7.6.1 DISTRIBUTION

7.6.1.1 Spring Distribution. In early spring (mid-March through April), the distribution of yearlings corresponds to the deep-water overwintering areas of juvenile fish in the lower regions of the Hudson River estuary (Sections 7.5.4, 6.2). Yearlings begin to move from deeper areas to beaches in late April and early May (Fig. 7.6-1) as water temperatures increase to about 15°C. Beach seine catch data in late spring suggest that the population may split into several groups, some yearlings remaining in the river (Section 7.6.1.2) while others are moving downstream toward the ocean (Section 7.6.1.3). By mid-June, yearlings are distributed throughout the estuary and lower bays from Albany to the western end of Long Island.

7.6.1.2 Summer, Fall, and Early Winter Distribution in the Hudson River Estuary. By mid-June, yearling striped bass appear in beach seine catches from Yonkers through Albany (Fig. 7.6-2 and 7.6-3). Some of the fish that overwinter in the lower river may migrate upstream in March and April and then move into the shorezone as water temperature increase. It is also possible that some yearlings overwinter in upriver channel areas (above the regions sampled by epibenthic sled and bottom trawl in the fall, Yonkers-Poughkeepsie) and then move into the shorezone during May and June. Impingement of yearlings at the Albany Generating Station (RM 142; km 227) begins in April and continues into summer, suggesting that they are not present in the shorezone in the upriver areas during winter and early spring.

Yearlings are rather evenly distributed throughout the estuary during the summer and into mid-October (Fig. 7.6-2 and 7.6-3) but decline in the shorezone by November, particularly above Cornwall, suggesting movement to deeper water or downstream or both. By December, yearlings are most abundant in the Yonkers and Tappan Zee regions and in the lower estuary.

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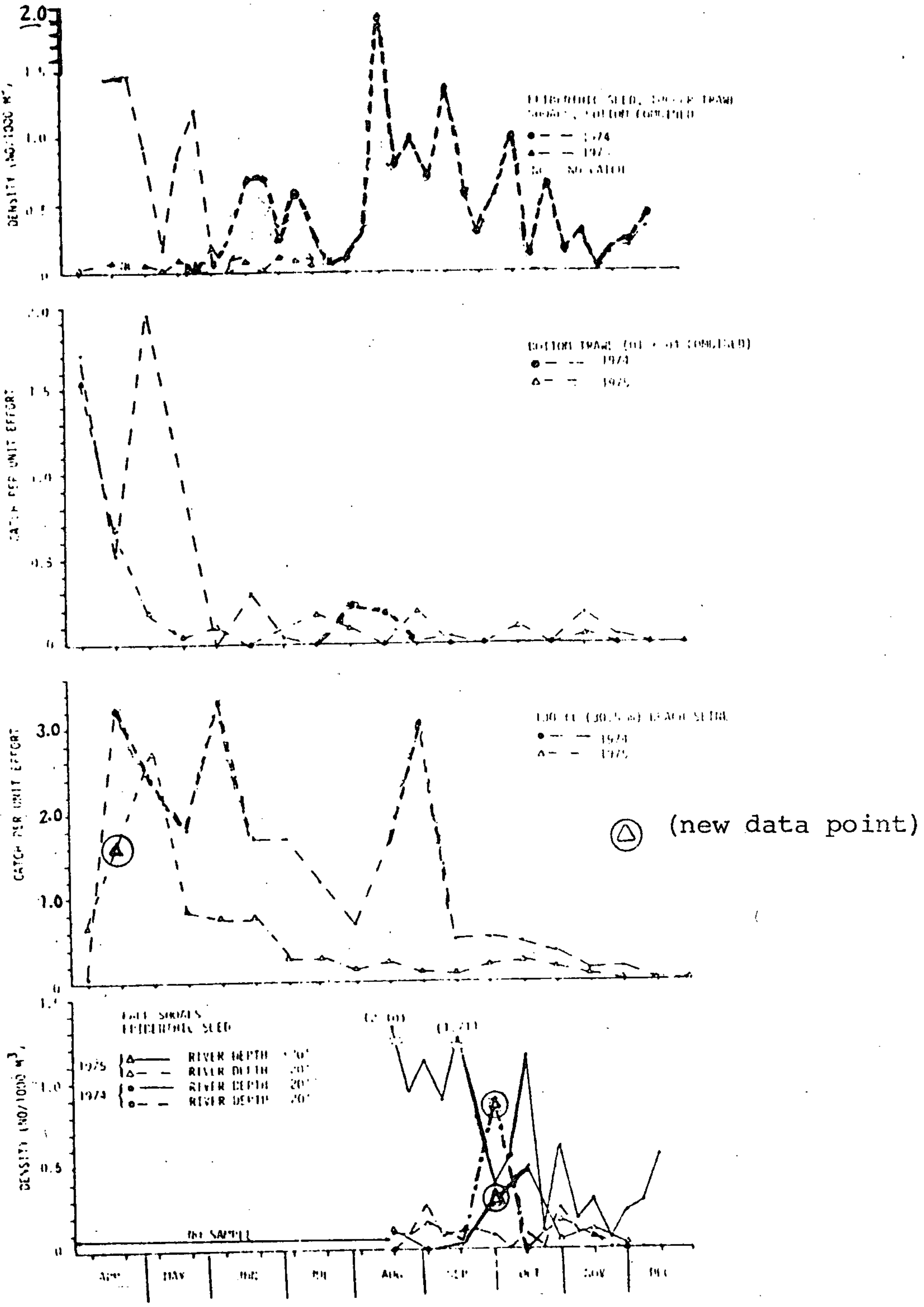
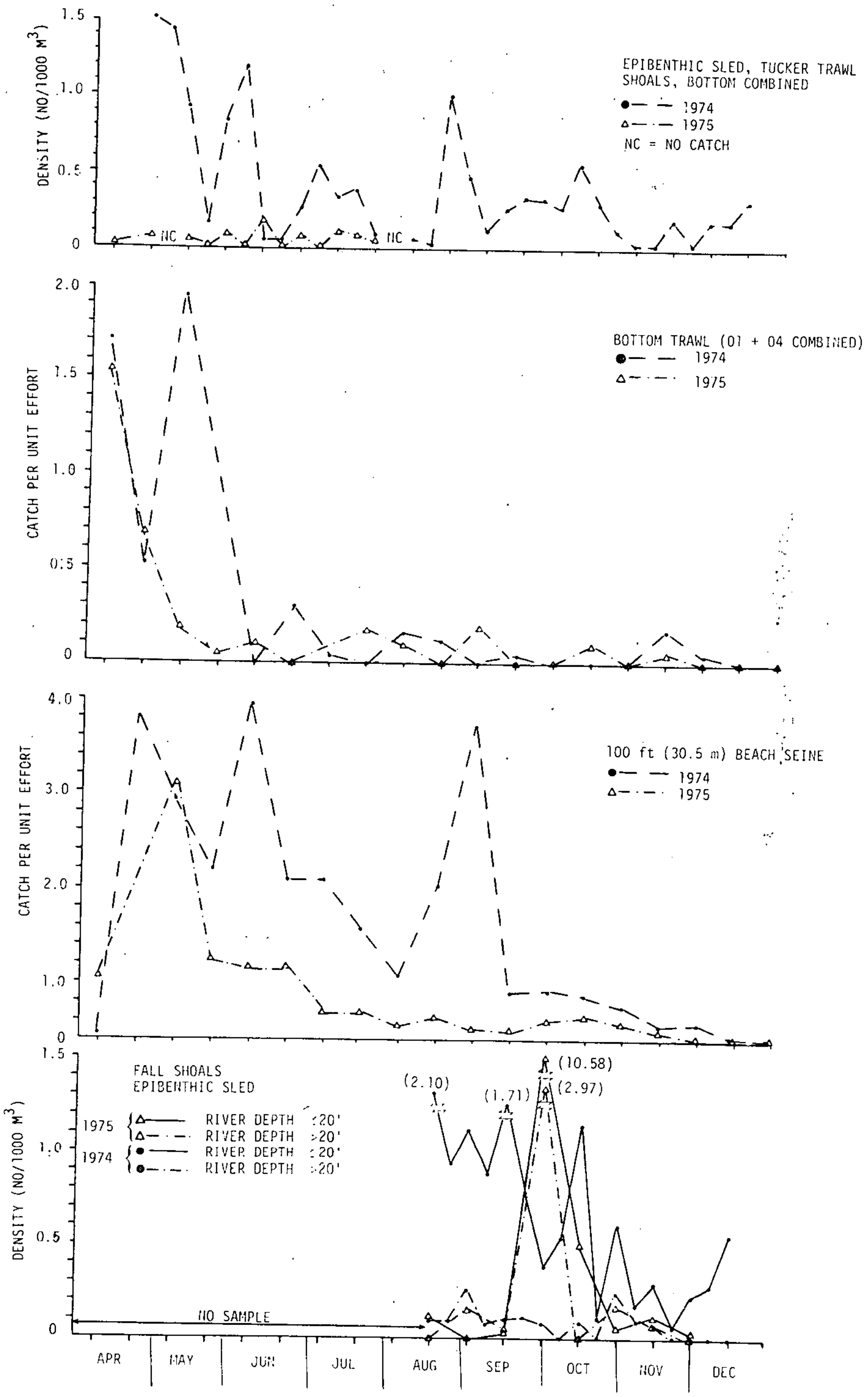


Figure 7.6-1 Abundance of Striped Bass Yearlings in Epibenthic Sled and Tucker Trawl 100-ft (30.5-m) Beach Seine (Day Only) and Bottom Trawl Samples Taken in Hudson River Estuary (RM 12-76; km 19-~~123~~) during . 1974, and 1975



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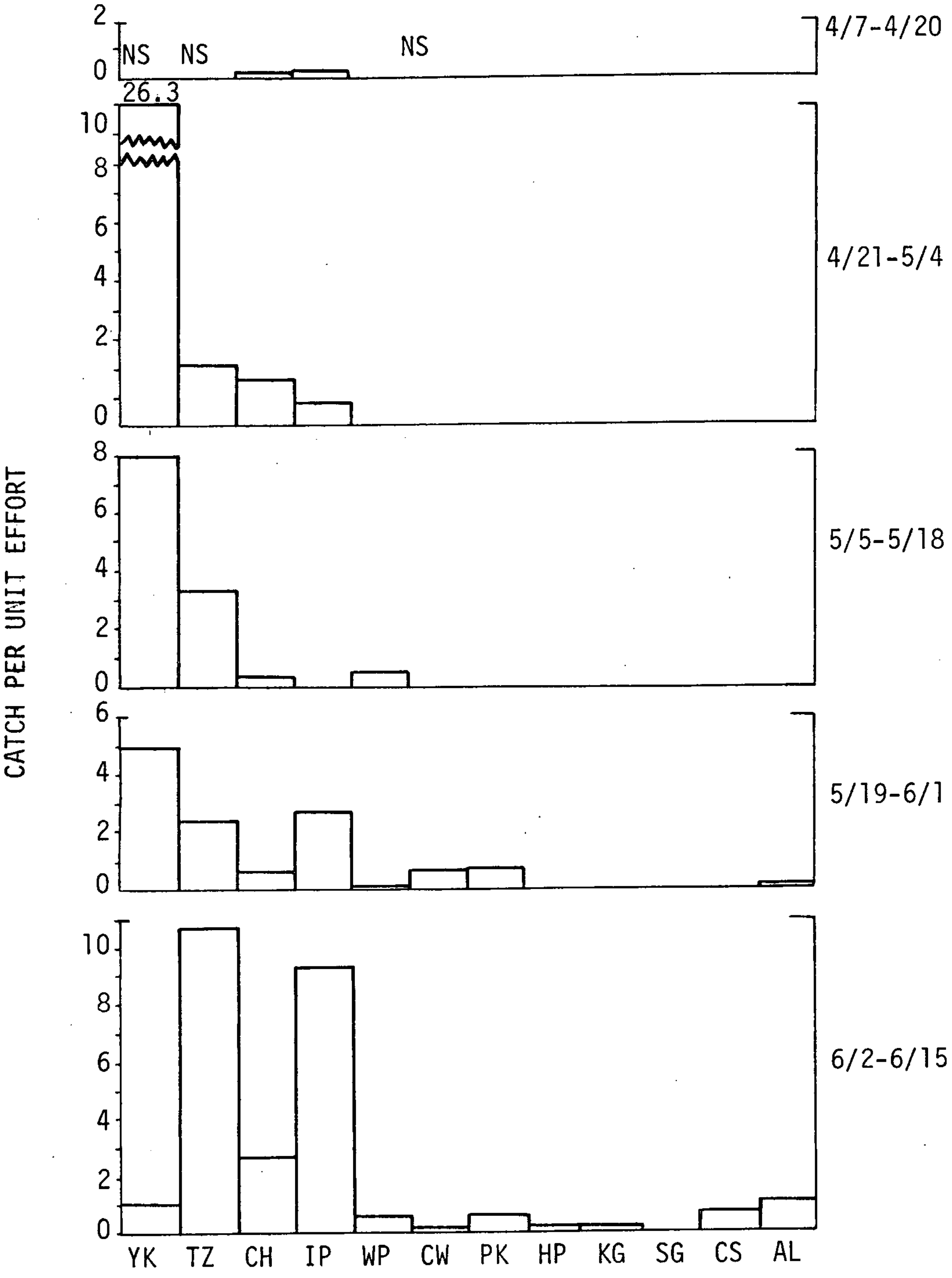

Figure 7.6-2 Beach Seine Catch per Unit Effort for Yearling Striped Bass in 12 Regions of the Hudson River during 1974 (page 1 of 2)

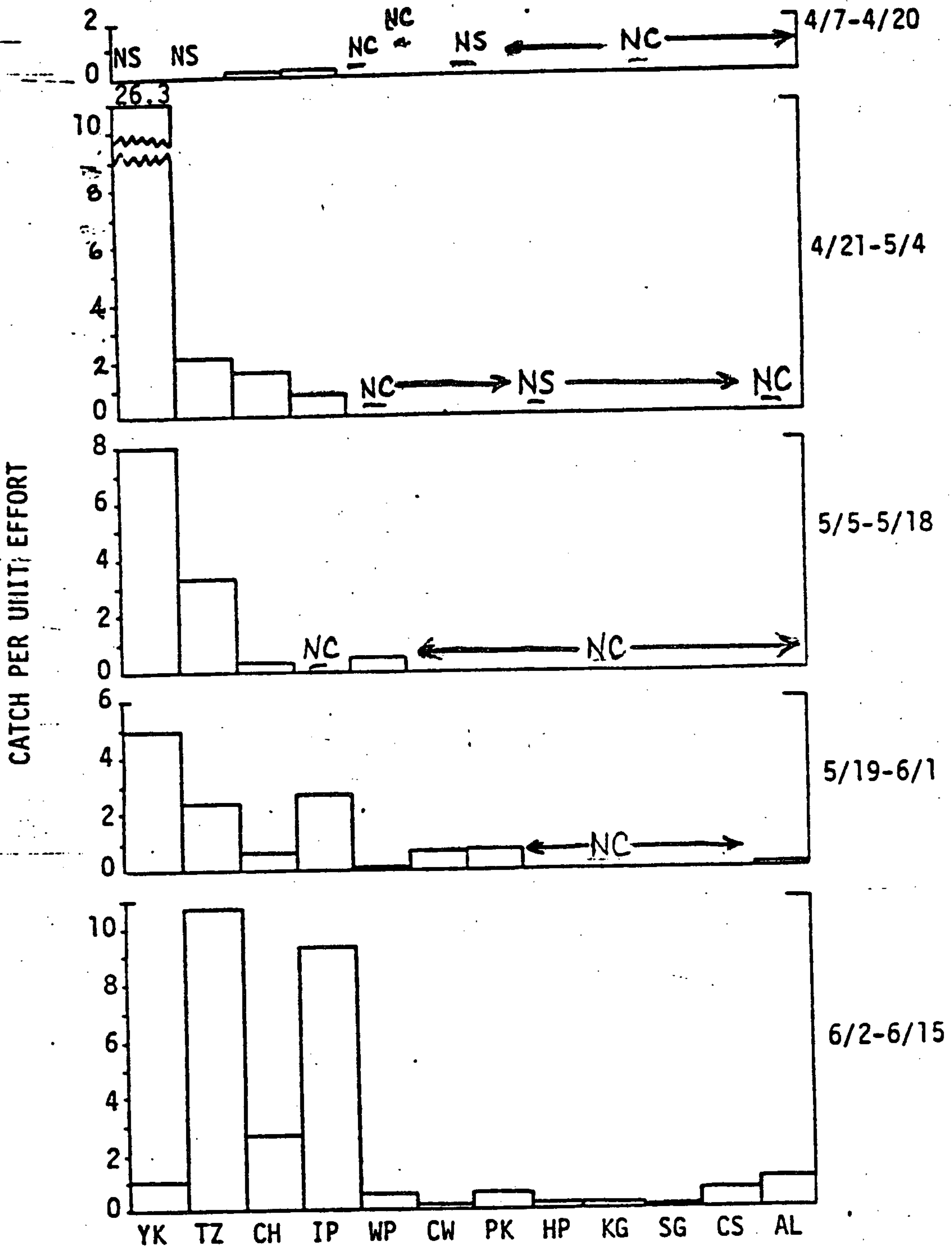

Figure 7.6-2 Beach Seine Catch per Unit Effort (Day Only) for Yearling Striped Bass in 12 Regions of the Hudson River during 1974 (page 1 of 2)

