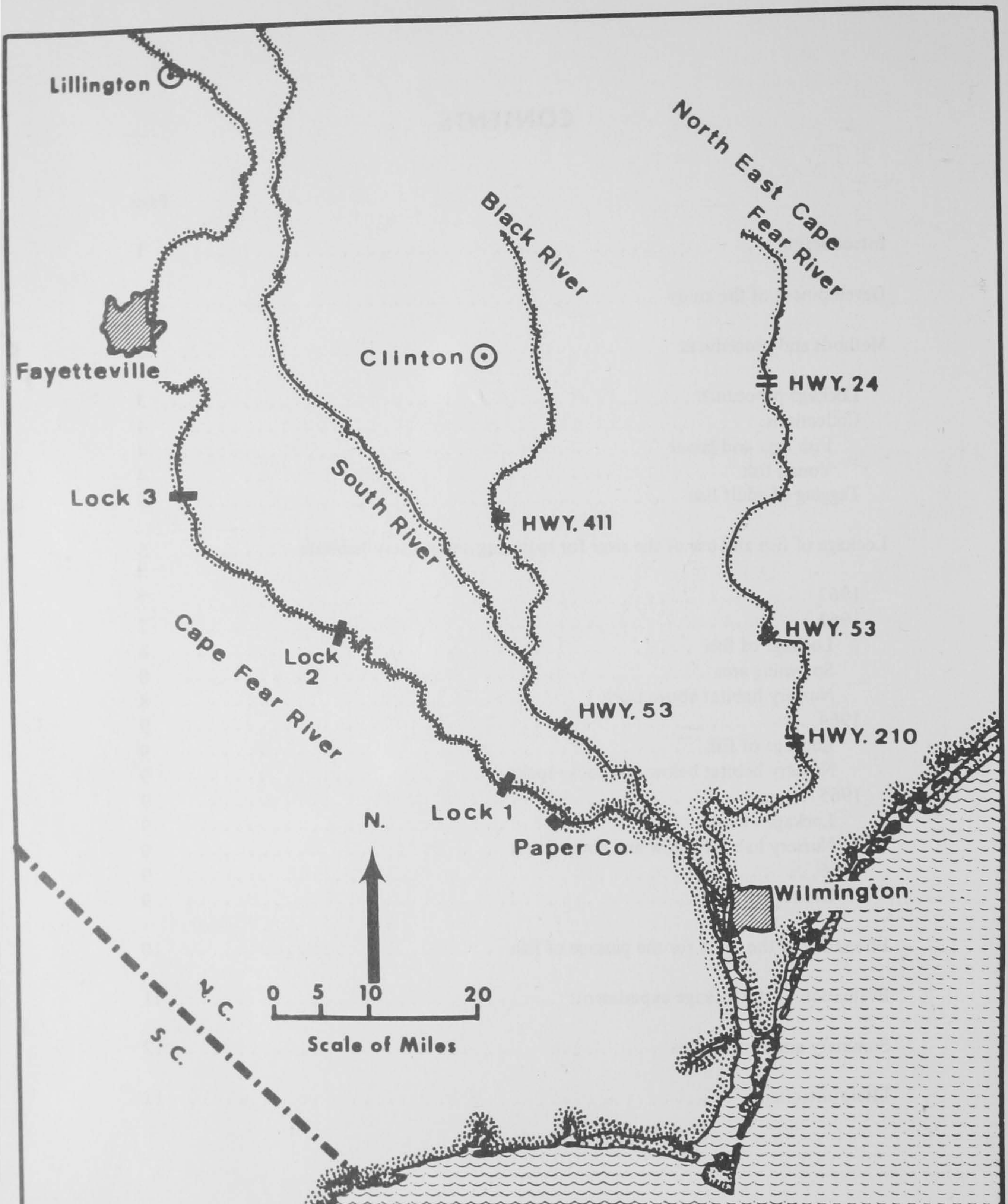


Figure 1.–Cape Fear River system, N. C.

Upstream Passage of Anadromous Fish Through Navigation Locks and Use of the Stream for Spawning and Nursery Habitat Cape Fear River, N.C., 1962-66

By

PAUL R. NICHOLS, Fishery Biologist

Bureau of Commercial Fisheries, Washington, D.C. 20240[1]

and

DARRELL E. LOUDER, Supervisor of Fisheries

North Carolina Wildlife Resources Commission

Raleigh, N.C. 27602

ABSTRACT

Studies were made of the feasibility of using navigation locks to pass anadromous fish upstream during their spawning migration in lieu of installing fishways. It was found that shad and other anadromous fish will use the locks to move upstream and locks may be used to restore, at least in part, spawning runs above barriers. Continued studies are needed to refine techniques for locking fish upstream.

INTRODUCTION

The Haw and Deep Rivers come together in Chatham County, N.C., and form the Cape Fear River which flows generally southeast for about 200 miles and empties into the Atlantic Ocean about 25 miles south of Wilmington, N.C. The principal tributaries are the North East Cape Fear River, which enters at Wilmington, and the Black River, which enters 15 miles upstream of Wilmington (fig. 1). The Cape Fear River drains an area of 9,000 square miles.

At the turn of the century, the Cape Fear River system was one of the most productive areas for American shad, *Alosa sapidissima* (Wilson), in North Carolina. In 1896, the estimated commercial catch in the river system was 317,620 pounds, of which the Cape Fear River produced 76 percent, the North East Cape Fear River 15 percent, and the Black River 9 percent (Stevenson, 1899). During that year, no manmade obstructions limited the upstream movement of fish in the Cape Fear River and shad ascended the river about 180 miles to Smiley Falls near Lillington, N.C. Cobb (1906) reported that in 1904 the commercial catch was 309,350 pounds, of which the Cape Fear River produced 77 percent, the Black River 14 percent, and the North East Cape Fear River 9 percent. In that year, shad ascended the Cape Fear River about 140 miles to near Fayetteville, N.C., and spawned from the mouth of the Black River to Fayetteville.

