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TOLERANCE OF STRIPED BASS AND AMERICAN SHAD TO CHANGES OF TEMPERATURE AND SALINITY

SPECIAL SCIENTIFIC REPORT—FISHERIES No. 388

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

United States Department of the Interior, Stewart L. Udall, Secretary
Fish and Wildlife Service, Clarence F. Pautzke, Commissioner
Bureau of Commercial Fisheries, Donald L. McKernan, Director

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United States Fish and Wildlife Service
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Washington, D. C.
August 1961

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ABSTRACT

Experiments were conducted to determine the effect of abrupt temperature and salinity changes on adult and juvenile striped bass *(Roccus saxatilis)* and American shad *(Alosa sapidissima)*. Transfers were made at specific temperature and salinity differences over the range 45° to 80° F. and 0 to 35 ‰. Adult and juvenile striped bass were tolerant to transfers between salt and fresh water at most temperature differences. Adult shad were tolerant to transfers from fresh to salt water and displayed some tolerance to transfers from salt to fresh water at limited temperature differences. Juvenile shad survived salinity and temperature differences from salt to fresh water, but did not survive these differences from fresh to salt water.

INTRODUCTION

Earth-fill barriers have been proposed for several streams tributary to San Francisco Bay to prevent salt-water intrusion into these rivers which would render them unfit for most industrial, agricultural, and domestic uses. The barriers would cause sharp temperature and salinity differences between the waters divided by the structures. The design of fish-passing facilities for migrating striped bass *(Roccus saxatilis)* and American shad *(Alosa sapidissima)* found in this area would in part depend upon the tolerance of these fish to such environmental differences. During 1959 and 1960, studies were conducted at the Bureau of Commercial Fisheries Biological Laboratory, Beaufort, N. C., to determine what effect transfers between salt and fresh water, of different temperatures, would have on adult and juvenile striped bass and shad. The majority of adult transfers were conducted between "cool-salt" and "warm-fresh" water to conform with the temperature pattern relevant to the San Francisco Bay system. Juveniles of these species normally do not migrate from salt to fresh water. In this study, however, juveniles were subjected to this transfer, since the placement of proposed barriers and the migratory habits of these fish in the San Francisco Bay system suggest that movements of this nature could occur.

LIFE HISTORY

Striped bass are anadromous members of the sea bass family (Serranidae). Their natural distribution includes the Atlantic coast from the St. Lawrence River, Canada, to the St. Johns River, Fla., and tributaries of the Gulf of Mexico from western Florida to Louisiana. This fish was introduced on the Pacific coast in 1879, and it now occurs from Washington to southern California. Striped bass of both coasts spawn in fresh or virtually fresh water of rivers in the spring and early summer. Most females mature in 4 to 6

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[1] This investigation was requested and financed by the U. S. Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Portland, Oregon.

Note:--Marlin E. Tagatz, Fishery Research Biologist, U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory, Beaufort, North Carolina.

years, and most males mature at 2 years (Raney, 1952). Approximately 65,000 eggs are produced by a 4-year-old female, and 4,500,000 eggs are produced by a 13- or 14-year-old fish (Raney, 1958). Time and pattern of movements of young and adult vary with different populations.

American shad are the largest members of the herring family (Clupeidae) in the United States. Their range extends from the St. Lawrence River, Canada, to the St. Johns River, Fla. Shad were successfully introduced on the Pacific coast in 1871, and their range now extends from Alaska to southern California. They are anadromous, and spawning migrations on the Atlantic coast begin as early as November in the south and are progressively later northward. Spawning migrations on the Pacific coast occur during spring and summer. The number of eggs produced per female each season averages about 250,000 (Talbot and Sykes, 1958). The young spend the first summer of life in the rivers (5 to 6 months) and then migrate to sea. In 3 to 6 years they reach sexual maturity and return to their native rivers to spawn. On the Atlantic coast, shad native to northern rivers return to spawn in successive years. Fish native to rivers south of Chesapeake Bay, and particularly south of North Carolina, die after spawning (Talbot and Sykes, 1958).