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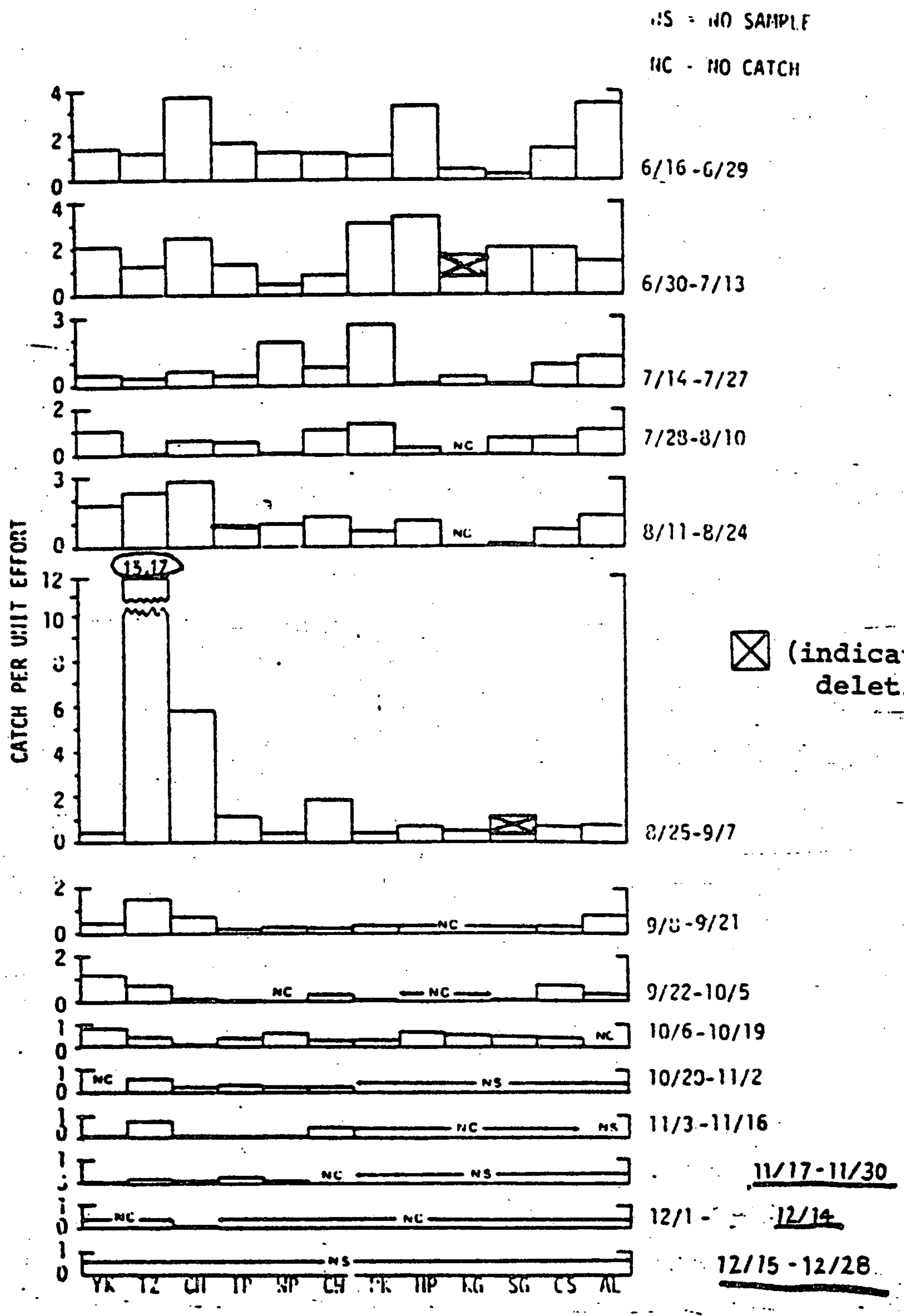

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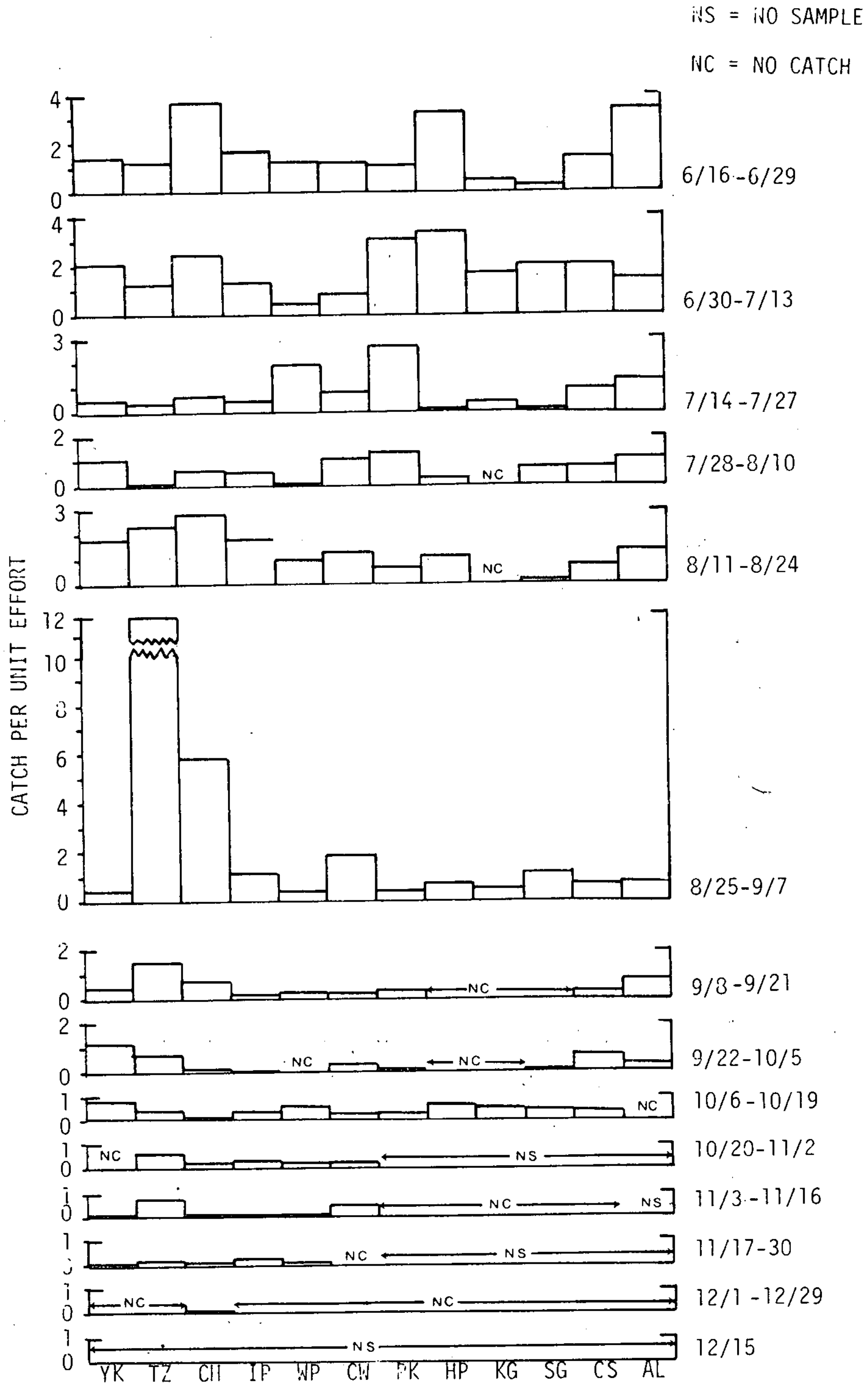
Figure 7.6-2 (Page 2 of 2)



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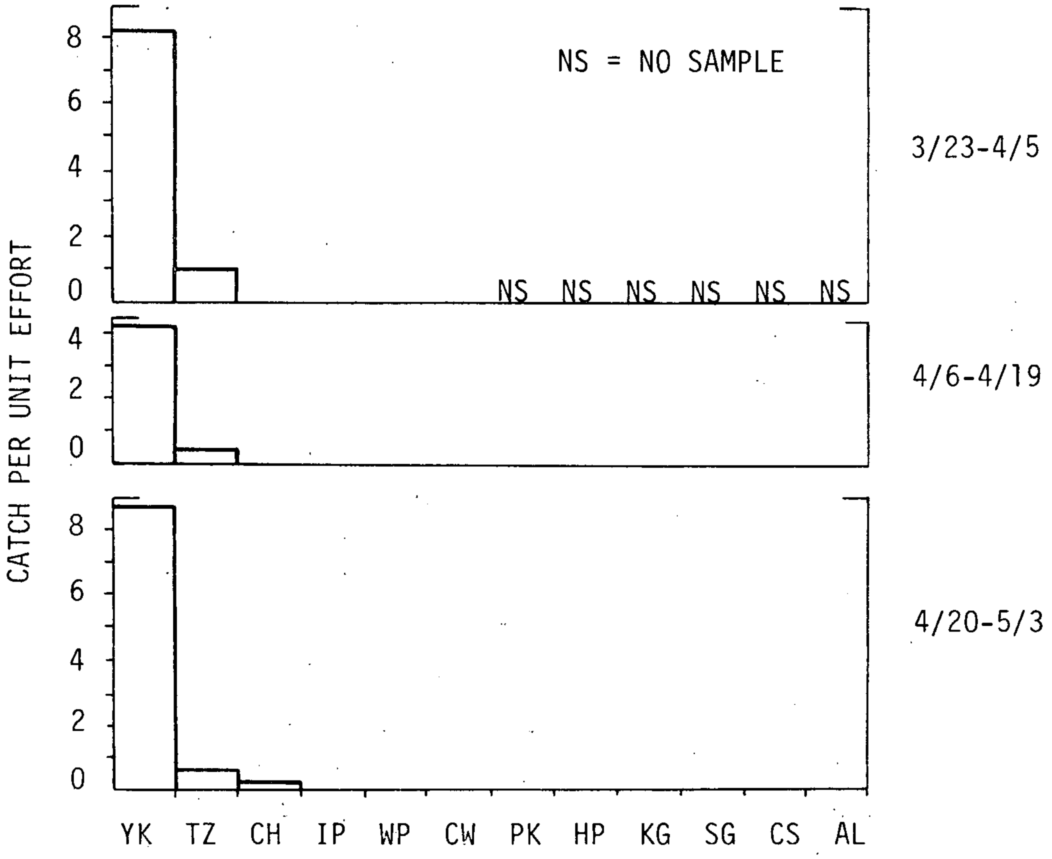

Figure 7.6-3 Beach Seine Catch per Unit Effort for Yearling Striped Bass in 12 Regions of the Hudson River during 1975 (Page 1 of 2)

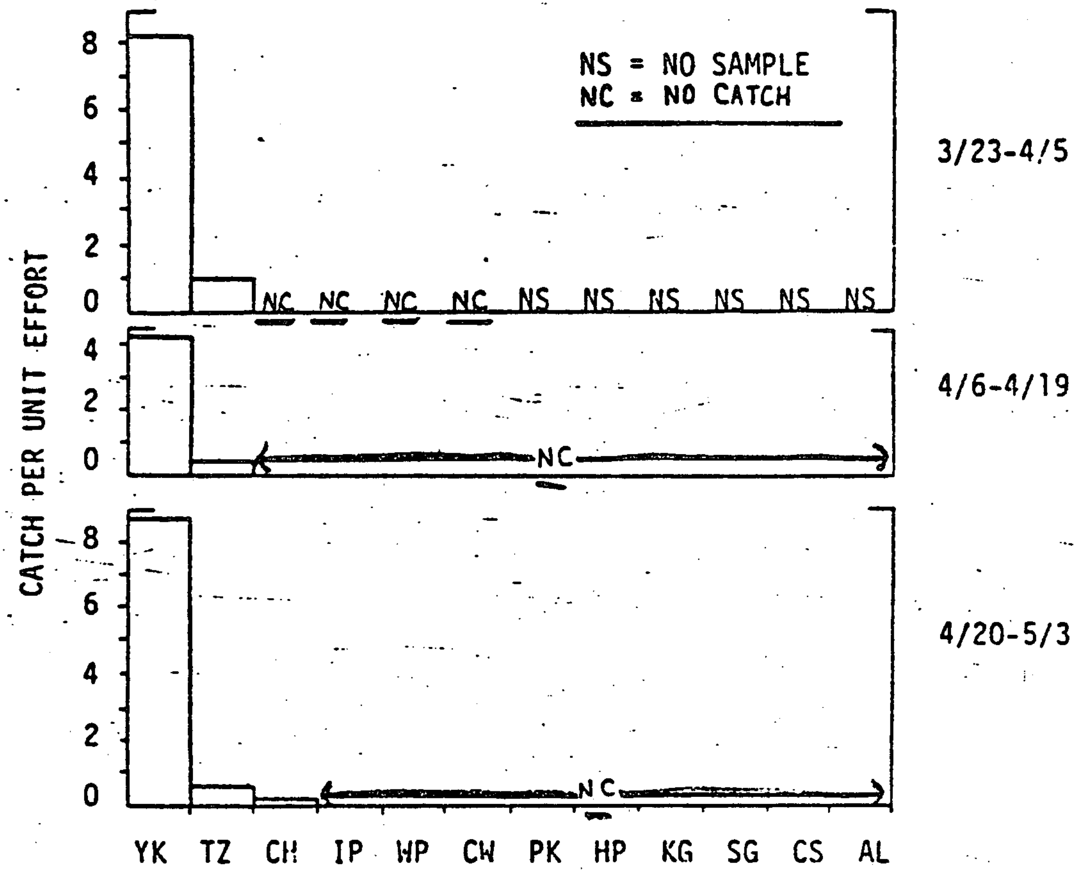

Figure 7.6-3 Beach Seine Catch per Unit Effort for (Day Only) Yearling Striped Bass in 12 Regions of the Hudson River during 1975 (Page 1 of 2)

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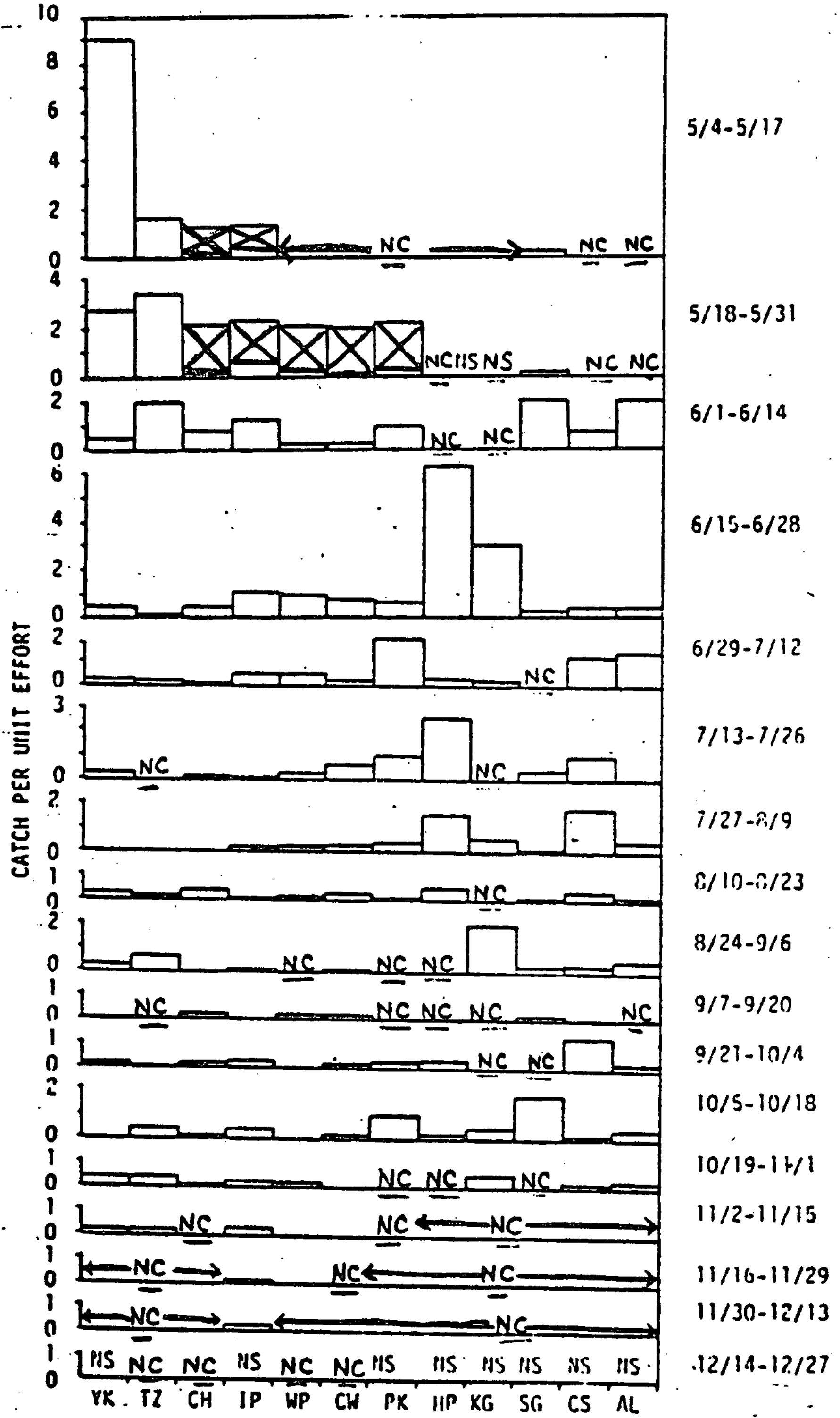

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Figure 7.6-3 (Page 2 of 2)