[1] Paul Nichols did this work while he was at the Bureau of Commercial Fisheries Biological Laboratory, Beaufort, N.C.

From 1915 to 1934, three navigation locks and dams were built on the Cape Fear River. Lock and Dam 1 (fig. 2) was constructed about 65 miles upstream from the river mouth in 1915. Lock and Dam 2, 34.5 miles upstream from Lock 1, was constructed in 1917; and Lock and Dam 3 (fig. 3) was completed in 1934, 23.5 miles upstream from Lock 2. The structures prevented fish from entering the river above, except during boat lockage and periods of extended high flow. Ladder-type fishways were provided at each dam, but anadromous fish are not known to have used them.

The locks and dams blocked anadromous fish from about 76 miles of spawning and nursery grounds and eliminated productive fishing areas, which in turn brought a decline in the commercial catch. The average annual commercial catch of shad from 1957 to 1965 was about 177,000 pounds, compared with more than 300,000 pounds in 1896 and 1904 (table 1). The decrease in yield of the Cape Fear River was responsible for the decline in the total catch.

DEVELOPMENT OF THE STUDY

In 1961, the U.S. Army Corps of Engineers asked the U.S. Fish and Wildlife Service to review the plans for repair of the fishway at Lock 1 during the rehabilitation of the dam. The Service, however, reported that the fishway was ineffective, so the Corps of Engineers did not repair the fishway.

The need for adequate fish passage facilities at all locks and dams on the river was recognized by both agencies, however, a new fishway at Lock 1, conforming to the criteria furnished by the Fish and Wildlife Service (estimated cost $100,000 or more), was far beyond the scope of the Corps project.

As an alternate procedure, the North Carolina Wildlife Resources Commission suggested that instead of installing new fishways, it might be possible to use the existing navigation locks to pass fish upstream during their spawning migration. In cooperation with the Corps of Engineers and the North Carolina Wildlife

Figure 2.–Lock and Dam 1, Cape Fear River, N. C.

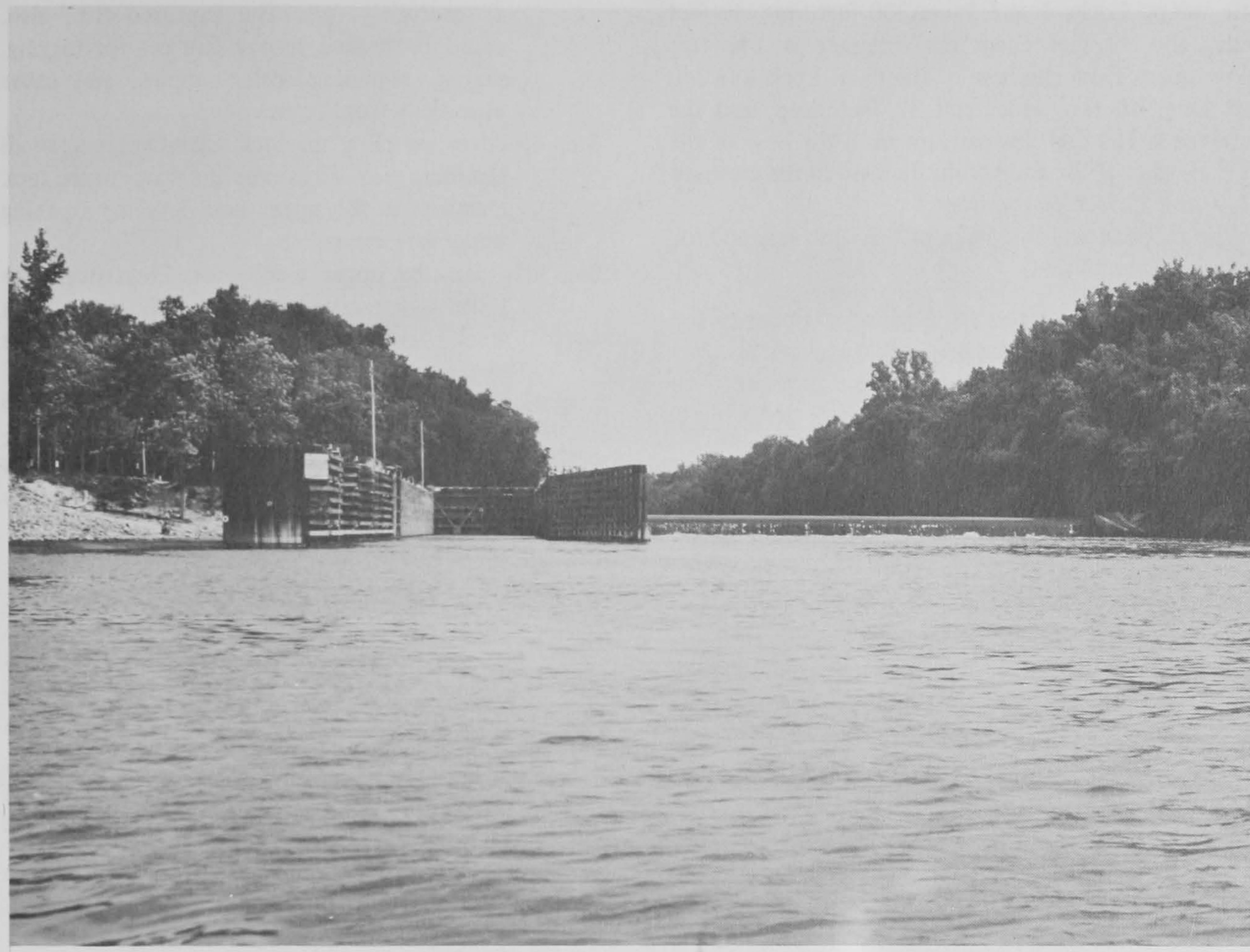


Figure 3.–Lock and Dam 3, Cape Fear River, N. C.