TOLERANCE OF ADULTS

Materials and Methods

Adult fish were obtained during February, March, and April from commercial pound-net fishermen. Striped bass were obtained in Albemarle Sound near Mackeys, N. C. (salinity less than 1 ‰, temperature 51° to 69° F.), and shad were obtained at the mouth of the Neuse River near Cedar Island, N. C. (salinity 10 to 17 ‰, temperature 45° to 58° F.). Striped bass ranged from 12 to 24 inches fork length, and shad ranged from 15 to 19 inches fork length. The fish were transported to the laboratory by means of a 200-gallon wooden tank mounted on a truck (Sykes, 1950). At the laboratory, fish were dipped for 20 seconds into a malachite green solution (1:15,000) to prevent fungus infection and placed in holding ponds.

Three rectangular concrete pools and two ponds were used in these studies. The pools were 6 feet by 16 feet by $2\frac{1}{2}$ feet deep and were supplied with salt and fresh water. The pH of the pools during the tests was 7.4 to 7.6, and dissolved oxygen remained above 6.0 p.p.m. The ponds were 30 feet by 40 feet, and their depth varied from 1 to 4 feet. Each pond was divided into two sections by a hardware cloth fence, one section for holding stock fish and the other for experimental use. One pond was continuously supplied with sea water (salinity range 23 to 36 ‰) and the other with fresh water. The pH of the ponds ranged from 7.3 to 7.8, dissolved oxygen ranged from 9.5 to 10.5 p.p.m., and temperature ranged from 44° to 86° F.

Abrupt transfers of adult striped bass and shad were made from salt to fresh water and from fresh to salt water at specific temperatures and salinities over the range 45° to 80° F. and 0 to 35 ‰. Temperature could be regulated only in the pools as it was not feasible to consider temperature control for the large ponds. Desired temperatures were obtained by heating with Calrod units or cooling with ice. When ice was used in salt water, sea salt was added as necessary, to maintain proper salinity.

Test transfers were made from the small rectangular pools (initial environment) to the large ponds (receiving environment). The ponds were used for the receiving environment as mortalities occurred among the larger fish after 4 or 5 days' confinement in the rectangular pools, apparently because of crowding. Experimental fish were marked so that each specimen could be identified.

Tests were carried out by placing 10 fish (if available) of random size in each of the rectangular pools. One pool served as a control. In tests where initial environment was salt water, fish were taken from the salt-water holding pond. In tests in which initial environment was fresh water, fish were taken from the fresh-water holding pond. All pools contained water at the same salinity and temperature as the holding ponds from which the fish were taken. For a 24-hour period the fish were acclimated to initial environment by gradually changing the temperature and salinity of the water in the pools over a 6- to 8-hour period and maintaining these conditions for an additional 16 to 18 hours. The fish were then transferred into either the fresh- or salt-water pond (receiving environment) at the prevailing water temperatures. The fish remained in the experimental ponds for 10 days before termination of a test to observe any delayed mortality. Mortality was recorded on the day of occurrence.

Controls conducted with the striped bass experiments involved transfers in which the change in salinity duplicated that of the accompanying test, but with no change in temperature. Shad controls involved transfer of fish with no change in temperature or salinity since preliminary tests showed this fish could not tolerate transfers from salt to fresh water without mortality.

Dissolved oxygen concentration was determined in parts per million using the Winkler method, and pH was determined using a Hellige comparator. Salinity in parts per thousand (‰) was determined using a hydrometer (salimeter), and temperature was recorded in degrees Fahrenheit.

Striped Bass Experiments

Adult striped bass were tolerant to transfers between salt and fresh water at the different temperatures tested (table 1). In the widest range temperature and salinity change from salt to fresh water (salt water at 45° F. and 35 ‰ to fresh water at 74° F.), one early mortality occurred (experiment 1). No deaths resulted from salt to fresh water transfers over lesser increments of either temperature or salinity or both (experiments 2 through 6).

TABLE 1.--Abrupt transfers of adult striped bass between salt and fresh water at different temperatures.

[Ten fish in each test]

Experiment	Initial environment		Receiving environment		Cumulative mortality		
	Temperature ° F.	Salinity ‰	Temperature ° F.	Salinity ‰	1 day	5 days	10 days
1	45	35	74	0	1	1	1
2	45	34	80	34	0	0	0
3	45	15	76	0	0	0	0
4	55	35	74	0	0	0	0
5	55	34	80	34	0	0	0
6	55	15	76	0	0	0	0
7	74	0	56	28	1	1	1
8	73	0	59	28	0	0	0
9	45	0	76	33	0	0	0
10[1]	55	0	76	33	0	0	0

[1] Seven fish used in this test.