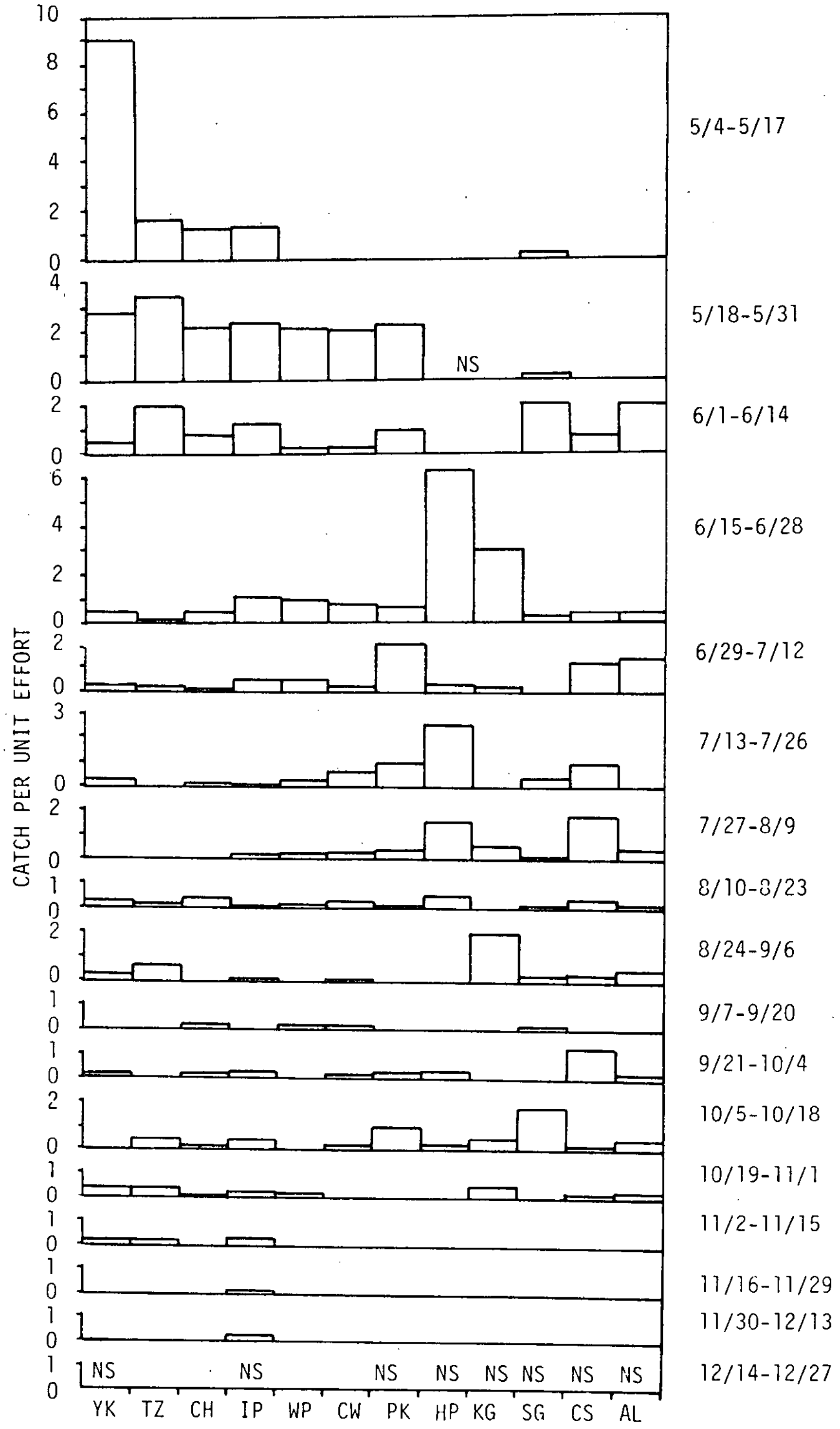

Figure 7.6-3 (Page 2 of 2)

7.6.1.3 Summer, Fall, and Early Winter Distribution in Lower Bays. Some of the yearling population moves into the lower bays of the Hudson River estuary (Fig. 7.6-4) during summer and fall. The lower bays were sampled during July-November 1974 and April-July 1975 to determine the timing and directional movements of fish emigrating from the Hudson River estuary. Most of the sampling was with 200-ft (61-m) haul seines* in western Long Island bays, Staten Island, lower New York Bay, and the Hackensack River (Fig. 7.6-4). Yearlings were collected in late March (1975) in Little Neck Bay but were not abundant in seine samples until early May (Fig. 7.6-5 and 7.6-6). In 1974, they were present during initial sampling (July) in Little Neck Bay, Manhassett Bay, and Jamaica Bay off the southwestern end of Long Island. August-October 1974 sampling suggested yearling movements eastward along the north shore of Long Island and possibly west to Staten Island (Fig. 7.6-5). By the end of October, no yearling striped bass were caught in the lower bay area.

Yearlings were also impinged in September and November (1973) at the Essex Generating Station (IA 1974a:63) and in October (1973) at the Kearny Generating Station (IA 1974b:63), two power plants located in the lower bay area (Fig. 7.5-8). Yearlings were not impinged again until January and February at the Astoria (QLM 1973b) and Kearny Generating Stations; this group was the young-of-the-year population that had moved downstream into the lower bays during the previous fall (Section 7.5.4).

7.6.1.4 Size Distribution in Estuary and Lower Bays. Larger yearlings may emigrate from the river earlier than the smaller individuals. During May 1975, yearling striped bass caught by haul seines in the lower bays were larger than yearlings caught by beach seines and bottom trawls in the Hudson River estuary (Table 7.6-1). This size differential continued through June in most areas and into July in Little Neck Bay.

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*wing: 0.375 in (9.5 mm) mesh; bunt: 0.25 in (6.4 mm) delta mesh

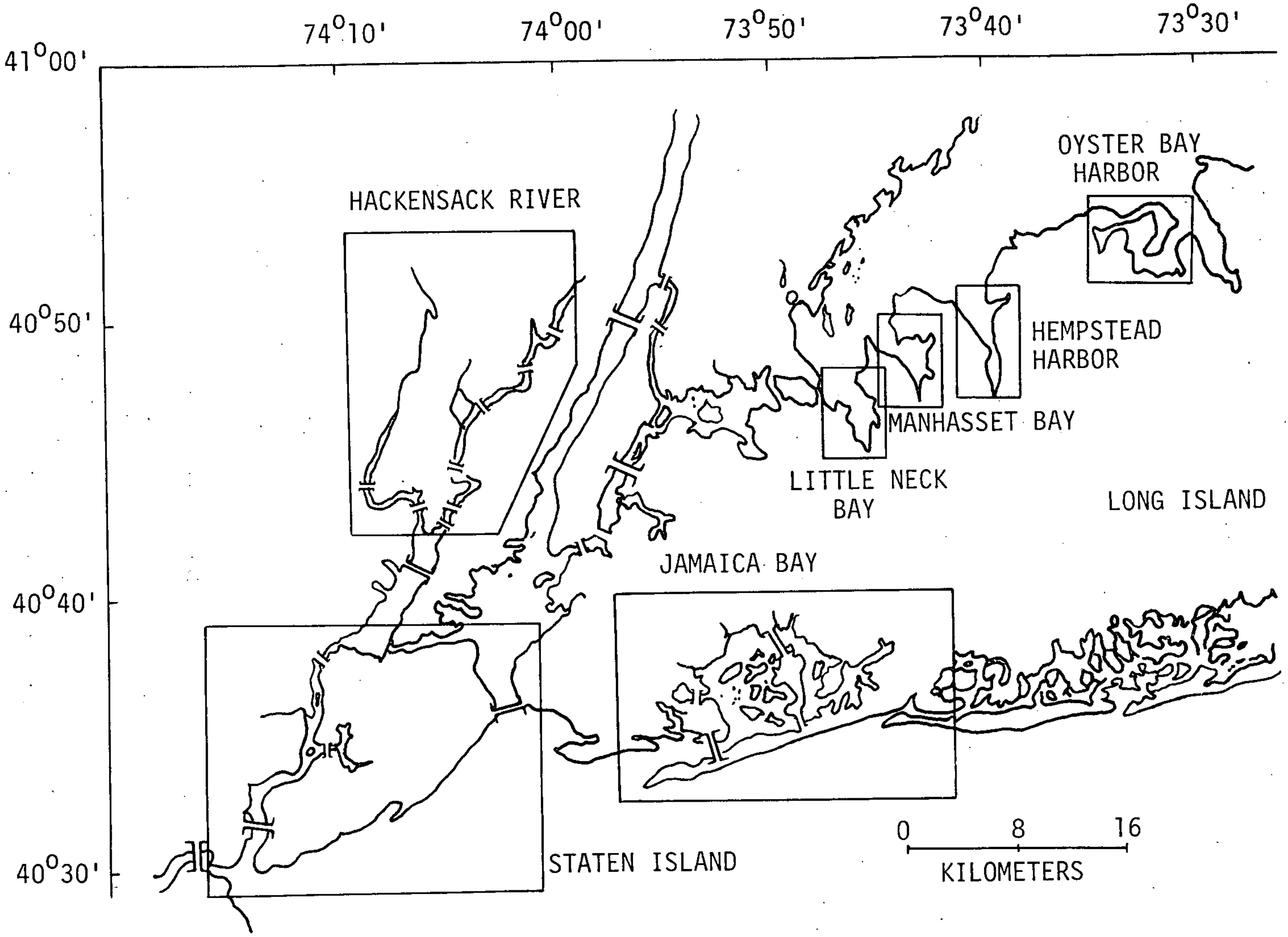

Figure 7.6-4 Major Areas Surveyed in Lower Bay Study

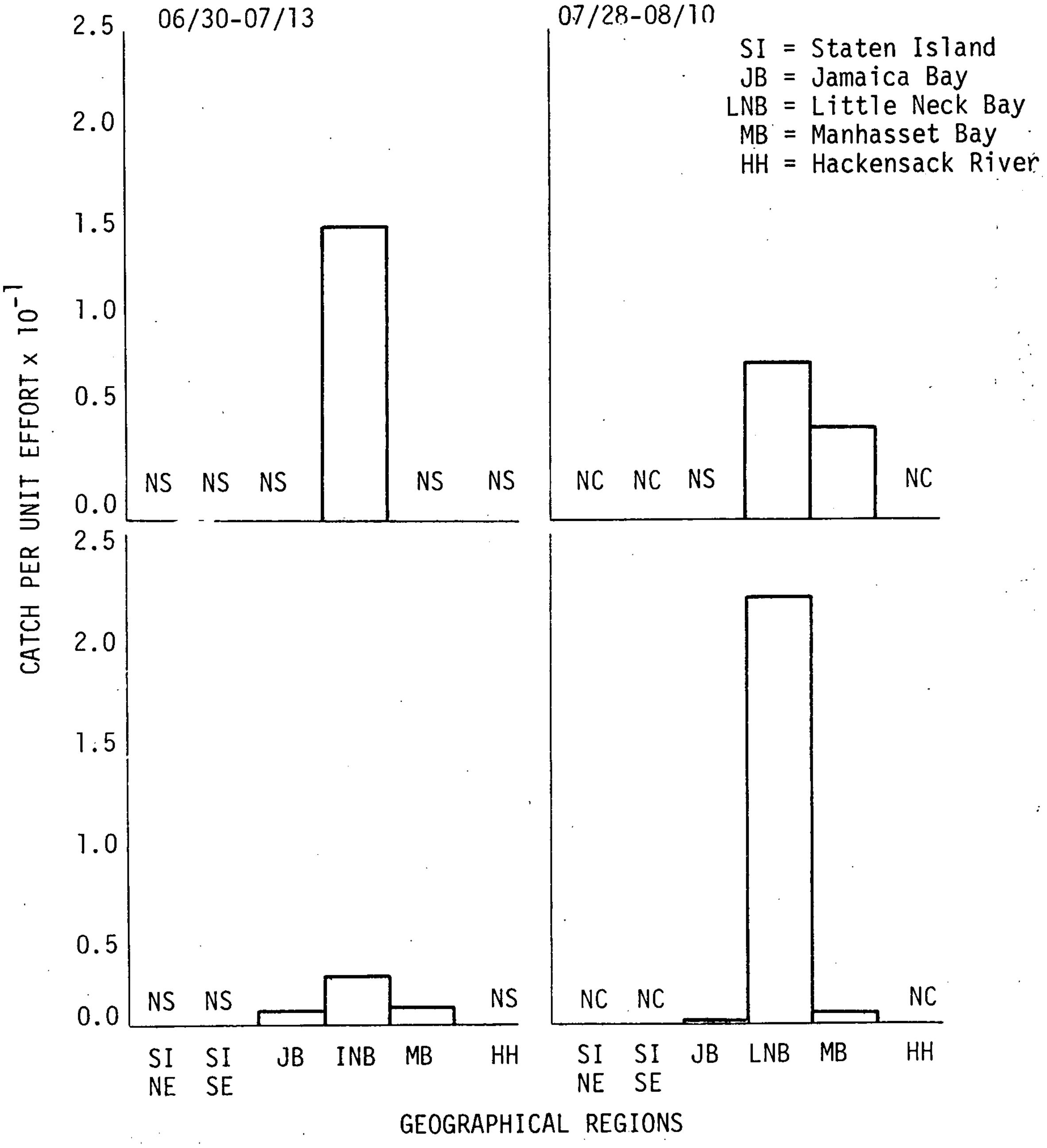

Figure 7.6-5 Yearling Striped Bass Catch per Unit Effort Within Six Regions of Lower Bays of Hudson River Estuary Based on Day Sampling with 200-ft (61-m) Haul Seine during 1974 (Page 1 of 2)

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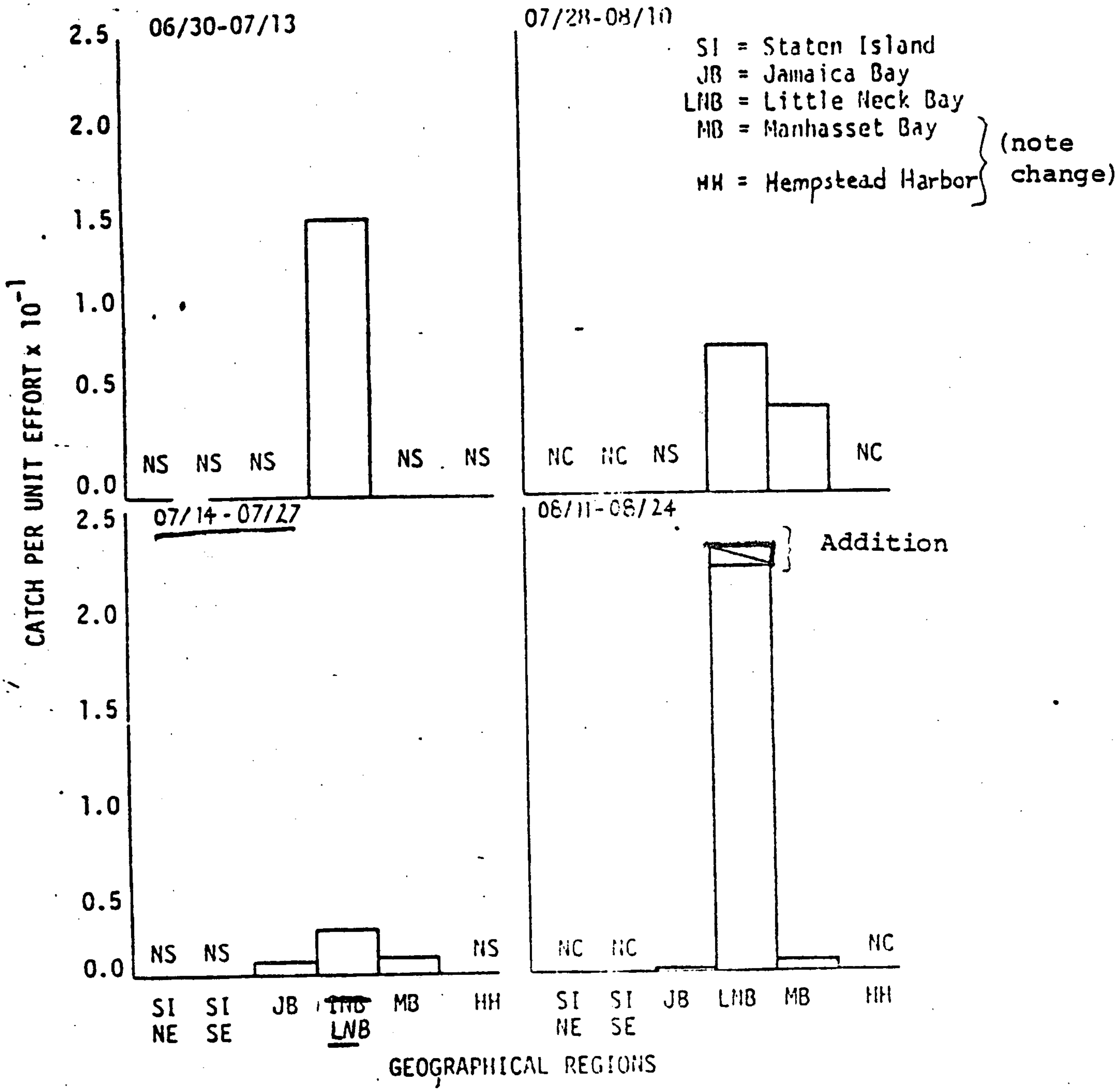

Figure 7.6-5 Yearling Striped Bass Catch per Unit Effort Within Six Regions of Lower Bays of Hudson River Estuary Based on Day Sampling with 200-ft (61-m) Haul Seine during 1974 (Page 1 of 2)