Table 1.–Estimated commercial catch of American shad, Cape Fear River system, N. C., for certain years 1896-1965

[Stevenson (1899), 1896; Cobb (1906), 1906; and unpublished data, Bureau of Commercial Fisheries Biological Laboratory, Beaufort, N.C., 1957-65]

Year	Area			Total
	Cape Fear River	North East Cape Fear River	Black River	
	Pounds	*Pounds*	*Pounds*	*Thousand pounds*
1896. . .	245,165	46,604	25,852	318
1906. . .	27,167	44,066	238,117	309
1957. . .	--	--	--	137
1958. . .	--	--	--	141
1959. . .	--	--	--	181
1960. . .	63,365	43,374	106,033	213
1961. . .	70,248	35,054	88,337	194
1962. . .	79,138	26,555	77,353	183
1963. . .	68,255	20,592	87,683	176
1964. . .	114,579	15,306	83,266	213
1965. . .	63,915	21,056	69,030	154

Resources Commission, BCF (Bureau of Commercial Fisheries) began field studies in the spring of 1962 and continued them through the spring of 1966. These studies were to determine the feasibility of using the locks instead of the proposed fishways. We also made studies to observe the use of the river by shad for spawning and nursery habitat. Our findings are reported here.

METHODS AND PROCEDURES

Lockage Procedure

The locks and dams on the Cape Fear River are reinforced concrete structures, with electrically operated steel gates in the locks. Each pair of lock gates has eight manually operated valves that control the water level in the lock chamber. During normal river flow, a flow through the lock chamber of 0 to 6 f.p.s. (feet per second) can be produced by opening and closing the gate valves. Locks 1 and 2 are 200 feet long, 40 feet wide, and 32 feet deep; the entrance is 140 feet downstream from the base of the dam. Lock 3 is 240 feet long, 40 feet wide, and 32 feet deep, and the entrance is 160 feet downstream from the base of the dam. Heights of the dams from the base to the crest are 12, 9, and 12 feet, respectively.

The procedures for lockage of fish upstream and for sampling were:

Step 1.–Lower the water in the lock chamber to the lower pool level. Open lower lock gates. Then open the upper gate valves sufficiently to create an attraction flow of 2 to 3 f.p.s. through the lock chamber (fig. 4).

Step 2.–Leave the lock set in this position for about 1 hour to allow fish to enter the lock chamber from the river below the dam.

Step 3.–Close the upper lock gate valves and lower lock gates to trap fish in the lock chamber (fig. 5). With the lock in this position, the fish in the lock chamber could be sampled with modified haul seine (18 feet by 40 feet and 1-inch mesh, with rigid float and lead lines) to estimate the number and kinds of fish trapped. A stop net had to be placed near the upper lock gate during sampling to prevent fish from moving into the gate "V's" and escaping. The haul seine was pulled through the lock chamber to the stop net and lifted (fig. 6). After fish were dumped over the stop net, the fish in the lock chamber could be resampled as many times as necessary to determine the efficiency of the sampling gear in capturing fish. The captured fish, also, could be brailed into a live car for tagging, sexing, obtaining scale samples, and other purposes (front cover).

Step 4.–After sampling the lock chamber, remove all sampling gear. Then raise the water in the lock chamber to the upper pool level by opening upper gate valves.

Step 5.–Open the upper lock gates. Then open the lower lock gate valves sufficiently to create an attraction flow of about 1-2 f.p.s. through the lock chamber (fig. 7).

Step 6.–Leave the lock in this position for about 30 minutes to allow the trapped fish to move out of the lock chamber and upstream–usually, all the fish will move out of the lock chamber within 15 minutes.

Step 7.–Close the lower lock gate valves and the upper lock gates. Then lower the water in the lock chamber to the lower pool level. With the lock in this position, the lock chamber could be sampled as in Step 3 to determine the time necessary for trapped fish to move upstream from the lock chamber.

Step 8.–Repeat the cycle.

Figure 4.–Navigation lock in position to attract fish from the river below the dam.

During the lockage of fish, the Corps did not permit the water level in the upper pool to be reduced below elevation 15.5 feet because of the adverse effect on commercial navigation. Also, no lockages were made for the passage of fish on Saturdays, Sundays, and holidays because of heavy recreational boat traffic. Weekday lockages for fish passage were made between 8:00 a.m. and 4:30 p.m.

Collections

To determine the success of spawning of the shad passed and locate spawning and nursery grounds, collections were made of egg, larval, and juvenile stages. Also, adult shad were marked and recaptured in the locks to observe the efficiency of the locks for passing fish.

Fish eggs and larvae.–Egg and larval stages were collected with 1-meter (39-inch) plankton nets anchored on the river bottom in moderate current. The nets were fished at selected stations for varying periods during daylight and at night.

Young fish.–Young clupeid fishes were collected by surface trawl. The trawl (1/2-inch mesh nylon netting

Figure 5.–Sampling the lock chamber with modified haul seine to collect trapped fish.

with 4- by 12-foot opening, 15 feet long and tapered to form a cod end) was pulled by two 18-horsepower outboard motors (fig. 8). Prior to making a collection, we released in the collection area 5 percent emulsifiable rotenone to make it easy to collect the fish. Rotenone was applied to areas of about 1,000 square feet. Young fish were measured to the nearest mm. fork length (fig. 9).

Tagging of Adult Fish

Adult shad were marked with streamer tags consisting of a red plastic disk, with an identification number on one side and return address and reward notice on the other, to which a loop of nylon twine was tied. The nylon loop was fastened under the origin of the dorsal fin to allow the disk to trail immediately behind the fin.