In those tests involving change from water at 45° F. to water between 74° and 80° F., the fish turned ventral side up, apparently as a result of shock, but usually they revived in a few seconds. A single mortality occurred in a transfer from fresh water of 74° F. to salt water at 56° F. (experiment 7), but no deaths occurred in other fresh to salt water transfers at temperature differences as great as 31° F. (experiments 8 through 10). No deaths occurred among fish used as controls.

American Shad Experiments

Adult shad were tolerant to transfers from fresh to salt water, but were much less tolerant to transfers from salt to fresh water at the different temperatures tested (table 2). In the greatest temperature change (25° F.) employed in tests from salt to fresh water, total mortality occurred within $2\frac{1}{2}$ hours (experiment 1). These fish turned ventral side up immediately after transfer, but quickly revived and appeared normal until further distress occurred 15 minutes later. Conflicting results occurred in other salt- to fresh-water tests. In transfers over a 10° F. difference in temperature, two mortalities occurred in experiment 2, and no mortality occurred in experiment 3. In transfers with practically no change in temperature but with salinity changes similar to those employed in the above tests, greater mortality occurred (experiments 4 and 5). Some shad in each of the salt- to fresh-water tests were observed to eject bubbles from their mouths, at or near the surface of the water. Fish in distress swam near the surface apart from the school; no violent movements accompanied death as the fish simply sank to the bottom of the pond.

TABLE 2.--Abrupt transfers of adult American shad between salt and fresh water at different temperatures

[Ten fish in each test]

Experiment	Initial environment		Receiving environment		Cumulative mortality		
	Temperature ° F.	Salinity ‰	Temperature ° F.	Salinity ‰	1 day	5 days	10 days
1	48	27	73	0	10	10	10
2[1]	54	25	64	0	0	2	2
3	48	13	58	0	0	0	0
4	45	27	47	0	0	4	5
5	63	13	65	0	0	3	3
6[1]	74	0	58	23	0	0	0
7	61	0	59	24	0	0	0

[1] Nine fish used in this test.

No adult shad distress or mortality took place in fresh- to salt-water transfers over the same temperature (experiment 7) or a 16° F. temperature difference (experiment 6). No mortality occurred among the controls conducted with the adult shad tests.

TOLERANCE OF JUVENILES

Materials and Methods

Juvenile striped bass were obtained from the Chowan River approximately 10 miles above Edenton, N. C., and juvenile shad were obtained from the Neuse River near New Bern, N. C. Striped bass ranged from 3.9 to 5.7 inches fork length, and shad ranged from 2.2 to 3.1 inches fork length. Collections were made during the months of September and October, using a 70-foot bag seine. Fish were transported to the laboratory by means of a 200-gallon wooden tank mounted on a truck (Sykes, 1950). At the laboratory, each species was placed in separate holding pools containing Neuse River water from the seining site. Subsequently, a percentage of the stock fish was acclimated to salt water over a 24-hour period. Water temperature in the stock pools ranged from 57° to 82° F., and salinity in the salt-water stock pool ranged from 28 to 32 ‰.

Equipment used in these studies consisted of 5-gallon glass jars which were used as experimental containers, and a three-compartment constant temperature bath which maintained desired temperatures within the jars with plus or minus 1° F. variation. Neuse River water (pH 7.6; salinity range 1 to 4 ‰ but diluted with rain water to less than 1 ‰), Beaufort Channel water (pH 7.4; salinity range 28 to 32 ‰), and sea salt were used to prepare experimental waters. Dissolved oxygen was maintained between 6.0 and 7.5 p.p.m. by ball-type air mist releasers connected to an air compressor system.

Abrupt transfers of juvenile striped bass and shad were made between salt and fresh water at specific temperatures and salinities over the range 45° to 70° F. and 0 to 33 ‰, or within fresh water over this same range of temperatures. Test jars were filled with experimental waters, and fish from the stock pools were placed in those jars which served as initial environments. If initial environments were salt water, fish were taken from the salt-water stock pool, and if initial environments were fresh water, fish were taken from the fresh-water stock pool.