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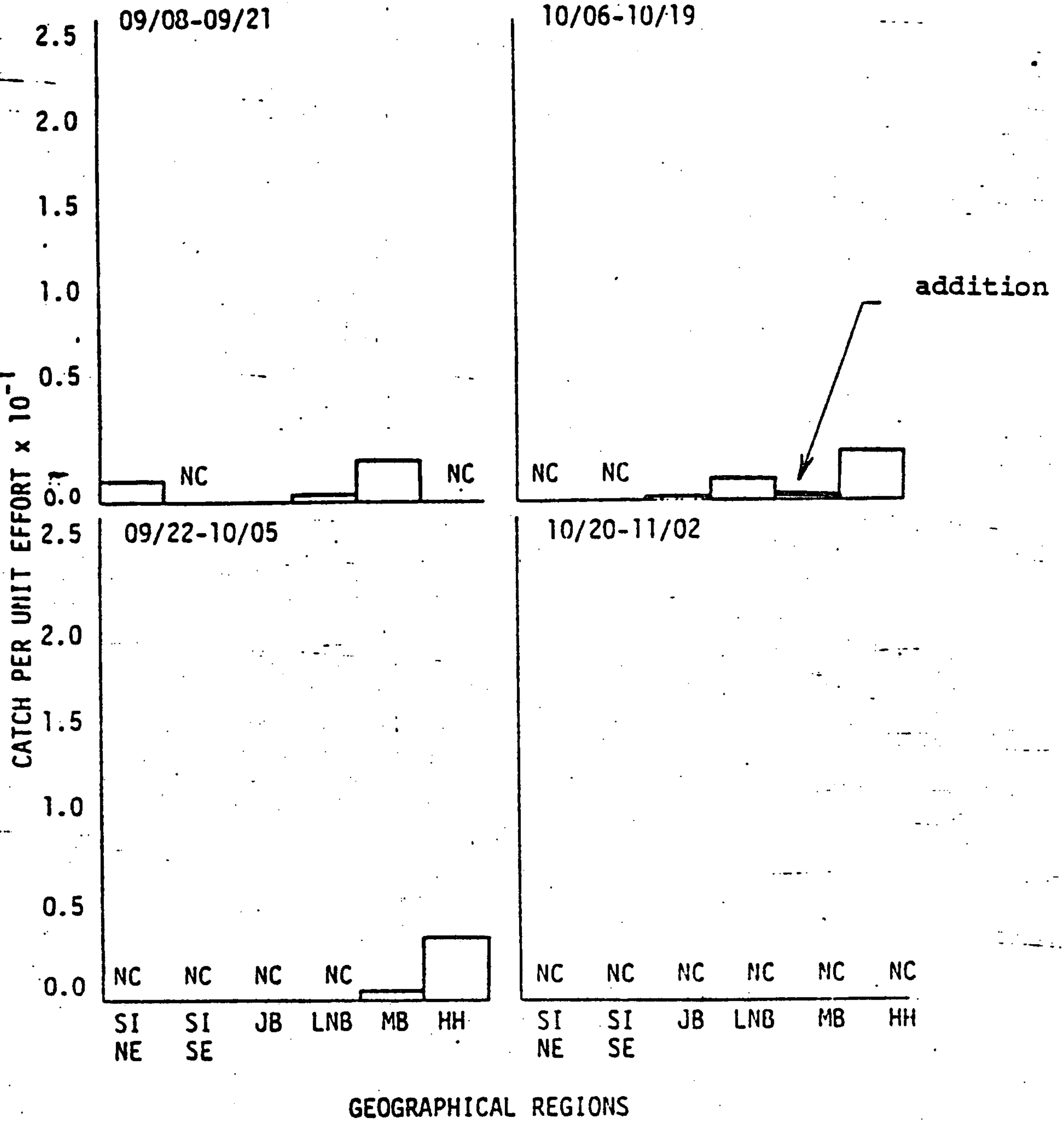
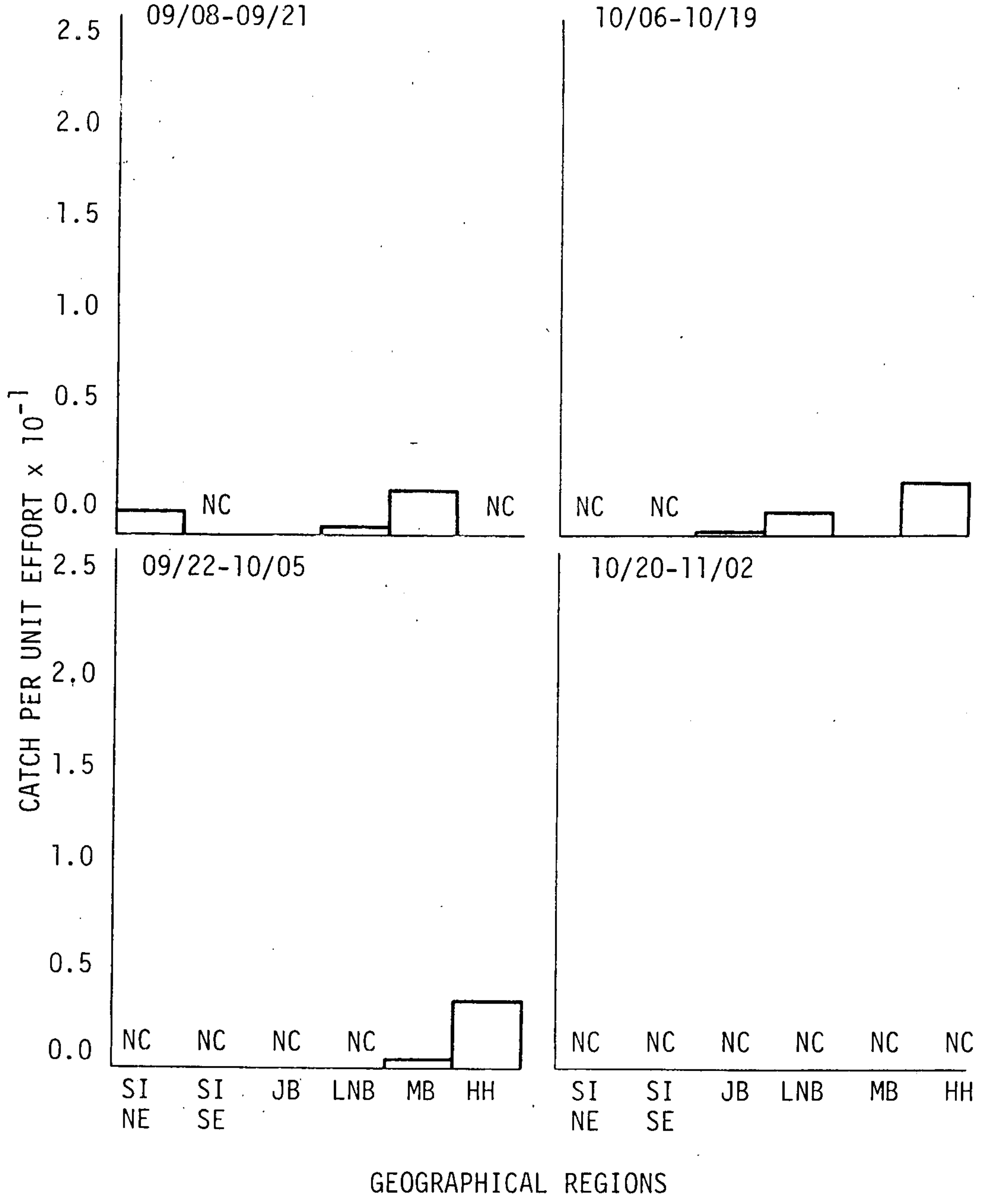


Figure 7.6-5 (Page 2 of 2)



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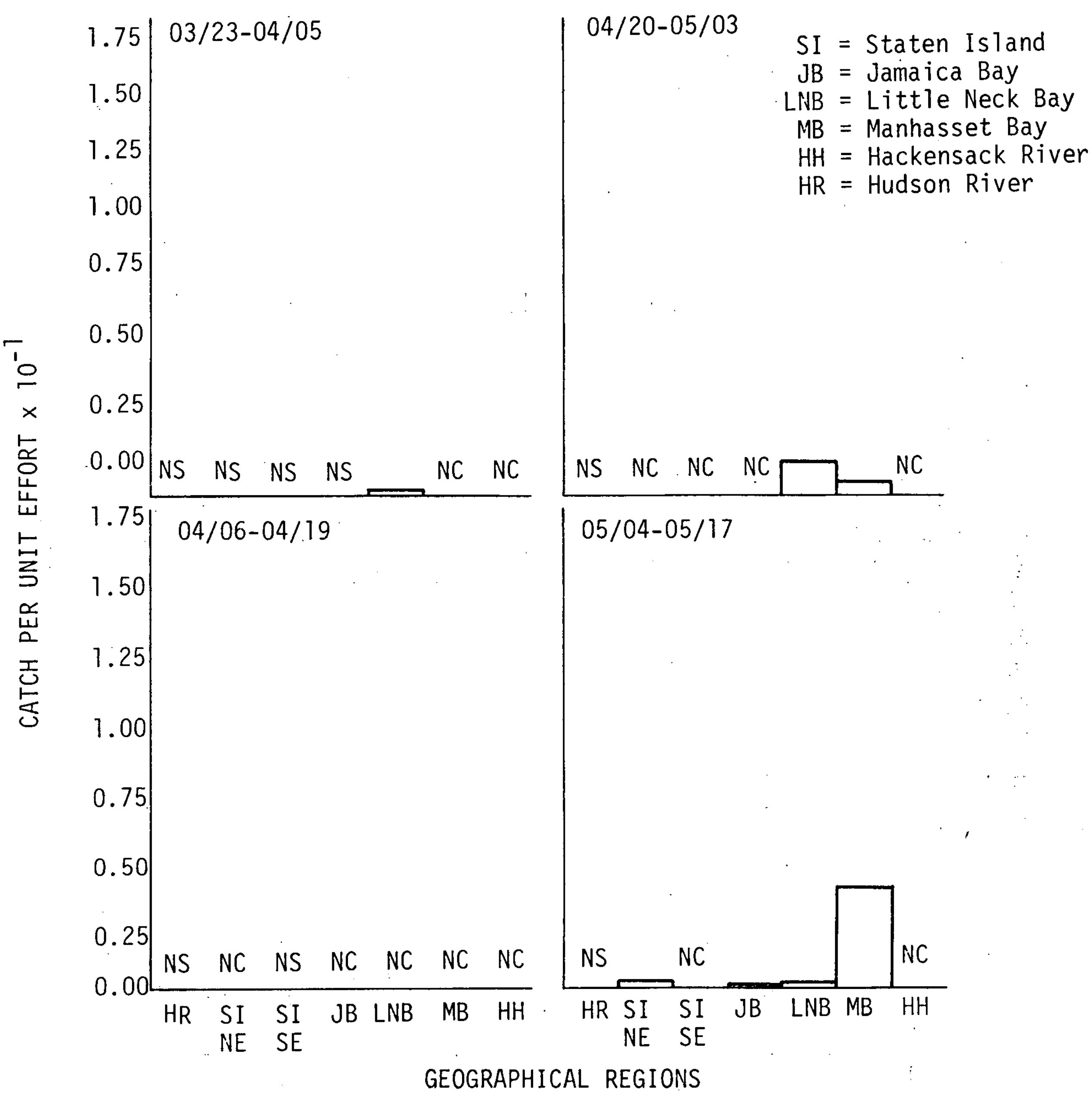

Figure 7.6-6 Yearling Striped Bass Catch per Unit Effort Within Seven Regions of Hudson River Estuary and Lower Bays Based on Day Sampling with 200-ft (61-m) Haul Seine during 1975 (Page 1 of 2)

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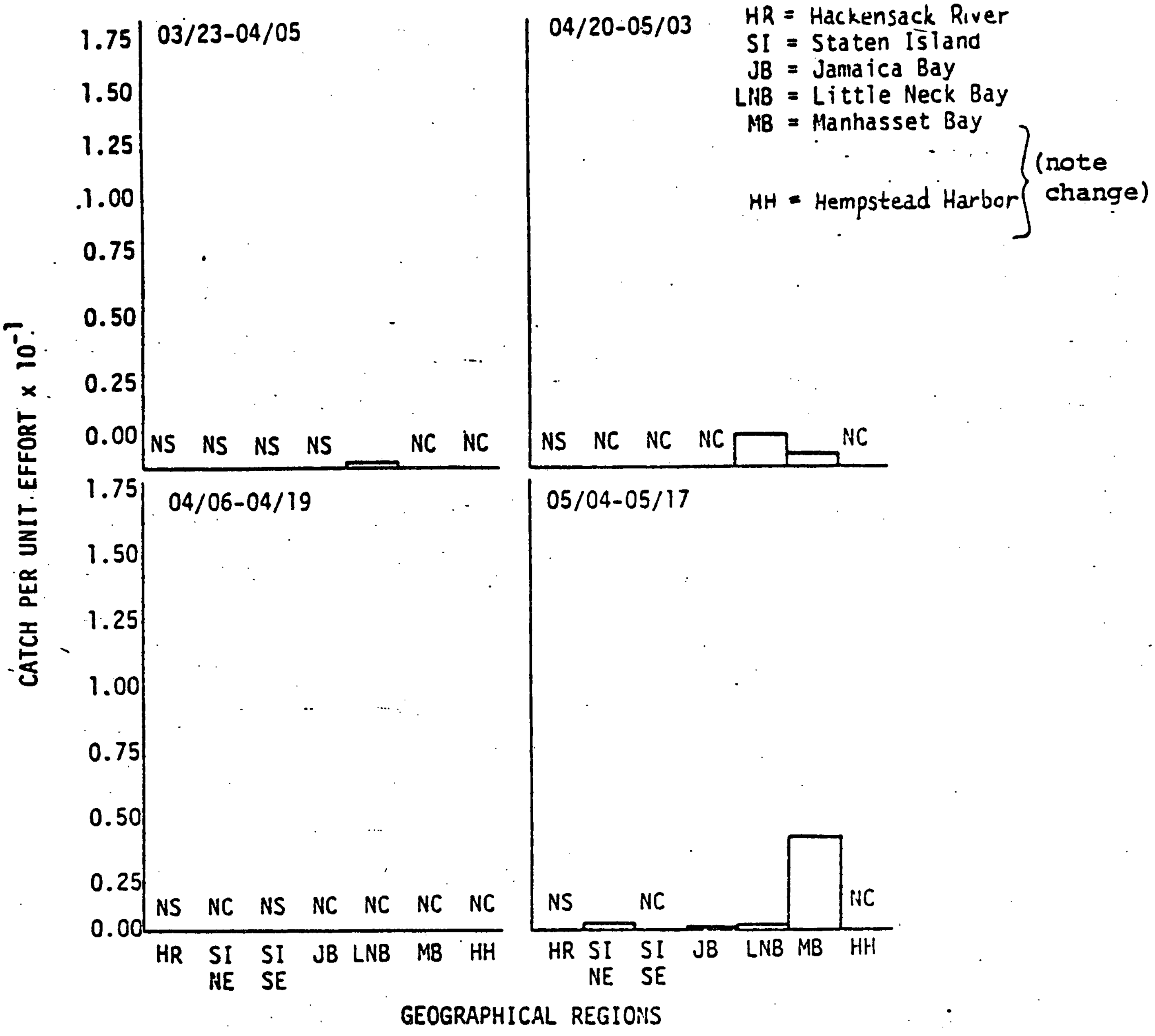

Figure 7.6-6 Yearling Striped Bass Catch per Unit Effort Within Seven Regions of Hudson River Estuary and Lower Bays Based on Day Sampling with 200-ft (61-m) Haul Seine during 1975 (Page 1 of 2)