LOCKAGE OF FISH AND USE OF THE RIVER FOR SPAWNING AND NURSERY HABITATS

We operated the locks for the passage of fish when anadromous species were migrating upstream (water levels permitting) each spring in 1962-66. Species passed in addition to American shad were alewife, *Alosa pseudoharengus*; blueback herring, *Alosa aestivalis*; and striped bass, *Roccus saxatilis*. The lockage experiments began at Lock 1 in 1962 and included Locks 2 and 3 by 1966 (table 2). Also, during the 1963-65 studies, observations were made on how clupeid fishes used the river for spawning and as nursery grounds.

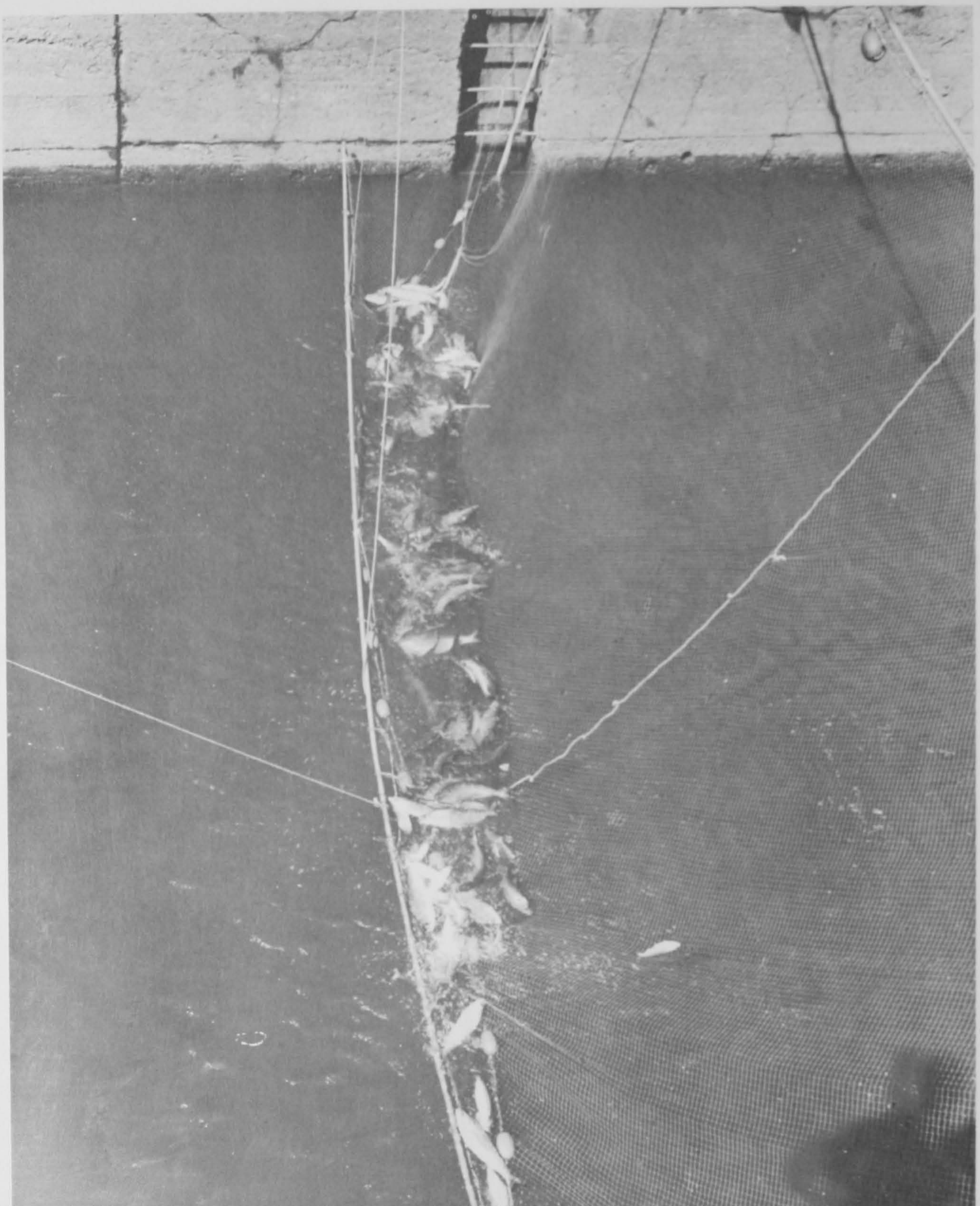


Figure 6.–Lifting haul seine at stop net after sampling the lock chamber.

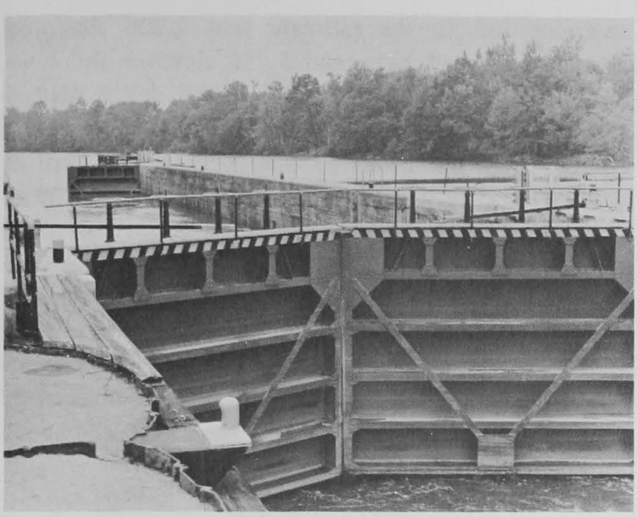


Figure 7.–Navigation lock ready for release of fish from the lock chamber to the river above the dam.