Ten shad in a jar or ten striped bass divided between two jars because of their larger size constituted each test lot. Jars were placed within constant temperature baths at temperatures designated for the tests. Fish were acclimated to the initial environment for a minimum of 48 hours and then transferred to the receiving environment. Transfer of fish from jar to jar was accomplished by pouring fish and water into a mounted funnel having a cloth net insert, and then releasing them from the net into the new container. Mortality was determined 24 and 48 hours after transfer to receiving environment. Cessation of respiratory movement was taken as the criterion of death.

Experiments were also conducted to determine the ability of juvenile fish to acclimate to gradual changes in temperature or salinity over ranges not tolerated with abrupt transfer. Gradual changes in temperature and salinity could not be effected simultaneously with experimental apparatus used in this study. The rate of temperature decrease in the test containers was controlled by the depth the jars were immersed in the temperature baths. Air releasers used for oxygenation created enough circulation to provide uniform temperatures within the jars. Rate of salinity increase was controlled by adjustment of flow from a salt-water line. Two striped bass tests were conducted by jar-to-jar transfers in a series of "step changes" in salinity with gradual decrease in temperature. Controls of 10 fish each were used in the juvenile studies. Controls involved handling the fish in the same manner as those of the accompanying test, with no change in temperature or salinity.

Striped Bass Experiments

Juvenile striped bass in general were tolerant to abrupt transfers between salt and fresh water and to transfers within fresh water at the different temperatures tested. No appreciable mortality occurred in transfers from fresh to salt water over a temperature range of 70° to 55° F., and no deaths occurred in tests conducted within fresh water at decreases in temperature over the same range (table 3). High mortality resulted, however, in transfers from fresh water at 70° or 55° F. to salt water (33 ‰) at 45° F., and low mortality occurred in transfers from these same initial conditions to fresh water at 45° F. Test fish momentarily turned ventral side up after transfers from 70° to 45° F. water, but this did not necessarily indicate later distress or mortality. No juvenile striped bass deaths or distress occurred in abrupt changes from salt to fresh water over the temperature range 45° to 70° F. or in transfers within fresh water at increases in temperature over the same range (table 4).

TABLE 3.--Abrupt transfers of juvenile striped bass from fresh water to fresh or salt water at different temperatures

[Ten fish in each test]

Fresh water initial environment	Receiving environment		Cumulative mortality	
Temperature ° F.	Temperature ° F.	Salinity ‰	24 hours	48 hours
70	45	0	2	2
70	45	33	5	7
70	55	0	0	0
70	55	15	0	0
70	55	33	0	0
70	62	0	0	0
70	62	15	0	0
70	62	33	1	1
70	70	15	0	0
70	70	33	0	0
62	55	0	0	0
62	55	33	1	1
55	45	0	0	1
55	45	33	8	9

TABLE 4.--Abrupt transfers of juvenile striped bass from fresh or salt water to fresh water at different temperatures

[Ten fish in each test]

Initial environment		Fresh water receiving environment	Cumulative mortality	
Temperature ° F.	Salinity ‰	Temperature ° F.	24 hours	48 hours
45	0	70	None	
45	33	70		
55	0	70		
55	33	70		
62	0	70		
62	33	70		
70	33	70		
45	0	62		
45	33	62		
55	0	62		
55	33	62		
45	0	55		
45	33	55		

All control fish survived with the exception of single mortalities in each of three controls.

Juvenile striped bass were able to acclimate to gradual change in temperature, but not to change in both temperature and salinity over the range in which mortality occurred in abrupt transfer. In two identical experiments, no distress took place within 48 hours after a 3-hour temperature decrease from 70° to 45° F. However, in a test employing a decrease in temperature from 70° to 45° F. with step increases in salinity from 0 to 33 ‰ (0 ‰ at 70° F.; 10 ‰ at 62° F.; 20 ‰ at 55° F.; and 33 ‰ at 45° F.) over 3 hours, a 50 percent mortality resulted within 48 hours. These conditions were repeated over a 6-hour period, and 50 percent mortality again occurred within 48 hours.