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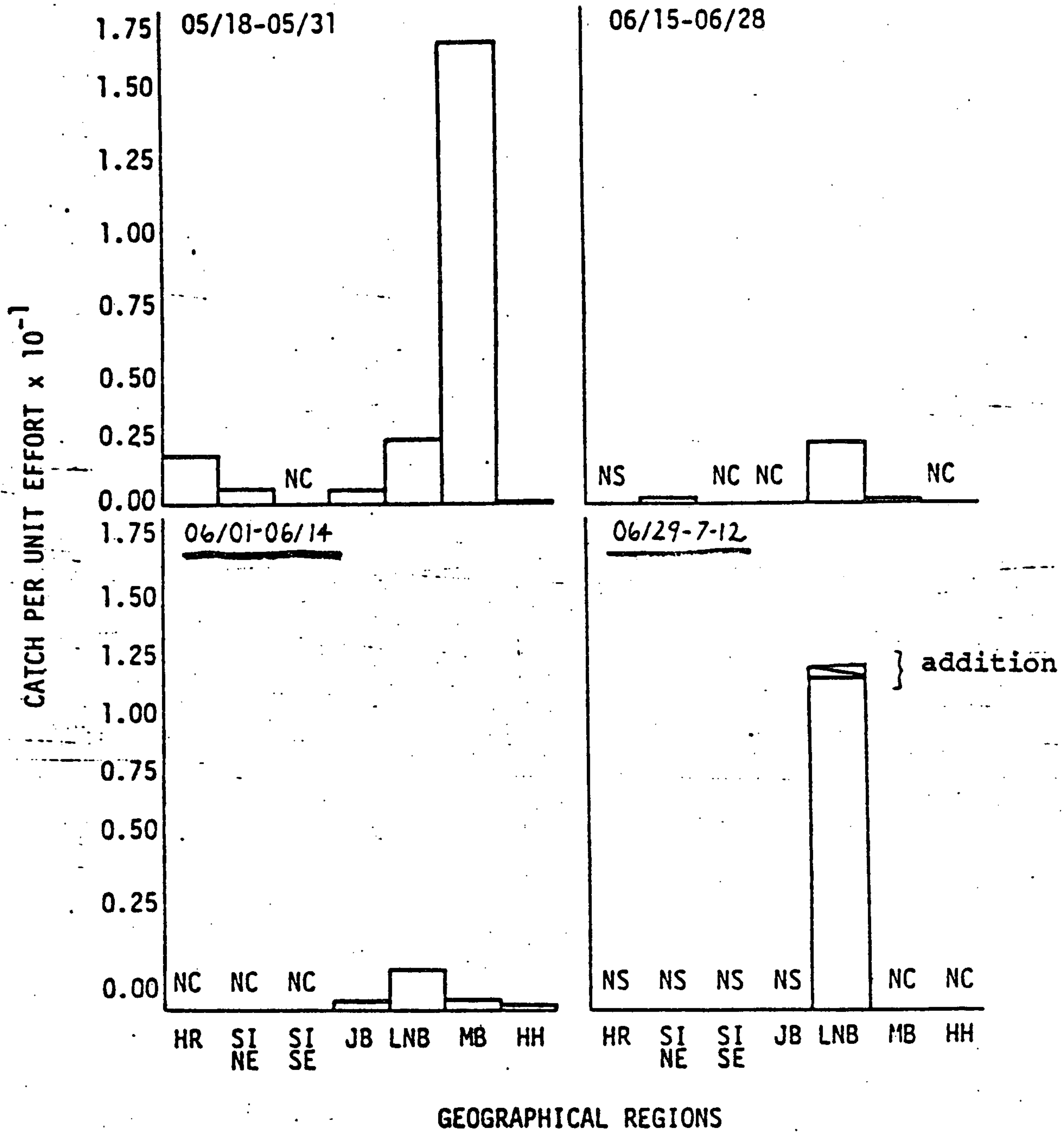

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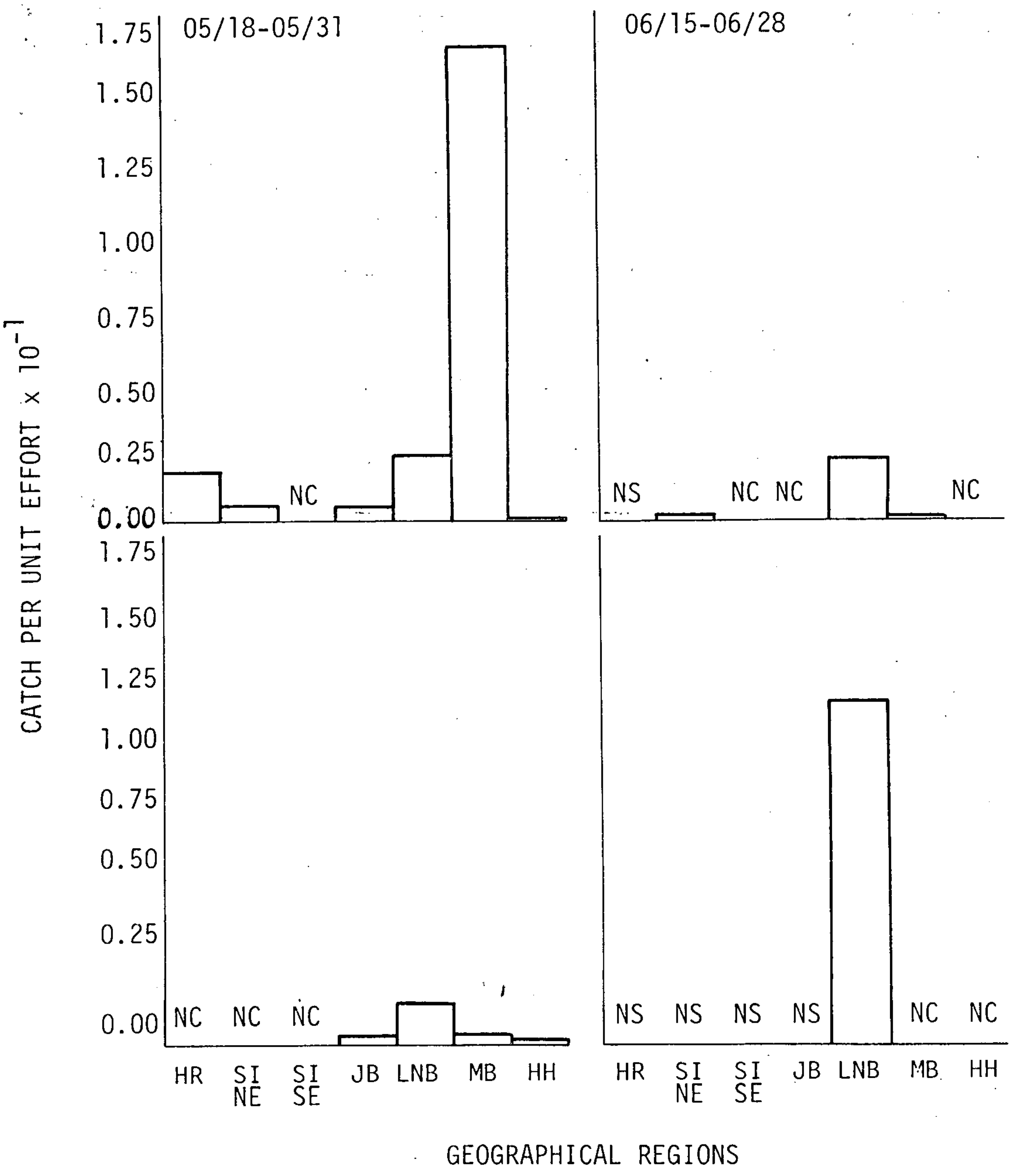

Figure 7.6-6 (Page 2 of 2)

Table 7.6-1 Comparison of Mean Total Lengths of Yearling Striped Bass* during May-July 1975 from Hudson River† and Five Areas in Lower Hudson River Estuary**

Region	Date (1975)	Mean TL (mm)	Standard Error	Number Measured
Hudson River	May	~~89.14~~ 88,90	~~2.82~~ 2,88	~~42~~ 41
	Jun	~~104.60~~ 99,58	~~3.67~~ 2,97	~~30~~ 33
	Jul	114.40	4.74	5
Little Neck Bay	May	~~118.06~~ 116.65	~~3.22~~ 2,92	17
	Jun	124.72	3.13	29
	Jul	~~134.11~~ 134,98	~~1.50~~ 1,36	~~103~~ 119
Manhasset Bay	May	~~124.16~~ 118,23	~~6.38~~ 0.93	~~207~~ 203
	Jun	127.0	~~8.09~~ 8,10	6
Jamaica Bay	May	117.40	2.51	10
	Jun	~~123.80~~ 117,25	~~7.11~~ 3,57	~~5~~ 4
Staten Island	May	~~105.92~~ 107.27	~~7.87~~ 8,49	~~12~~ 11
	Jun	100.0	2.0	2
Hackensack River	May	109.0	2.80	6
	Jun	~~122.33~~ 124,50	~~2.60~~ 2,50	~~3~~ 2

*Excludes hatchery-reared fish

**From haul seining

†From beach seine and trawl standard stations (Indian Point area, Section 7.5.4.5)

7.6.1.5 Movement - Mark/Recapture. Movement of yearlings appears to be minimal in the spring, with the greatest abundance occurring in the Tappan Zee, Croton-Haverstraw, and Indian Point regions. Of approximately 8,150 juveniles fin-clipped in the Hudson River in the Fall of 1974 (August-November), only 13 were recaptured in the river as yearlings during January-June 1975 and none reappeared in samples from the lower bays. Movement among regions was negligible (Table 7.6-2). Data for the 1975 year class showed similar trends (Table 7.6-3). A single yearling fin-clipped in the Yonkers region in spring 1976 was recaptured in Little Neck Bay in June 1976, further evidence that yearlings are emigrating from the Hudson River estuary during spring and summer. Of 254 yearling striped bass fin-clipped during April and May 1975 in the lower bays, eight were recaptured during summer 1975 in the same areas, suggesting that yearlings present in the lower bays of the Hudson River estuary do not move back into the river but remain in the lower bays or continue emigration to the ocean.

7.6.1.6 Distribution Related to Diel Periods and Tidal Stage. During 1974, average beach seine catches of yearlings from August through December were greater at night ($P = 0.065$, Wilcoxon signed rank test, 1-tailed) than during the day (Fig. 7.6-7). This is similar to day/night movements shown by juveniles (Section 7.5.4.5) and may indicate movement to the shorezone at night to feed or escape predation, although daytime gear avoidance may be a factor.

Tidal fluctuations apparently do not influence the abundance of yearling striped bass in the shorezone. Beach seine catches during four tidal stages (low slack, flood, high slack, and ebb) were not significantly different ($P > 0.10$, Friedman rank sums test, Hollander and Wolfe 1973).

7.6.2 SUMMARY. The distribution and movements of yearling striped bass in the Hudson River estuary and lower bays of the river mouth vary throughout the year. In early spring, yearlings are found in the deep-water overwintering areas of the lower Hudson River estuary. Movement

Table 7.6-2 Recaptures (from all sources) of Juvenile Striped Bass Fin-Clipped in Fall (August-November) 1974 (adjusted for 14-Day Mortality) and Recaptured in Spring (January-June) 1975

Release Area		Recapture Area (RM)					
(RM)	No. Marked	12-23	24-38	39-46	47-61	62-152	Total Recaptures
12-23	239		1	1			2
24-38	4687		2	1			3
39-46	2486	1	3	3			7
47-61	490						
62-152	255		1				1
Total Marked	8157						13

% Recaptured= 0.16

Table 7.6-3 Recaptures (from all sources) of Juvenile Striped Bass Fin-Cipped in Fall (August-November) 1975 (adjusted for 14-Day Mortality) and Recaptured in Spring (January-June) 1976

Release Area		Recapture Area (RM)					
(RM)	No. Marked	12-23	24-38	39-46	47-76	77-152	Total Recaptures
12-23 ~~12-33~~	1239	2	1	1			4
24-38	9213	1	10	2			13
39-46	3200	1		3			4
47-76	710				2		2
77-152	107				1		1
Total Marked	14469						24

% Recaptured= 0.17

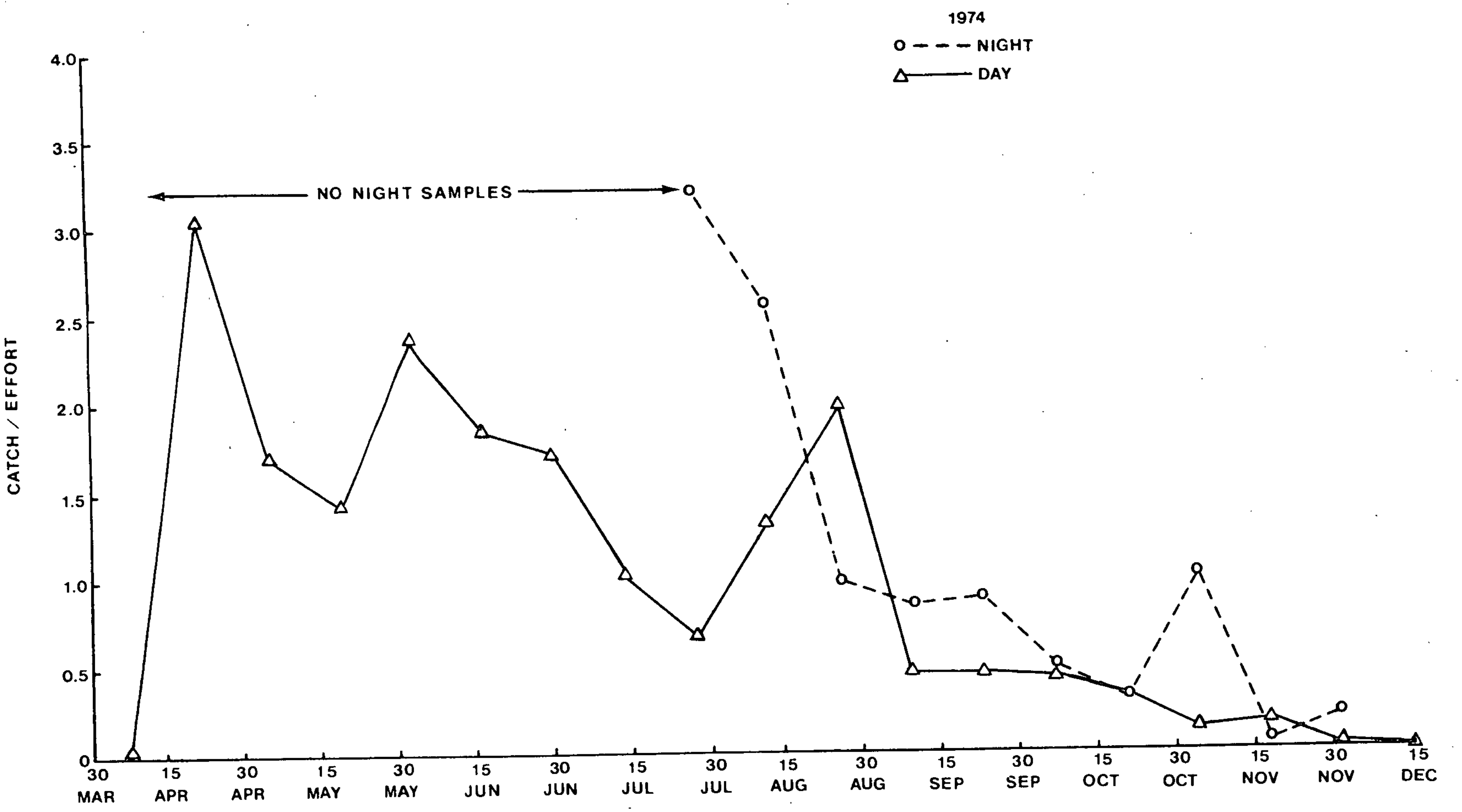

Figure 7.6-7 Beach Seine Survey Catch per Unit Effort for Yearling Striped Bass in Day and Night Sampling during 1974

from the deeper areas to the shorezone and beaches begins in late April. By mid-June, yearlings are distributed throughout the estuary and lower bays from Albany to the western end of Long Island. By November, those in the estuary move into deeper water and downstream, while those in the lower bays either remain in the same area or continue their emigration to the ocean. Tidal fluctuations do not appear to affect the abundance of yearlings; however, these fish move into the shorezone at night to feed and/or escape predation.

7.7 SUMMARY OF STRIPED BASS EARLY LIFE HISTORY

7.7.1 DEVELOPMENT. Striped bass eggs, which are semibuoyant and nonadhesive, depend on suspension in the water column for proper development (Table 7.7-1). Eggs can be maintained in suspension by either water movement or a high specific gravity of the water itself. Of these factors, water movement is the most important in the Hudson River, where eggs are almost always found in fresh water (low specific gravity).

Development of striped bass eggs is related to temperature. Time to hatch decreases as temperature increases. Hatching apparently does not occur below 12°C, and a decrease in percent of hatch occurs when temperatures exceed 18.9°C. Maximum egg hatches in the Hudson River occurred in the 14-18°C range in 1974 and in the 16-20°C range in 1975.

The yolk-sac stage extends from hatching until the digestive tract is complete (Table 7.7-1). At hatching, larvae are 2.0 to 3.7 mm long and have a large yolk-sac and well-defined oil globule; during this stage, the eyes become pigmented, the jaws and digestive tract form, fin buds appear, and the yolk-sac and oil globule are partially absorbed. Speed of development varies with temperature, the yolk-sac stage lasting 4-6 days at 19-21°C. Prolonged exposure to temperatures that are <12°C and >24°C may be lethal in some cases. Nearly all yolk-sac larvae collected in the Hudson River during 1974 and 1975 by Texas Instruments were found in water of 14-22°C, with the greatest catches occurring in water of 17-20°C. Because of

Table 7.7-1 Summary of Striped Bass Early Life Stage Development

Life Stage	Average Size	Motility	Physical Characteristics
Egg	3.4 mm diameter	None (semibuoyant)	A large oil globule; lightly granulated yolk mass; wide perivitelline ~~perivitteline~~ space; clear chorion
Yolk-sac larvae	Hatching: 2.0-3.7 mm End of stage: 5 - 6 mm	Little weak, irregular swimming movement	A large yolk-sac and well defined oil globule; eyes become pigmented; jaws and digestive tract form; fin buds appear
Post Yolk-sac larvae	End of stage: ~16 mm	Moderate: directed movement; can oppose current	Complete digestive tract; yolk-sac and oil globule completely absorbed; fins begin to form
Juvenile	End of stage: ~100 mm	Strong: long-distance migration possible; 5.7-11.2 bl s^{-1} for 3 or 4 min	Complete set of fin rays; scales develop; fins fully develop; adult form and coloration
Yearling	180-200 mm	Similar to adult	Adult characteristics other than sexual maturity

their anatomy and buoyancy, yolk-sac larvae drift in a headup position and are oriented vertically during their short, irregular swimming movements. Observed swimming movements have varied from 100 to 400 mm in distance and 3 to 15 s in duration. This potential for limited movement suggests that larvae are essentially planktonic but can migrate somewhat if not opposed by a current.

The post yolk-sac stage starts with completion of the digestive tract and ends with development of the complete set of adult fin rays (Table 7.7-1). During this stage, body pigmentation becomes visible, fins begin to form, and the remaining yolk-sac is absorbed. During 1974 and 1975, post yolk-sac larvae were collected in the Hudson River where temperatures ranged from 16-24°C, which was within the tolerance range noted for this life stage. Post yolk-sac larvae are active swimmers and are more capable of strong, directed movement than are yolk-sac larvae. Swimmming ability during this stage is sufficient to oppose currents, capture prey, and avoid predators. Presumably, post yolk-sac larvae are also capable of limited directed movement to avoid environmental stress.