1962

The 1962 work was confined to experimental lockage. Lock 1 was operated 108 hours for the passage of fish from April 2 to June 4. From the number of fish netted in the lock chamber during 27 lockages that required a total of 48 hours, we estimated that 1,030 shad, 2 immature striped bass, and 1,140 alewives and blueback herring passed. During lockages, the water temperature ranged from 13.3° to 26.7° C., and water elevations in the upper and lower pools varied from 15.5 to 20.8 feet and 5.5 to 20.3 feet, respectively.

1963

During 1963, Lock 1 was operated for experimental fish passage, and the stream above the lock was sampled for eggs and young fish.

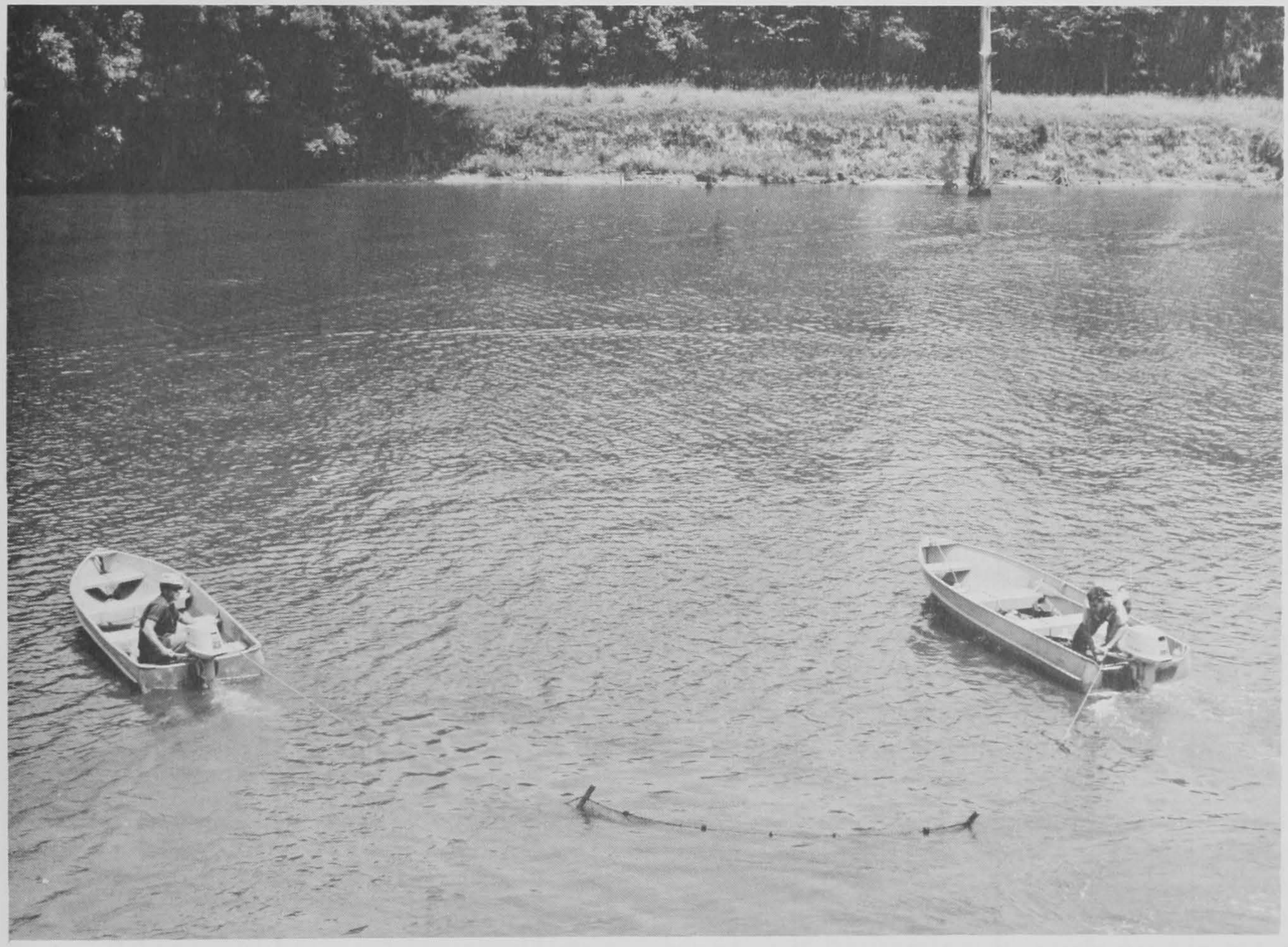


Figure 8.–Trawling for young clupeid fishes.

Figure 9.–Emptying captured young fish from cod end of surface trawl.

Lockage of fish.–We began periodic sampling of the upstream movement of fish through Lock 1 on April 9 and continued to June 6. During this interval, we observed 13 lockages requiring a total of 21 hours. The Corps of Engineers operated the lock for fish passage for an additional 145 hours. The number of fish netted in the lock chamber during periodic sampling led to the estimate that 2,208 shad, 24 immature striped bass, and 5,458 alewives and blueback herring passed. Of the fish passed, 1,725 shad, 4 striped bass, and all alewives and blueback herring passed in 54-1/2 hours of operation during April at water temperatures of 15.5° to 20.0° C.; 396 shad passed in 91-1/2 hours of operation in May at water temperatures of 18.3° to 22.2° C.; and 60 shad and 20 striped bass were passed in 20 hours of operation in June at water temperatures of 22.2° to 23.9° C. The number of shad passed per hour increased about 40 percent over the previous season, and the number of alewives and blueback herring per hour increased about 150 percent (table 2).

Spawning area.–We sampled the Cape Fear River above Lock 1 with 1-meter plankton nets from May 21 to 23, and found that shad and blueback herring spawned throughout the 34.5-mile area to Lock 2. Although most eggs of both species were collected within 500 yards of Lock 2, clupeid-type larvae were found throughout the river between the two locks.