American Shad Experiments

Juvenile shad were not tolerant to transfers from fresh to salt water at the different temperatures tested, nor to temperature decreases within fresh water. They were tolerant, however, to transfers from salt to fresh water and to temperature increases within fresh water. All fish succumbed to changes from fresh water of 70° F. to salt water (33 ‰) of 45° or 55° F. (table 5). Total or appreciable mortality occurred in all other tests from fresh to salt water over lesser temperature differences. Total mortality likewise resulted from transfers conducted within fresh water from 70° F. to 45° or 55° F. At lesser temperature differences, fewer mortalities generally occurred in fresh water transfers than occurred when salinity was also involved. No juvenile shad deaths or distress occurred in changes from salt to fresh water over the temperature range 45° to 70° F. or in transfers within fresh water at increases in temperature over the same range (table 6). Other than single mortalities in each of three controls, all control fish survived.

Juvenile shad were able to acclimate under certain conditions to a gradual decrease in temperature or increase in salinity (table 7). They successfully acclimated to a 6-hour temperature decrease from 70° to 55° F., but did not adjust to a 15-hour decrease from 70° to 45° F. The majority of test fish died after a 1.5-hour increase in salinity from 0 to 32 ‰ at the same temperature; however, all but one survived a 4.5-hour increase.

The interval between initial distress (loss of equilibrium) and death of juvenile shad (also striped bass) was usually less than 1 hour when resulting from abrupt transfers over extreme differences in temperature and salinity. When these differences were slight, however, young shad often remained inverted at the bottom of the experimental containers, except for erratic swimming spurts, for as long as 10 hours before death.

TABLE 5.--Abrupt transfers of juvenile American shad from fresh water to fresh or salt water at different temperatures
[Ten fish in each test]

Fresh water initial environment	Receiving environment		Cumulative mortality	
Temperature ° F.	Temperature ° F.	Salinity ‰	24 hours	48 hours
70	45	0	10	10
70	45	33	10	10
70	55	0	9	10
70	55	33	10	10
70	62	0	1	3
70	62	0	2	4
70	62	15	3	6
70	62	15	3	5[1]
70	62	33	4	5
70	70	8	4	6
70	70	8	4	6
70	70	15	2	6
70	70	15	4	7
70	70	33	4	6
62	55	0	1	3
62	55	15	1	2[2]
62	55	33	10	10
55	45	0	10	10
55	45	33	10	10

[1] Two survivors in distress.
[2] Four survivors in distress.

TABLE 6.--Abrupt transfers of juvenile American shad from fresh or salt water to fresh water at different temperatures
[Ten fish in each test]

Initial environment		Fresh water receiving environment	Cumulative mortality	
Temperature ° F.	Salinity ‰	Temperature ° F.	24 hours	48 hours
45[1]	33	70		
55	0	70		
55	33	70		
62	0	70	None	
62	33	70		
70	15	70		
70	33	70		

[1] Only six shad were successfully acclimated for this test.

TABLE 7.--Acclimation of juvenile American shad to gradual decrease in temperature and increase in salinity

Initial environment		Final environment		Hours acclimated	Number of fish	Hours observed after acclimation	Mortality after acclimation
Temperature ° F.	Salinity ‰	Temperature ° F.	Salinity ‰				
70	0	45	0	7.5	10	24	7
70	0	50	0	3.5	10	24	4
70	0	50	0	9.5	10	24	3[1]
70	0	55	0	2.5	10	24	4
70	0	55	0	6.0	10	48	0
70	33	45	33	15.0	10	8	6[1]
70	33	55	33	6.0	20	24	0
70	0	70	32	1.5	10	24	[illegible]
70	0	70	30	4.5	10	48	1
70	0	70	30	19.0	10	48	[illegible]

[1] Two survivors in distress.