Early juveniles collected during 1973-75 ranged from 14 to 31 mm in total length; the adult body shape, scales, and fully developed fins are not present until total length is about 35 mm, and adult coloration does not appear until the young are about one year old and have an average length of approximately 130 mm. Juveniles are strong swimmers, so they can avoid predators, capture prey, and undergo migration. Most juveniles are able to swim between 5.7 and 11.2 bl s^{-1} (body lengths per second) for 3 min or more. They are quite tolerant of moderate changes in physicochemical factors within the range necessary for survival; an abrupt temperature change, however, may momentarily immobilize them, and temperatures <12°C or low dissolved oxygen levels may impair swimming ability.

Juveniles are classified as yearlings after January 1 of the first year of life. Growth is minimal during winter. In spring, yearlings average about 130 mm in total length and resemble the adults in appearance. Yearlings also resemble adults in swimming ability except for absolute speed and endurance values.

7.7.2 DISTRIBUTION AND MOVEMENTS. Riverwide distribution for the early life stages was deduced from catch statistics for different gear types and sampling areas. Two areas of the Hudson River, Cornwall and Indian Point were studied intensively to determine the distribution of striped bass eggs and larvae in relation to day/night abundances, position in the water column (surface, middle, and bottom), and area of the river. Each river region studied is unique with respect to current velocities, upwellings, and water depths, and these physical characteristics create complex patterns of distribution of young fish. However, some patterns such as vertical distribution are similar in the Indian Point study and the Cornwall study and are consistent with other studies reported in the literature, so the migration phenomena that produce them must be of river-wide occurrence.

Striped bass spawning was concentrated upriver from the salt front in fresh water. Maximum catches of eggs during May were from the Indian Point and West Point regions, with densities declining both up and downriver; however, some eggs were collected in all regions sampled except Yonkers. Both the Cornwall and Indian Point studies indicated that the eggs were concentrated near the bottom of the river. The Cornwall study also revealed higher egg densities during the day than during the night.

During May and June 1975, yolk-sac larvae exhibited greatest densities in the Indian Point and West Point regions, although substantial catches also occurred in the Tappan Zee-Saugerties regions. Yolk-sac larvae were more dispersed throughout the river than eggs. The Cornwall and Indian Point studies suggested that yolk-sac larvae were concentrated near the bottom during the day but dispersed upward through the water column at night. Since striped bass eggs exhibited no day/night differences in vertical distribution, yolk-sac larvae must have had sufficient swimming ability to move vertically at night.

Post yolk-sac larvae reached maximum abundance during June, when the highest densities occurred in the Indian Point and West Point regions. The overall distribution resembled that of yolk-sac larvae, with some post yolk-sac larvae having been taken in all river regions except Albany. The vertical distribution was complicated by differences between regions and the gradual transformation from the post yolk-sac to juvenile stage. Post yolk-sac larvae generally exhibited nighttime migrations similar to those of yolk-sac larvae, but were more strongly oriented toward the bottom, a behavior trait that may intensify as the larvae approach the juvenile stage.

Juvenile striped bass were first collected in late June, occurring in depths exceeding 20 ft (6 m). As the water temperatures increased, juveniles migrated from deeper water to the shoals and shorezone (Fig. 7.7-1). This shoreward movement was largely completed by the end of July, when over 90% of the standing crop estimated from ichthyoplankton sampling was in shoal areas. During July, the largest catches were taken in Indian Point and surrounding regions; however, juveniles were distributed throughout the entire river region sampled. From August through October, catches remained high from Indian Point through Yonkers. Catches in upriver areas declined in the fall as the temperature dropped to approximately 12°C, suggesting a net downstream movement of the juvenile population and emigration of some individuals from the estuary during October and November. By December, juveniles were nearly absent from the shoals and shorezone, having either left the estuary or moved to deeper water.

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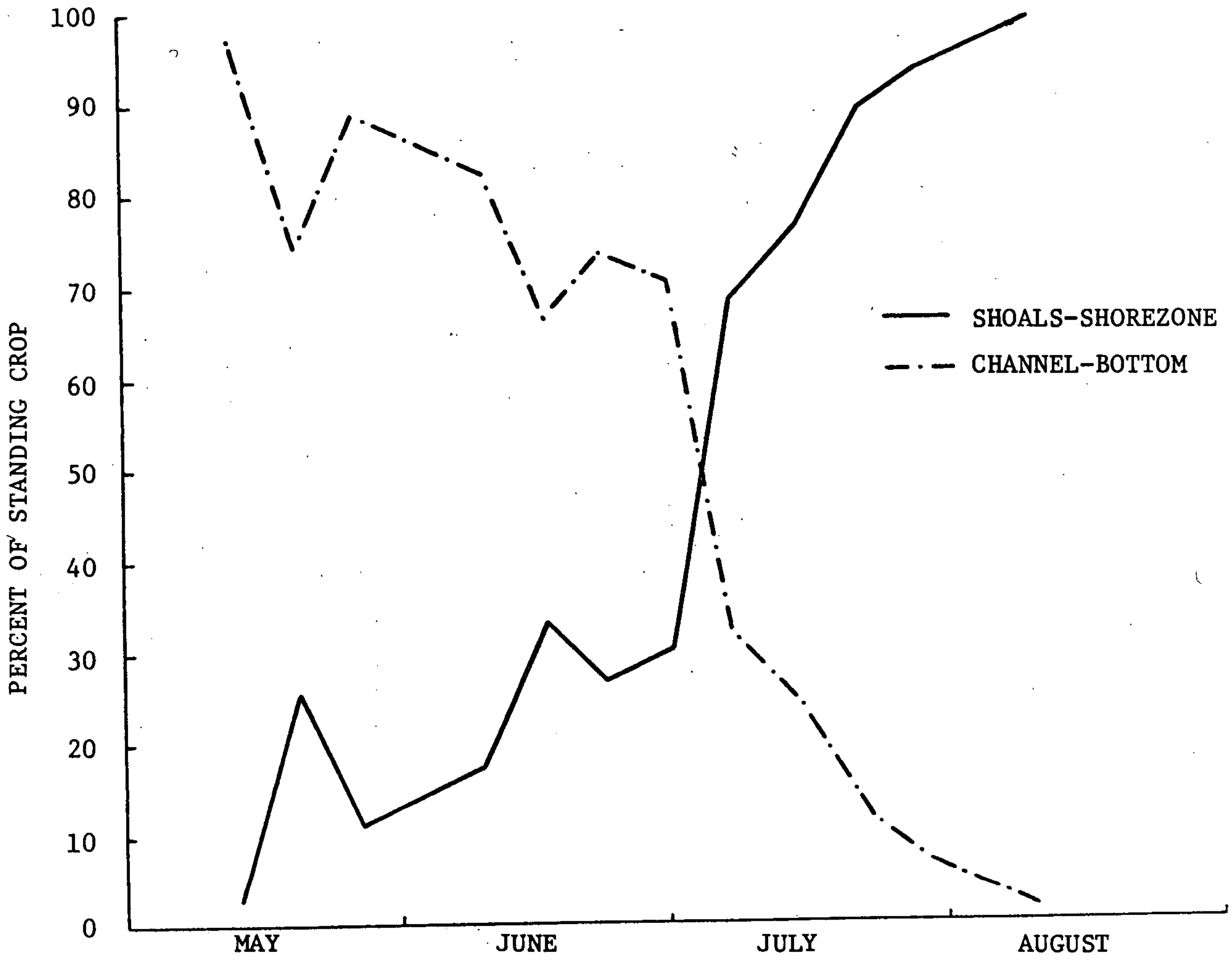


Figure 7.7-1 Percent of Standing Crop of Young-of-the-Year Striped Bass (all life stages combined) in Shoal Areas and Channel-Bottom Areas of the Yonkers-Indian Point regions (RM12-46) of the Hudson River Estuary during 1975

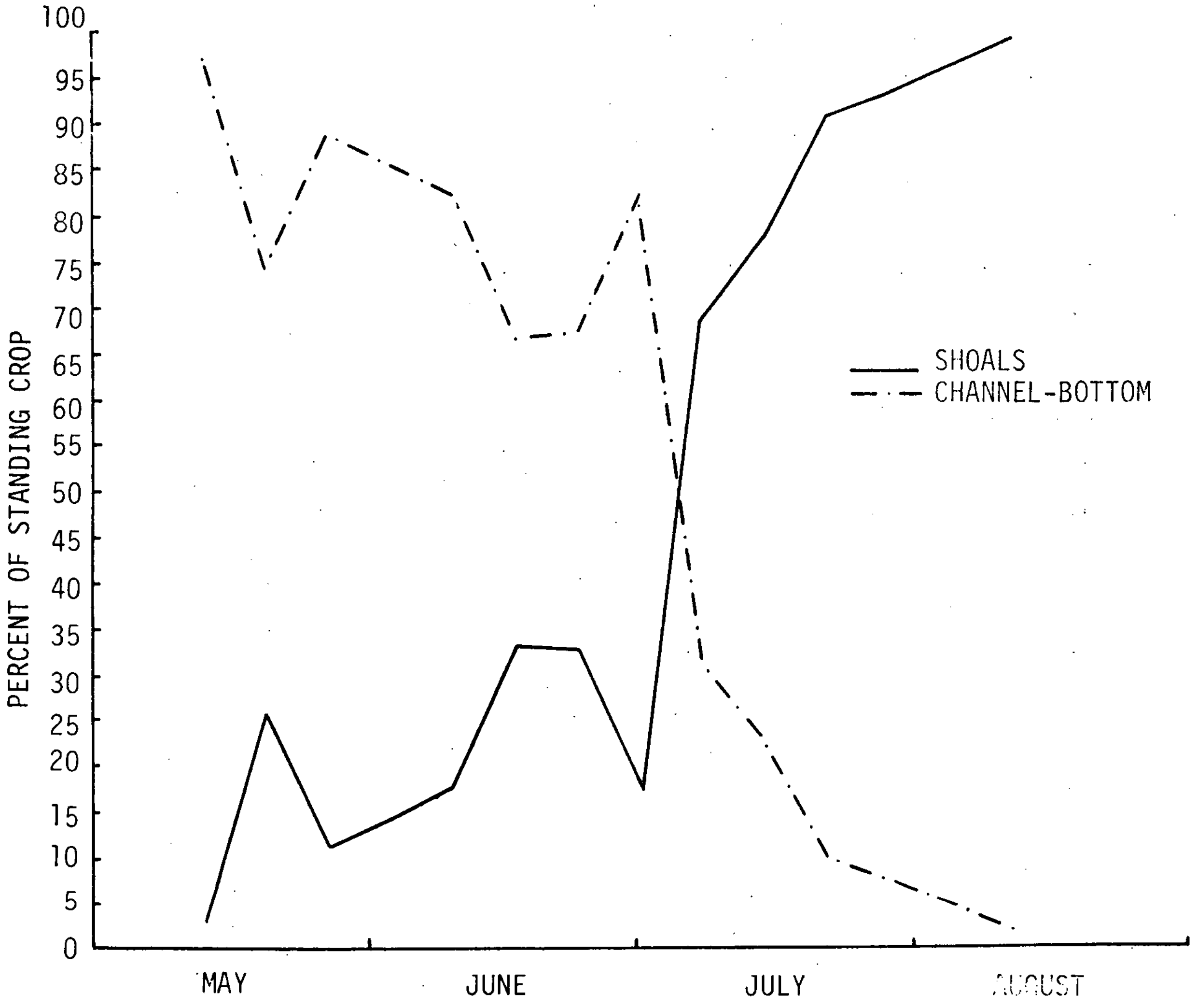


Figure 7.7-1 Percent of Standing Crop of Young-of-the-Year Striped Bass (all life stages combined) in Shoal Areas and Channel-Bottom Areas during 1975

Local abundances of striped bass juveniles during summer and fall were influenced by changes in temperature, salinity, habitat type, day/night patterns, and tidal stage. There were significantly more juveniles on beaches adjacent to deep water than on beaches adjacent to heavily vegetated areas. Shorezone density was greater at night. Juveniles caught at night were smaller in length than those taken during the day, suggesting that the larger night catches were not the result of daytime gear avoidance. Juveniles presumably moved into the shorezone at night to feed or escape predation. Daytime juvenile density was significantly greater during flood and ebb tides than during high and low slack tides; juveniles may concentrate on the beaches to avoid tidal currents in the channel, then disperse during slack tide.

Yearlings were found in early spring in deep-water areas of the lower Hudson River estuary, where a portion of the population is believed to have overwintered. This segment of the yearling population then appeared to disperse both upstream and downstream to become distributed by mid-June throughout the estuary and lower bays (Albany to the western end of Long Island). It is not known what fraction of the entire yearling population this riverine group represents. By November, declining yearling abundance in the shorezone, particularly above Cornwall indicated a movement to deeper water and downstream. Yearlings already present in the lower bays appeared to move eastward along the north shore of Long Island and possibly west to Staten Island. From August through December 1974, yearlings were more abundant in the beach areas at night, indicating that they have the same day/night movements exhibited by juveniles. Tidal fluctuations, however, did not appear to influence the abundance of yearling striped bass in the shorezone.

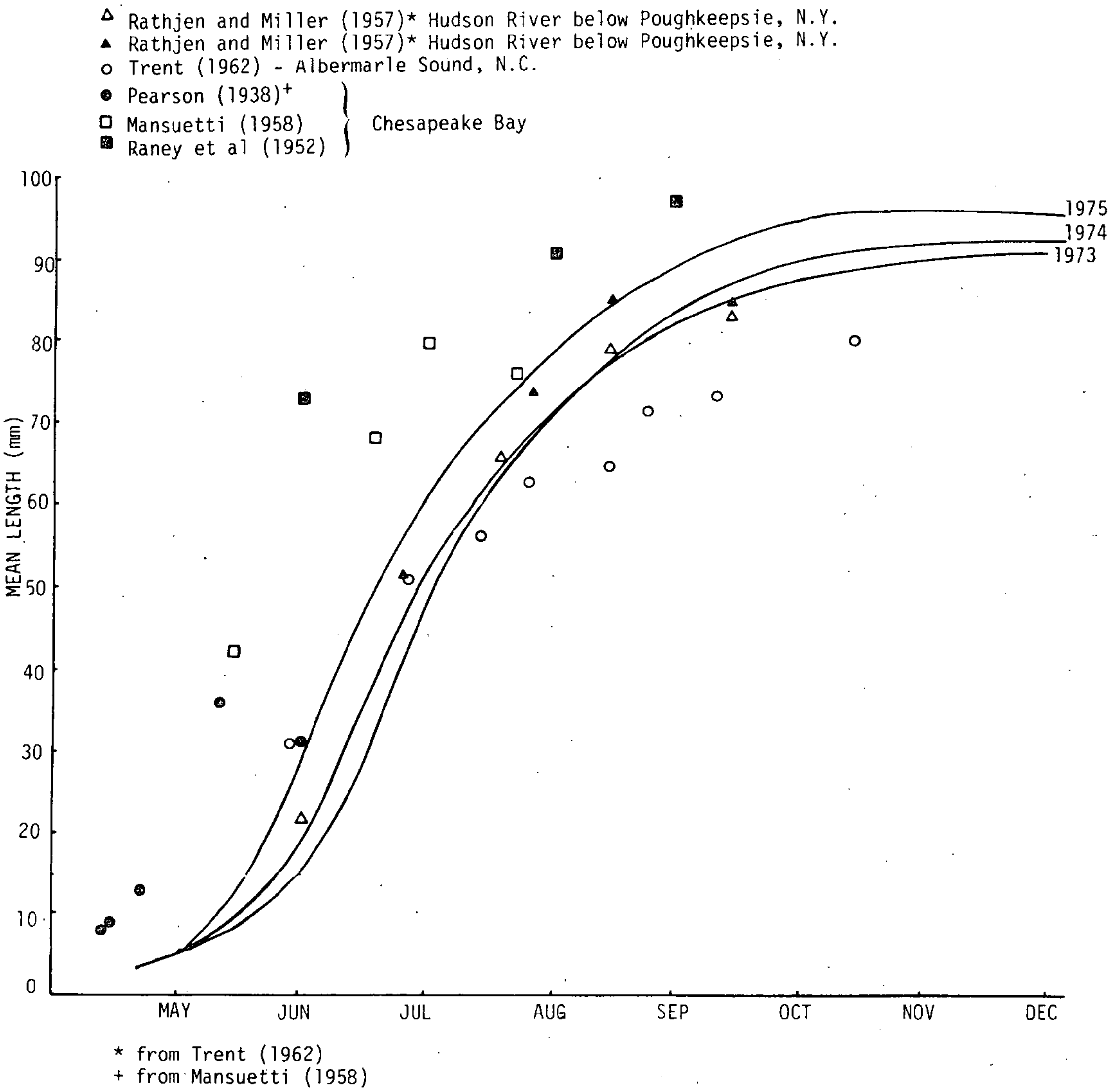
7.7.3 GROWTH

7.7.3.1 Hudson River Striped Bass Growth. To define first-year growth of striped bass in the Hudson River estuary, length-frequency data were collected from ichthyoplankton and fisheries sampling programs conducted in many sections of the estuary during 1973, 1974, and 1975. Mean lengths for striped bass were computed for each sampling period. Since traditional growth equations (e.g., von Bertalanffy) are generally applicable only to the postjuvenile life stages (Ricker 1975:225), curves relating mean length and time were fitted by eye (Fig. 7.7-2). These curves' S shape suggests that first-year growth can be divided into three phases.