Nursery habitat above Lock 1.–In mid-August, we collected young shad and blueback herring, about 4 to 6 cm. long throughout the river between Locks 1 and 2. Continued weekly sampling after mid-August indicated that the young fish remained distributed throughout the area until mid-November, at which time they moved downstream from above Lock 1 during an increase in water level from 7.6 to 16.7 feet, and a drop in water temperature from about 16° to 11° C. At this time the young fish 9 to 13 cm. had a mean fork length of 11 cm.

Table 2.–Number and kinds of fishes passed by navigation locks, Cape Fear River, N.C., 1962-66

Year	Lock	Time operated	Water temperature	Fish passed per hour			Total fish passed		
				American shad	Alewives and blueback herring	Striped bass	American shad	Alewives and blueback herring	Striped bass[1]
	Number	*Hours*	*°C.*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
1962. . .	1	108	13.3-26.7	9.5	10.6	0.02	1,030	1,140	2
1963. . .	1	166	15.5-23.9	13.3	32.9	0.1	2,208	5,458	24
1964. . .	1	95	12.8-20.5	10.0	44.0		950	4,180	--
	2	9	20.5-22.5	18.2	5.0	0.3	164	45	3
1965. . .	1	99	17.8-20.0	15.0	159.8	4.0	1,485	15,818	400
	2	17	17.9-18.8	5.4	42.6	0.4	92	724	6
1966. . .	1	111	13.9-22.2	36.9	182.8	1.8	4,097	20,296	200
	2	145	14.4-22.2	5.9	81.1	0.1	854	11,762	19
	3	3	19.2-19.2	16.7	116.6		50	350	--

[1] All fish passed were immature.

1964

The 1964 work was confined to experimental lockage at Locks 1 and 2, and collection of young fish.

Lockage of fish.—Periodic sampling of fish movement through Lock 1 began March 17 and continued through May 12. During this interval, we observed 18 lockages requiring 33 hours. The Corps of Engineers operated the lock for fish passage an additional 62 hours. From the number of fish netted in the lock chamber during periodic sampling, we estimate that 950 shad and 4,180 alewives and blueback herring passed. About 86 percent of the shad passed from April 7 to May 7 when water temperatures were 12.8° to 20.6° C., and 75 percent of the alewives and blueback herring passed from March 17 to April 7 when water temperatures were 12.2° to 18.9° C. The number of shad passed per hour decreased 21 percent below the previous season, and the number of alewives and blueback herring passed per hour increased 91 percent (table 2).

Lock 2, 34.5 miles upstream from Lock 1, was operated for passage of fish on May 14 and 22. On May 14, one lockage was made requiring 4-1/2 hours. During this time, 87 shad, 2 immature striped bass, and 45 blueback herring passed. On May 22, another lockage required 4-1/2 hours, and 77 shad and 1 striped bass passed.

Nursery habitat below and above locks.—We sampled the Cape Fear River from 7 miles below Wilmington to Lock 3 to determine whether clupeid fish used the areas as a nursery. Young shad and blueback herring were collected from 4 miles below Wilmington to Lock 3 during July to October, and alewives were collected from 3 miles below Wilmington to 4 miles above in August and September (table 3).

Table 3.—Number of young clupeid fishes collected from Wilmington to Lock 3, Cape Fear River, N.C., July-November 1964

Month	Water temperature	Samples taken	Fish collected		
			American shad	Blueback herring	Alewives
	°C.	*Number*	*Number*	*Number*	*Number*
July	25.5-26.7	8	52	541	0
August	25.0-26.7	12	47	388	6
September	18.9-26.0	13	35	191	7
October	15.0-22.8	12	32	0	0
November	13.9-15.5	7	3	0	0

1965

The 1965 work included experimental lockage of fish and sampling to locate nursery areas.

Lockage of fish.—Periodic sampling of fish movement through Lock 1 began April 17 and continued through May 6. During this interval, we observed 13 lockages requiring 22 hours. The Corps of Engineers operated the lock for fish passage for an additional 77 hours. Based on the number of fish netted in the lock chamber during periodic sampling, we estimate that 1,458 shad, 400 immature striped bass, and 15,818 alewives and blueback herring passed. During lockage for fish passage, water temperatures were 17.8° to 20.0° C., and the upper pool level varied from 16.1 to 18.1 feet. The number of shad passed per hour increased 50 percent over the previous season, and the number of alewives and blueback herring passed per hour increased about 250 percent (table 2).

Lock 2 was operated for the passage of fish from April 21 to May 26. During this interval, we made seven lockages requiring 17 hours. A total of 92 shad, 6 immature striped bass, and 724 alewives and blueback herring passed.

Nursery habitat below and above locks.—We continued studies on the Cape Fear River as a nursery for clupeid fish and compared the growths of young shad hatched above Lock 1 with the shad hatched in the Black and North East Cape Fear Rivers.

In mid-August, we sampled these areas for water quality and distribution of young shad, alewives, and blueback herring (table 4). Water quality differed little in the areas. Distribution of the young fish was about the same as in previous years. The growth of young shad was excellent in all areas, but growth of those hatched above Lock 1 was greater than in the Black or the North East Cape Fear Rivers.

From October 2 to 14, we observed that young shad and blueback herring moved downstream from above Lock 1 and out of the tributaries, presumably to sea. Water flow increased sharply during this interval: Water level in the Upper pool at Lock 1 increased from 17.5 to 25.0 feet, and water temperatures dropped from 22.8° to 15.6° C.

1966

Lockage of fish.—From April 6 to May 24, we continued experimental lockage of anadromous fish upstream during their spawning migration. From the number of fish netted in the lock chamber during periodic sampling, we estimate that 4,097 shad, 200

Table 4.—Size of clupeid fishes by area in mid-August 1965, Cape Fear River System, N.C.