DISCUSSION

Differences in the physiological development of the fish might explain why mortality of adult shad was greater in salt to fresh water transfers at the same temperature than from similar transfers at a 10° F. difference in temperature. The former tests were conducted 2 to 3 weeks earlier than the latter, and, therefore, the fish in the earlier transfers may not have undergone as complete a physiological adjustment in preparation for migration into fresh water. Black (1957) stated that anadromous fishes were able to migrate because of normal activity that resulted in the physiological changes required for survival in the new environment. Black cited work by Sawyer on sea lamprey *(Petromyzon marinus)* which showed that fish migrating from the sea to fresh water assumed very quickly the functions of typical fresh water fishes. The cause of the conflicting results which occurred in transfers of adult shad from salt to fresh water may also have been due to individual variation. Sumner (1906) stated that the capacity of different individuals to endure transfers between salt and fresh water varied greatly, depending upon the condition of the fish.

Juvenile shad transferred from fresh to salt water could not survive comparatively small differences in temperature and salinity. It has been established that the young of certain anadromous fishes cannot tolerate high salinity until they approach the normal time of migration to the sea (Rounsefell and Everhart, 1953). Houston (1957) found that in juvenile salmon, marked positive reactions to concentrated sea water occurred only in that stage of development when the fish would normally migrate seaward. Juvenile shad used in the present experiments may not have been physiologically adjusted for migration to the ocean.

The greatest mortality of adult fish usually occurred during the second to the fifth day after transfer, while the greatest mortality of juveniles occurred within 24 hours after transfer. The longer period of survival of adults compared to that of juveniles may have been due in part to their larger size. Huntsman and Hoar (1939) found that, in young salmon, the larger the fish the longer it survived high salinity. The authors concluded that with increase in size young salmon became more resistant to sea water to the degree to which the exposed surfaces, through which the sea water must act, became less in proportion to the mass of the body, in particular, the blood.

When acclimating adult striped bass and shad to a water temperature of 74° F. and juvenile shad to a water temperature of 45° F. (temperatures desired for initial environments), distress and mortality occurred among the fish. Doudoroff (1942) discussed the limiting effects of heating and cooling upon fish and concluded that acclimation to cold was relatively slow. In addition, seasonal variations in lethal temperatures have been found for various fish corresponding to the temperature variation of their normal habitat (Brett, 1944). It follows that in the present tests either acclimation was too rapid or possibly the temperatures were in themselves adverse to the fish. Experimental facilities and seasonal availability of fish necessitated conducting tests involving acclimation to 74° F. at a time when normal water temperature was approximately 55° F., and acclimation to 45° F. was attempted when normal water temperature was approximately 70° F. In each case when the fish were returned to water of normal temperature, they immediately resumed natural activity.

SUMMARY AND CONCLUSIONS

1. Experiments were conducted to determine what effective abrupt transfers between salt and fresh water, of different temperatures, would have on adult and juvenile striped bass and American shad. Transfers were made at specific temperatures and salinities over ranges from 45° to 80° F. and 0 to 35 ‰. Experiments were also conducted to determine the ability of juvenile striped bass and shad to acclimate to gradual changes in temperature and salinity over ranges not tolerated with abrupt transfer.

2. Adult striped bass were tolerant to abrupt changes between salt and fresh water at differences in temperature over the range 45° to 80° F.

3. Juvenile striped bass survived abrupt transfers between salt and fresh water at differences in temperature over the range 55° to 70° F., but were not tolerant to transfers from fresh water at these temperatures to salt water of 45° F.

4. Adult shad survived abrupt changes from fresh to salt water at the same temperature and at a 16° F. difference in temperature. They displayed some tolerance to abrupt transfers from salt to fresh water at the same temperature and at a 10° F. difference in temperature, but showed no tolerance at a 25° F. temperature change.

5. Juvenile shad survived abrupt transfers from salt to fresh water at temperature differences over the range 45° to 70° F. They were not tolerant to abrupt changes from fresh to salt water at temperature differences over the range 70° to 45° F.

6. In transfers conducted within fresh water, juvenile striped bass mortalities occurred only in changes from water of 70° or 55° F. to water of 45° F. Juvenile shad mortalities occurred in all tests where temperature decrease was 7° F. or greater. For both species, however, mortality was less in tests conducted within fresh water than in tests conducted from fresh to salt water over identical temperature differences. No mortality of juveniles of either species resulted from fresh water transfers at an increase in temperature over the range 45° to 70° F.

7. Juvenile striped bass and shad were able to acclimate under certain conditions to gradual changes in temperature or salinity over most ranges not tolerated in abrupt transfers.

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MS #1097

GPO 917160