During the first phase (May 15 - June 15) striped bass larvae show a gradual increase in mean length, 0.13-0.26 mm day^{-1}. This period of slowly increasing size results from three factors: (1) the period represents a time of predominantly allometric growth, (i.e., body proportions are changing as length increases); therefore, changes in length do not necessarily reflect the extent of growth in all dimensions during this period; (2) because of the small size of the larvae, only a small change in absolute length is achieved even though instantenous growth rates are very high; and (3) hatching provides constant recruitment of small (approximately 3 mm TL) larvae, resulting in a low population mean length for a prolonged period of time.

During the second phase, June 15 - August 31, growth is extremely rapid, ranging from 0.83 to 0.87 mm day^{-1}. This phase begins with the onset of feeding after yolk-sac absorption and corresponds to the period of warm temperatures and high food availability. The transition from post yolk-sac larvae to juvenile life stage occurs later in this phase, resulting in a shift from allometric to predominantly isometric growth. This phase also corresponds to the time of movement of striped bass young from deep water to shoal nursery areas (Fig. 7.7-1).

During the last phase of first-year growth, September 1 - December 31, growth slows, then stops with the onset of cold temperatures. This appears to be a result of temperature-related changes in metabolism, although declining food availability also may occur. During this phase, juvenile striped bass move from the shoal areas to deeper water for overwintering (Section 7.5). By the end of their first year,



* from Trent (1962)
\+ from Mansuetti (1958)

Figure 7.7-2 First-Year Growth among 1973, 1974, and 1975 Year Classes of Striped Bass in Hudson River Estuary (solid lines) Related to Mean Lengths Reported for Striped Bass from Other Atlantic Coast Populations (individual point symbols)

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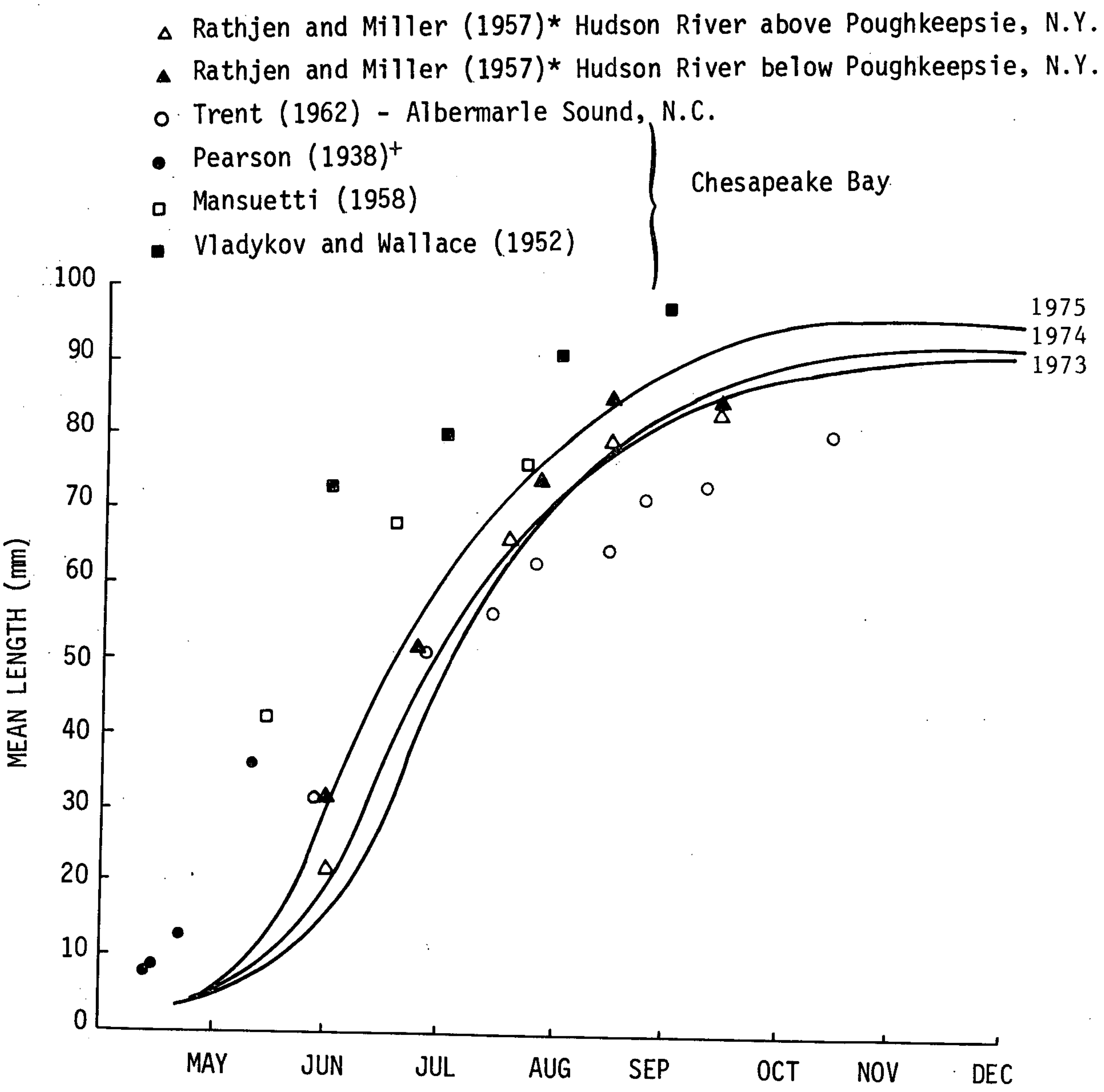

* from Trent (1962)
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Figure 7.7-2 First-Year Growth among 1973, 1974, and 1975 Year Classes of Striped Bass in Hudson River Estuary (solid lines) Related to Mean Lengths Reported for Striped Bass from Other Atlantic Coast Populations (individual point symbols) striped bass have experienced a thirty fold increase in length since hatching and have essentially attained adult body form.

Young-of-the-year striped bass were substantially larger during 1975 than during either 1973 or 1974; this appeared to have been the result of extremely rapid growth during the first phase (May 15 - June 15). Relating instanteous growth rate (Ricker 1975:207) to mean water temperature during this phase suggests that growth was dependent on water temperature (Fig. 7.7-3). The relationship between temperature and growth rate may have resulted from an increased metabolic rate (direct), or from a temperature-related increase in food availability (indirect).

The relationship between growth and temperature was further investigated using available length data from beach-seine sampling. ~~August~~ Late July mean length, available for the 1965-1975 ~~1965, 1967, 1968, 1970, 1973, 1974,~~ ~~and 1975~~ year classes of striped bass (excluding 1971) was ~~significantly~~ correlated with the mean May ~~15~~ 16 - June 15 water temperature for the same years ($r = 0.55$, $P = 0.10$ ~~($r = 0.811$, $P \leq 0.05$~~; Fig. 7.7-4), suggesting that juvenile size in late July is directly related to the temperatures that occurred during the larval period.

[~~The increment of growth between July and August was inversely related~~ to ~~density (Section 10.6). Thus, growth appeared to be regulated by both density-dependent and density-independent factors.~~]

The 1975 year class of striped bass was spawned later in the year than either the 1973 or 1974 year classes (Fig. 7.7-5). However, the 1975 year class reached the juvenile stage earlier in the season than either of the other two year classes, suggesting that warmer temperatures during 1975 not only increased growth rate but also decreased the duration of each of the early life stages (egg, yolk-sac larva, post yolk-sac larva).

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The relationship between growth and temperature was further investigated using available length data from beach-seine sampling. August mean length, available for the 1965, 1967, 1968, 1970, 1973, 1974, and 1975 year classes of striped bass, was significantly correlated with the mean May 15 - June 15 water temperature for the same years ($r = 0.811$, $P \leq 0.05$; Fig. 7.7-4), suggesting that juvenile size is related to the temperatures that occurred during the larval period.

The increment of growth between July and August was inversely related to density (Section 10.6). Thus, growth appeared to be regulated by both density-dependent and density-independent factors.

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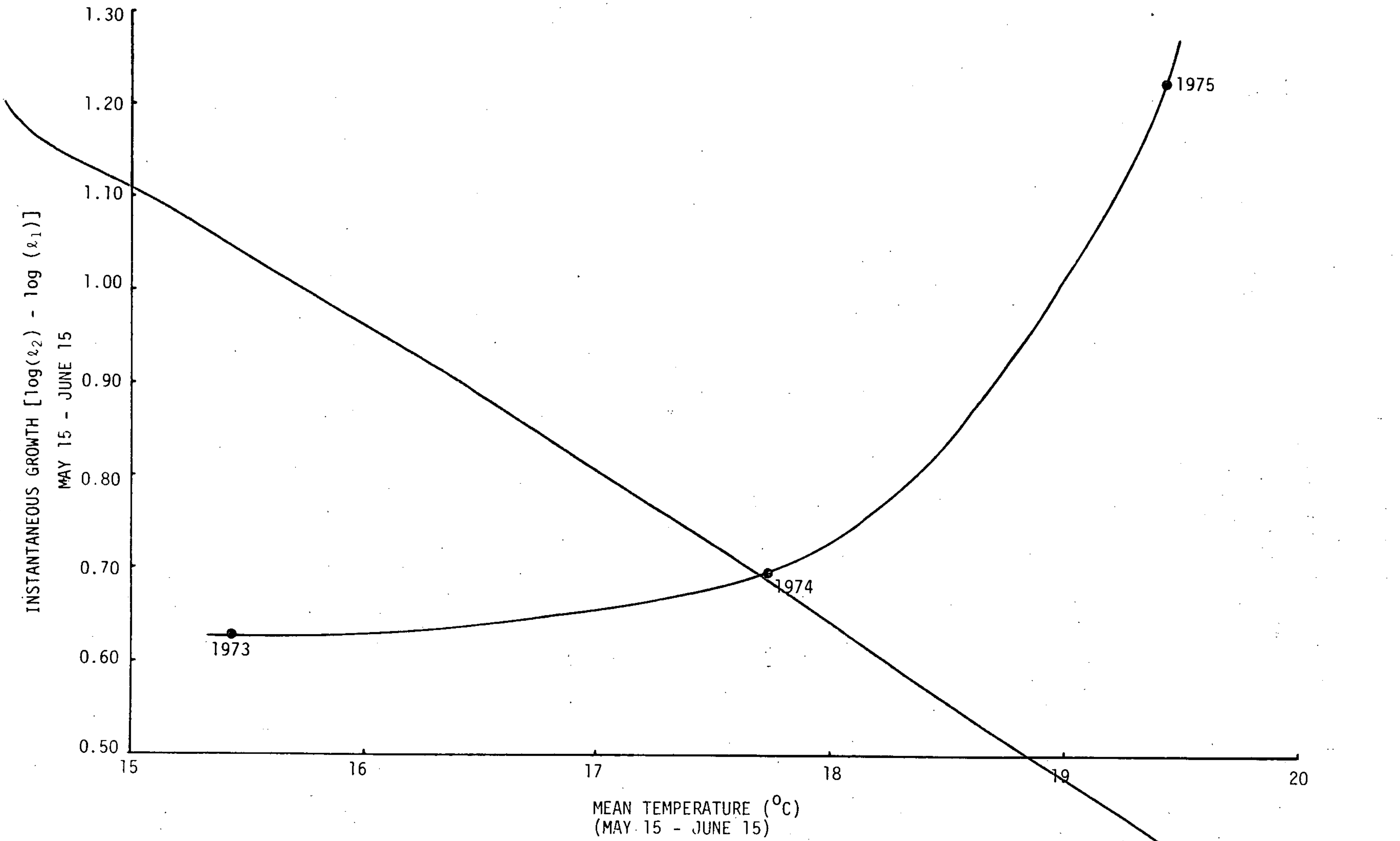

Figure 7.7-3 Relationship of Mean Water Temperature and Instantaneous Growth Rate during Same Period, May 15 - June 15, for 1973, 1974, and 1975 Year Classes of Striped Bass in Hudson River Estuary

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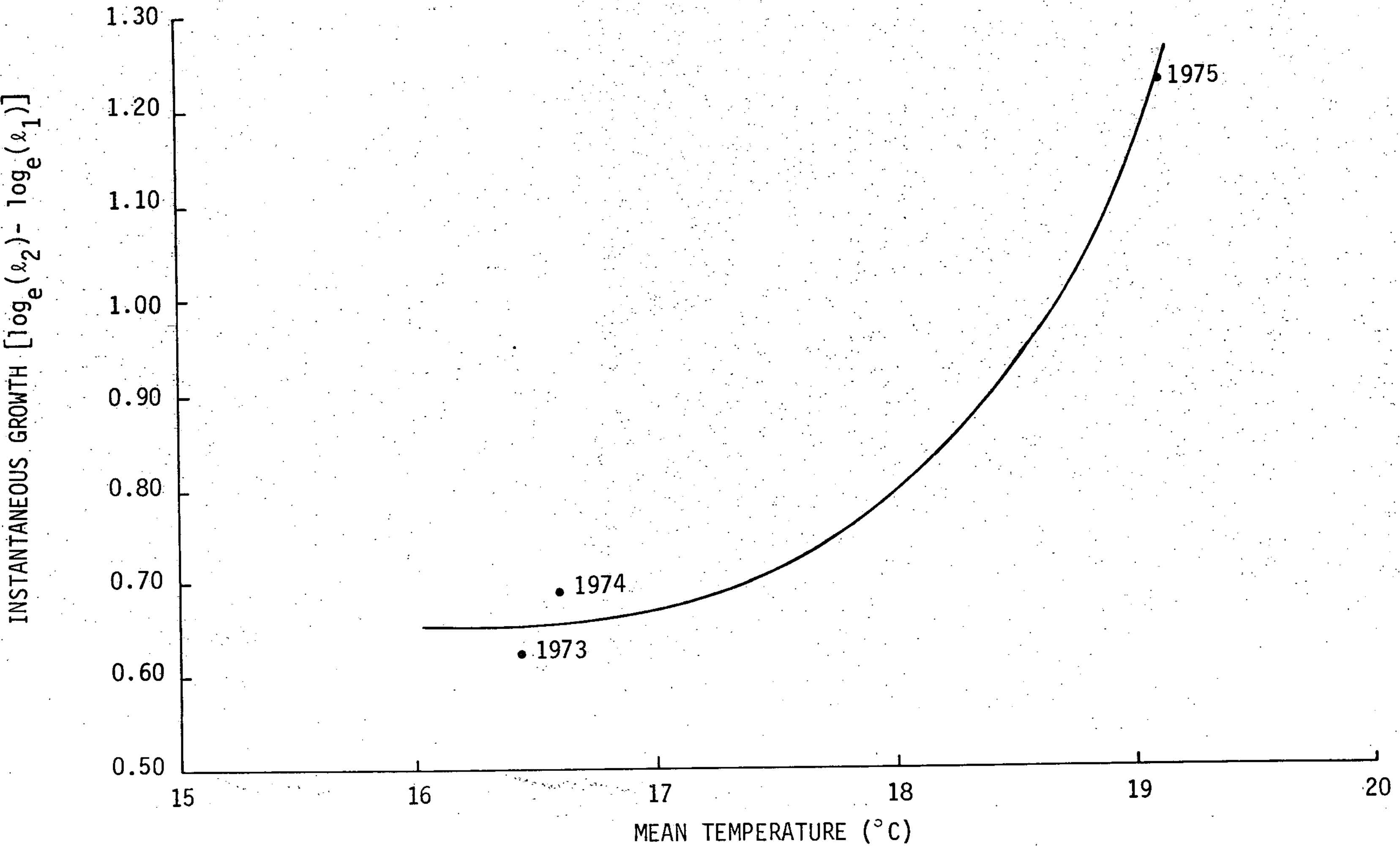