River and species	Distribution	Fish collected	Fork length[1]		Water properties		
			Range	Average	Temperature	Dissolved oxygen	pH
		No.	*Mm.*	*Mm.*	°*C.*	*P.P.m.*	
Cape Fear							
Shad.	From river mile 3 (10 miles from river mouth) to river mile 93 (Lock 3).	16	53-88	65.6	25.0-26.6	3.8-5.8	6.6-6.7
Alewives	From river mile 3 (32.5 miles below Lock 1) to river mile 9 (5 miles above Wilmington).	2	43-47	45.0	25.0-26.6	3.8-5.8	6.6-6.7
Blueback herring.	From river mile 3 (10 miles from river mouth) to river mile 93 (Lock 3).	157	34-68	49.9	25.0-26.6	3.8-5.8	6.6-6.7
Black							
Shad	From river mouth to Highway 411 bridge, about 35 miles.	8	33-78	52.4	25.5-27.8	2.8-7.0	5.0-6.5
Blueback herring.	. . . . do.	66	41-63	49.5	25.5-27.8	2.8-7.0	5.0-6.5
North East Cape Fear							
Shad	From 10 miles above river mouth to Highway 24 bridge, about 57 miles.	11	38-83	53.3	25.5-28.9	3.0-6.4	6.2-6.6
Alewives	From river mouth to Sones Ferry, about 25 miles.	3	43-64	51.0	25.5-28.9	3.0-6.4	6.2-6.6
Blueback herring.	From river mouth to 5 miles above Highway 53 bridge, about 45 miles.	69	34-55	49.8	25.5-28.9	3.0-6.4	6.2-6.6

[1] Fork length of young shad taken in the Cape Fear River are measurements of fish collected above Lock 1.

immature striped bass, and 2,296 alewife and blueback herring passed at Lock 1 in the 111 hours it operated. Water temperatures were 13.9° to 22.2° C., and water levels in the upper pool were 16.0 to 18.2 feet. The number of shad passed per hour increased about 176 percent over the previous season, and the number of alewives and blueback herring passed per hour increased 28 percent.

At Lock 2 an estimated 854 shad, 19 immature striped bass, and 11,762 alewives and blueback herring passed during the 145 hours the lock was operated for fish passage. Water temperatures were 14.4° to 22.2° C., and water levels ranged from 25.0 to 27.8 feet in the upper pool. The numbers of shad and striped bass passed per hour were about the same as in the previous season, and the number of alewives and blueback herring increased about 90 percent.

At Lock 3, 58 miles upstream from Lock 1, 50 shad and 350 alewives and blueback herring were passed in the 3 hours the lock was operated for fish passage.

EFFICIENCY OF THE LOCKS FOR THE PASSAGE OF FISH

During the lockage experiments, certain difficulties adversely affected the efficiency of the locks for upstream passage of fish: (1) The locks could be operated for fish passage only when boat traffic was light—operations ceased temporarily when the locks were used for navigation; (2) the downstream entrance of the lock chambers is located so as not to be attractive to fish—most fish are attracted to the base of the dam about 140 feet upstream from the lock openings; and (3) water was insufficient to operate Lock 1 for fish passage during much of the scheduled period.

During lockages in 1965, we tagged shad in an attempt to determine the efficiency of Lock 1 for this passage. We tagged 80 fish below Lock 1 and 122 in the lock chamber. Of the shad tagged below the lock, 36 were recaptured by the commercial fishery in the vicinity of release, 2 were recaptured during periodic sampling of the fish moving through Lock 1, and 1 was recaptured in Lock 2. These recaptures were made from 1 to 28 days after release. Of the 122 shad tagged in Lock 1 (an estimated 8.2 percent of the total number of shad passed that year), 9 were recaptured in Lock 2 (9.7 percent of the total number of tagged fish released in Lock 1) within 2 to 23 days after release. The tagging indicated that at least a portion of the fish passed at Lock 1 continued to move upstream beyond Lock 2. We made no conclusions, however, concerning the efficiency of Lock 1 because of the small number of fish tagged and recaptured. Lock 2 was operated too few hours for us to attach any significance to the number of shad passed.

EVALUATION OF THE LOCKAGE EXPERIMENTS

It appears that anadromous fish will use navigation locks to pass upstream and that locks may be used to restore, at least in part, spawning runs above such barriers where stream conditions are otherwise suitable. During the five seasons Lock 1 was operated for passage of fish, an estimated 17 shad and 81 alewives and blueback herring passed per hour. Most of the fish called alewives and blueback herring were the latter species, but exact separation of the two was not attempted. The number of fish passed per hour increased from about 10 shad and 11 alewives and blueback herring in 1962 to 37 shad and 183 alewives and blueback herring in 1966; the greatest increases were in the fourth and fifth seasons (table 2). The increase was probably due to refinement of our techniques and possible "homing" tendency of the species. Bell and Holmes (1962), Nichols (1961), and Talbot and Sykes (1958) reported that each stream, possibly each spawning area, supports a self-perpetuating population (race) of shad that return to spawn in the same area. The stream conditions above Lock 1 are evidently suitable for the survival and development of young shad, alewives, and blueback herring, since occasionally during sampling as many as 37 shad and 65 alewives and blueback herring were taken per 10-minute trawl tow. Movement of striped bass through the locks was probably a feeding migration.

Periodic sampling of the locks indicated that runs of alewives and blueback herring were earlier than the runs of shad. About 75 percent of the alewives and blueback herring passed upstream at Lock 1 from mid-March to mid-April when water temperatures were 12.2° to 18.5° C., whereas 30 percent of the shad were passed between April 10 and May 10 when the water temperatures were 13.5° to 20.5° C.

We had some concern about passage of anadromous fish over the dams during periods of high flow in early spring. Before the start of the lockage experiments at Lock 1 in the spring of 1966, Lock 2 was operated for the purpose of passage of fish on April 5 and 6. On April 5, when one lockage requiring 2-1/2 hours was made, 4 male shad and 90 alewives and blueback herring passed. On April 6, one lockage requiring 2 hours passed 4 suckers and 2 gizzard shad. The experiment showed that a few anadromous fish do pass over the dam during high flow or through the lock chamber during boat passage.

Each autumn, young shad move downstream from above Lock 1 at the time of a freshet in the river and a drop in water temperature. These changes probably stimulated the young fish to move. Also, observations showed that Lock and Dam 1 did not deter the young fish from moving downstream.

In addition to anadromous fish that passed upstream through the locks, resident species also used the locks. Those taken during periodic sampling of the lock chambers included: longnose gar, *Lepisosteus osseus* (Linnaeus); gizzard shad, *Dorosoma cepedium* (LeSueur); redhorse sucker, *Moxostoma* spp.; bluegill, *Lepomis macrochirus* Rafinesque; redbreast sunfish, *L. auritus* (Linnaeus); black crappie, *Pomoxis nigromaculatus* LeSueur; bowfin, *Amia calva* Linnaeus; carp, *Cyprinus carpio* Linnaeus; white catfish, *Ictalurus catus* (Linnaeus); channel catfish, *I. punctalus* (Fafinesque); brown bullhead, *I. nebulosus* (LeSueur); and black bullhead, *I. melas* (Rafinesque). With the exception of carp, longnose gar, and white catfish, none of the resident species appeared in large numbers at any time in the lock chamber. We made no estimate of the number in the samples.

As a result of locking shad upstream, a sport fishery developed for the species above Lock 1. The sport catch increased from 12 fish in 1963 to about 560 in 1966. Before the lockage experiment, no shad had been reported taken on hook and line in the Cape Fear River.

Probably the most important parts of any fishway passage facility are the attraction water and the fish entrance (Clay, 1961). As previously mentioned, spillage over the dams on the Cape Fear River possibly attracts most fish to the base of the obstruction so that they bypass the lock chamber entrance. If the locks could be modified so that the attraction water enters the river from the lock chamber immediately below the dam, it would be simpler to lead the fish into the lock chamber. Or, if it were feasible to control the spillage over the dam by flashboards or some other means and direct the river flow through the lock chamber, it would be easy to lead most of the migrating fish into the lock chamber. Also, if we knew what velocities in lock chambers are optimum to encourage the migrating fish to keep moving in the required upstream direction, we might be able to increase the efficiency of the locks for the upstream passage of fish regardless of whether the attraction water entered the river at the present location or at the base of the dam.

The locks provide a much needed outdoor laboratory for the study of fish passage, and the findings can be applied to the planning of water developments elsewhere. Continued studies are needed, however, to refine techniques for locking fish upstream and to modify the structures, to assure maximum efficiency of passage for fish.

SUMMARY AND CONCLUSIONS

Cooperative studies were made each spring in 1962-66 at navigation locks to determine the feasibility of locking anadromous fish upstream during their spawning migration in lieu of installing fishways on the Cape Fear River, N.C. Lock 1, about 65 miles upstream from the river mouth, was operated 579 hours for the passage of fish and an estimated 9,770 shad, 626 immature striped bass, and 46,892 alewives and blueback herring passed. Lock 2, 34.5 miles upstream from Lock 1, was operated 171 hours and an estimated 1,110 shad, 28 immature striped bass, and 12,531 alewives and blueback herring passed. At lock 3, 23.5 miles upstream from Lock 2, 50 shad and 350 alewives and blueback herring passed in 3 hours.

Most of the fish called alewives and blueback herring were the latter, but exact separation of the two species was not attempted. Resident species also used the locks, but no estimate was made of the number passed.

Certain difficulties adversely affected the efficiency of the locks for the upstream passage of fish: (1) the locks could be operated for fish passage only when boat traffic was light; (2) the downstream entrance of the lock chambers is poorly located to attract fish; and (3) water was insufficient to operate Lock 1 during much of the scheduled period. Using tagged shad we attempted to determine the efficiency of the locks for the upstream passage of shad but reached no conclusions.

Collection of young fish indicated that stream conditions above Lock 1 are suitable for the survival and development of young shad and other clupeid fish. Also, we showed that Lock and Dam 1 were not deterrents to the downstream movement of the fish.

We concluded that: (1) anadromous fish will use navigation locks to pass upstream, and hence locks may be used to restore, at least in part, spawning runs above barriers; (2) continued studies are needed to refine techniques for locking fish upstream and to develop modifications in the locks to assure maximum efficiency; and (3) the Cape Fear River locks provide a needed outdoor laboratory for the study of fish passage, and the findings can be applied in the planning of fish passage elsewhere.

LITERATURE CITED

BELL, MILO C., and HARLAN B. HOLMES.
1962. Engineering and biological study of proposed fish-passage at dams on Susquehanna River, Pennsylvania. Pennsylvania Fish Commission, 126 pp.

CLAY, C. H.
1961. Design of fishways and other fish facilities. Department Fish. Can., Ottawa, No. Fs 31-1961/1, 301 pp.

COBB, JOHN N.
1906. Investigations relative to the shad fisheries of North Carolina. N. C. Geol. Surv. Econ. Paper 12, 39 pp.

NICHOLS, PAUL R.
1961. Homing tendency of American shad, *Alosa sapidissima,* in the York River, Virginia. Chesapeake Sci. 1(3-4); 200-201.

STEVENSON, CHARLES H.
1899. The shad fisheries of the Atlantic Coast of the United States. Rep. U. S. Comm. Fish., Pt. 24, 1898: 101-269.

TALBOT, GERALD B., and JAMES E. SYKES.
1958. Atlantic Coast migrations of American shad. U.S. Fish Wild. Serv., Fish. Bull. 58: 473-490.

MS. # 1818