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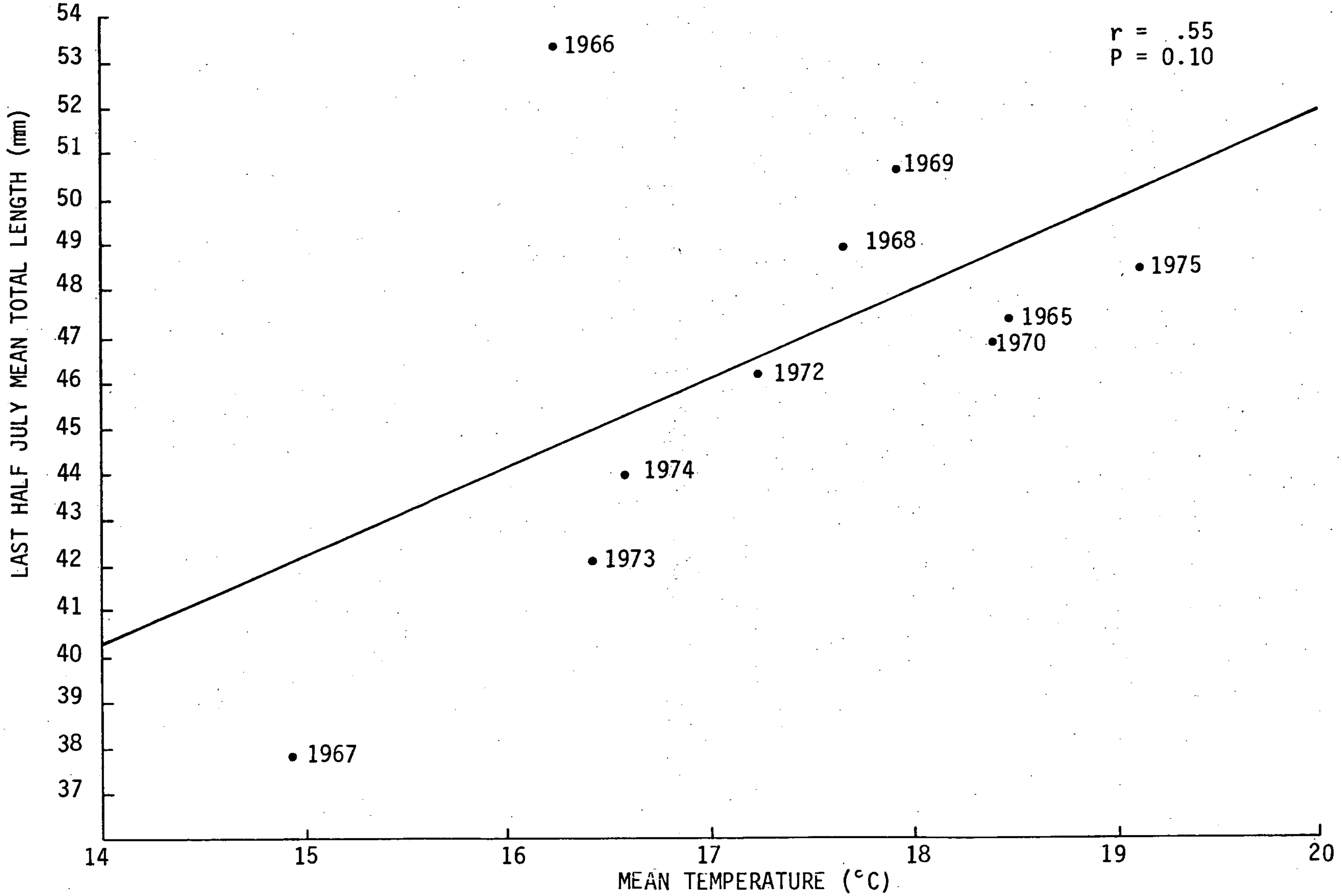

Figure 7.7.-4 Relationship of Mean Water Temperature, May 16-June 15, to Last Half July Size for Young-of-the-Year of 1965, 1966, 1967, 1968, 1969, 1970, 1972, 1973, 1974, and 1975 Year Classes of Striped Bass in Hudson River Estuary

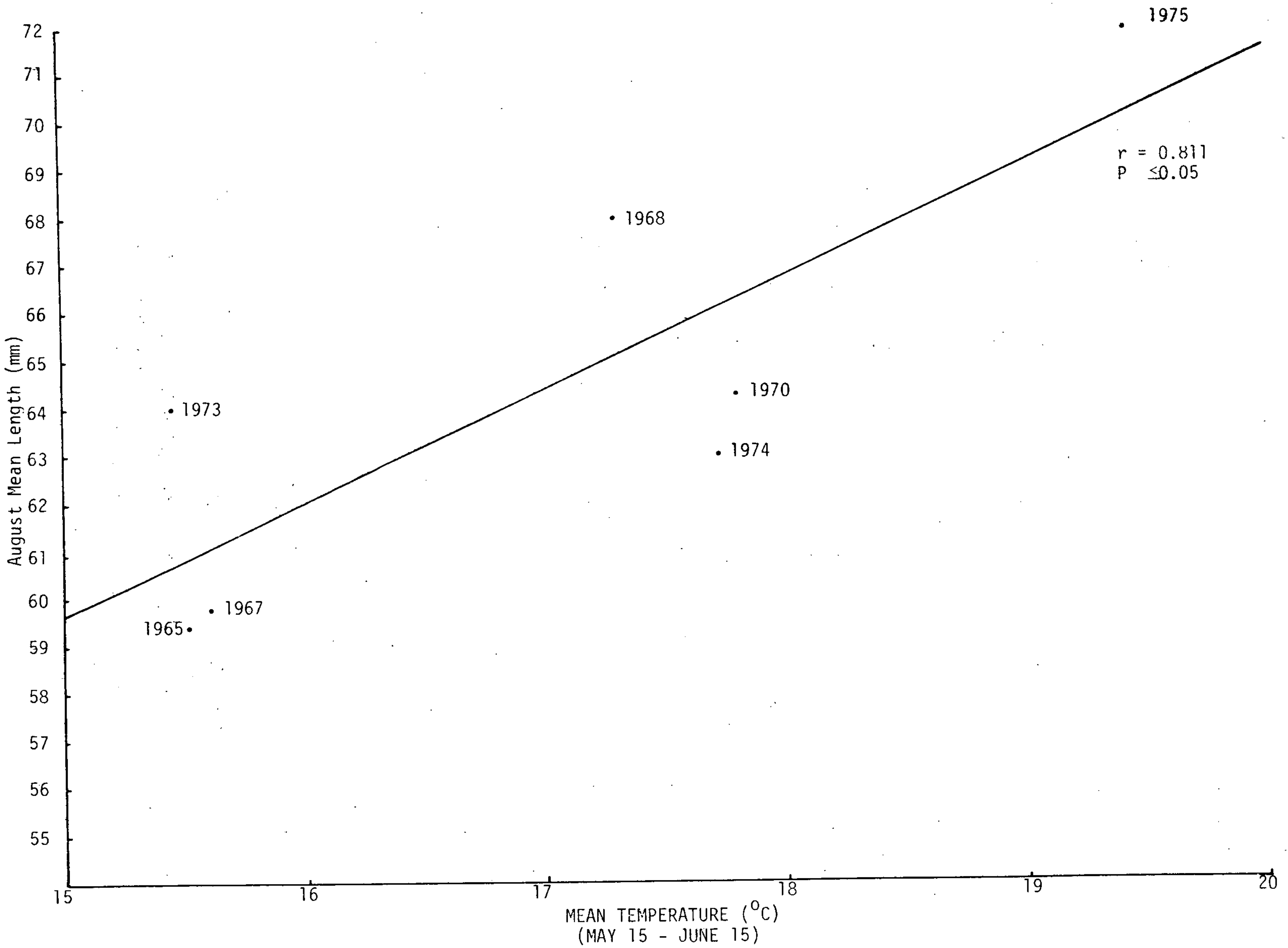

Figure 7.7-4 Relationship of Mean Water Temperature, May 15 - June 15, to August Mean Size for Young-of-the-Year of 1965, 1967, 1968, 1970, 1973, 1974, and 1975 Year Classes of Striped Bass in Hudson River Estuary

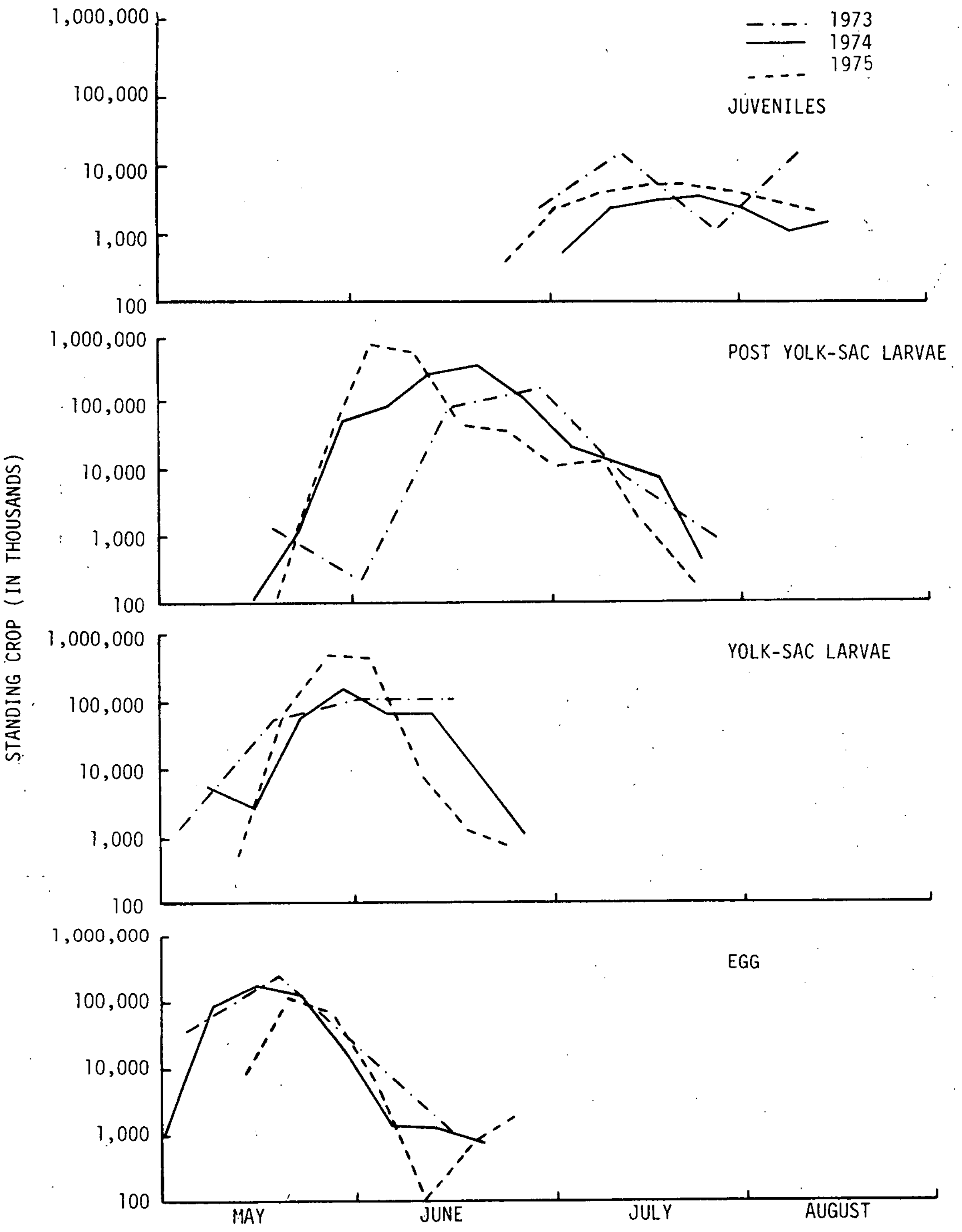

Figure 7.7-5 Standing Crops of Egg, Yolk-Sac Larvae, Post Yolk-Sac Larvae, and Juveniles of 1973, 1974, and 1975 Year Classes of Hudson River Striped Bass

Second-year growth was estimated from length-frequency data for yearling striped bass of the 1973 and 1974 year classes. Growth curves fit by eye to these data showed an S-shape similar to the curves for the young-of-the-year (Fig. 7.7-6) although second-year growth began earlier in the year than did the first-year growth. Since relatively few yearling striped bass were collected, year comparisons of second-year growth were not practical.

7.7.3.2 Comparisons With Other Striped Bass Populations. Comparisons of length, and consequently growth, between studies conducted with differing sampling gear must be made with care since it has been shown that juvenile striped bass mean length differs among sampling gear (Fig. 7.5-1). Even with this potential problem, generalized comparisons between the various striped bass populations can be cautiously made.

Growth rates for juvenile (young-of-the-year) Hudson River striped bass were within the range of reported growth rates for other Atlantic coast striped bass populations (Fig. 7.7-2). Striped bass from the Chesapeake Bay system were consistently larger than Hudson River striped bass at the same times during the year, which may reflect the earlier spawning date and a subsequently longer growing season for Chesapeake fish. Growth of the 1973, 1974, and 1975 year classes of Hudson River striped bass was similar to that previously reported for the Hudson River (Rathjen and Miller 1957) and generally greater than that of striped bass from the Albermarle Sound, North Carolina (Trent 1962).

7.7.4 MORTALITY IN HUDSON RIVER STRIPED BASS. The 1975 year class of Hudson River striped bass was chosen for survival estimates from the egg stage through the end of the first year of life because its short spawning season reduced estimation bias that results from a continued recruitment of eggs. Survival rates were calculated using number of eggs spawned estimated from the adult striped bass life table presented in Section 7.8, ichthyoplankton standing crops, and the combined estimates of juvenile population size presented in Section 7.9. These data suggested

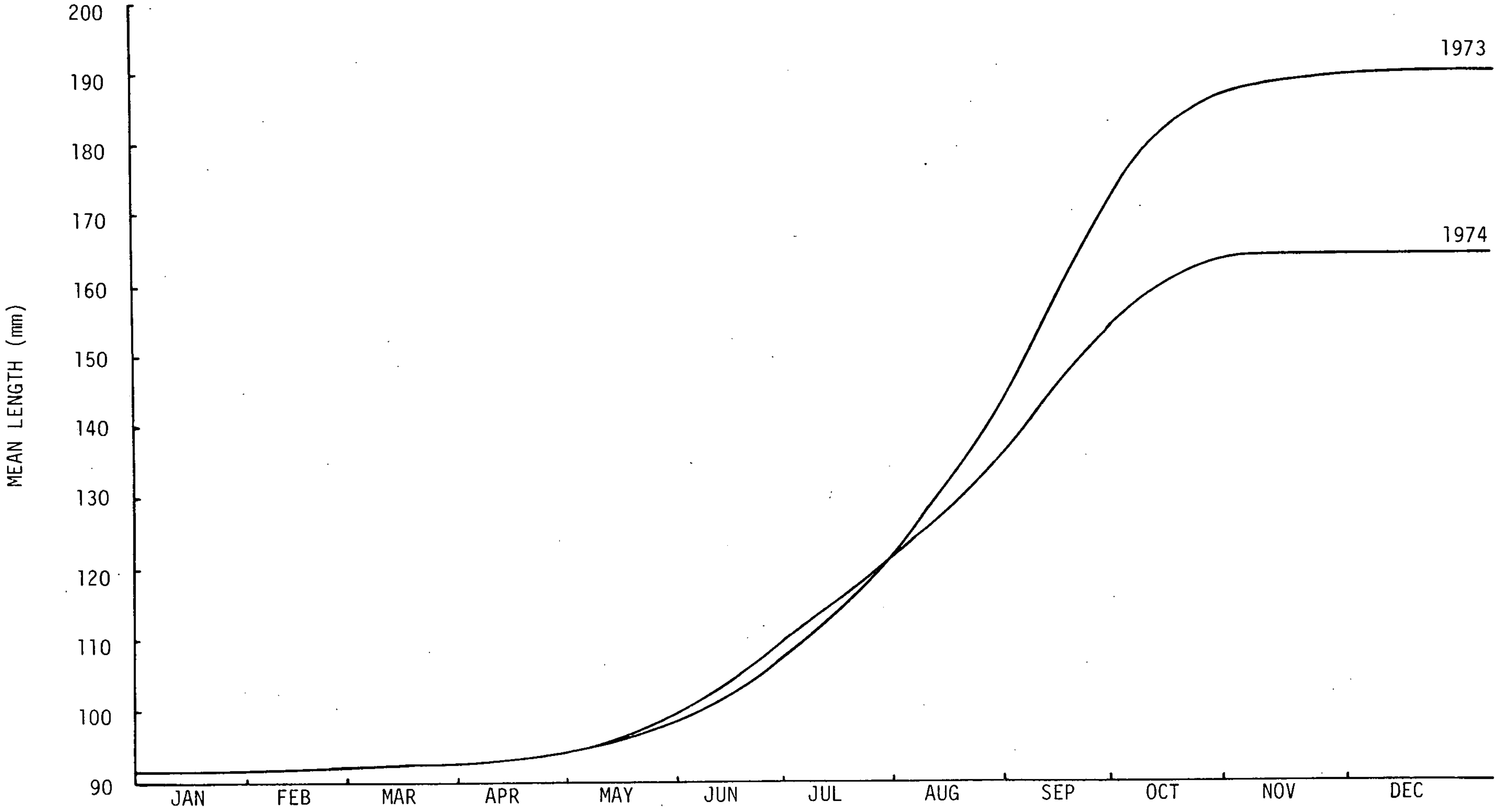

Figure 7.7-6 Second-Year Growth among 1973 and 1974 Year Class of Striped Bass in Hudson River Estuary

that the first year (May-December 1975) could be divided into four phases, characterized by different mortality rates (Fig. 7.7-7). During the first phase (I), the striped bass were in the egg and yolk-sac larval life stages; during the next phase (II), the striped bass were predominately yolk-sac and post yolk-sac larvae; the third phase (III) corresponded to the transition from post yolk-sac larvae to juvenile; and the final phase (IV) continued to the end of the year during which the striped bass were all juveniles. Within phases II, III and IV, the natural logarithm of the population size was regressed against time; the slope of the resultant line permitted estimate of the daily mortality rate for each of the three phases (Table 7.7-2).

Table 7.7-2 Time Interval and Corresponding Daily Mortality Rates for Each of Four Phases of Uniform Mortality in 1975 Year Class of Hudson River Striped Bass

Phase	Time Interval	Daily Mortality Rate
I	21 May 1975-30 May 1975	24.73%
II	31 May 1975-24 June 1975	17.59%
III	25 June 1975-26 July 1975	5.06%
IV	26 July 1975-31 December 1975	0.48%

For purposes of this discussion, it was assumed that all the eggs were spawned on May 21 with a fertilization rate of 50%. This resulted in an estimated 44 billion fertilzed eggs. Comparing this estimate to the standing crop of 3.4 billion on May 30, estimated from the phase II regression, resulted in an estimated 24.7% daily mortality rate over phase I (Table 7.7-2).

The daily mortality rates declined from almost 25% day^{-1} during phase I to < 1% day^{-1} during phase IV. This decrease in mortality may have been due to several potential factors including decreased density, changing environmental parameters, and growth and development of the individuals. Development may play an extremely important role as one of the periods of high mortality, phase II, coincides with the time of first feeding associated

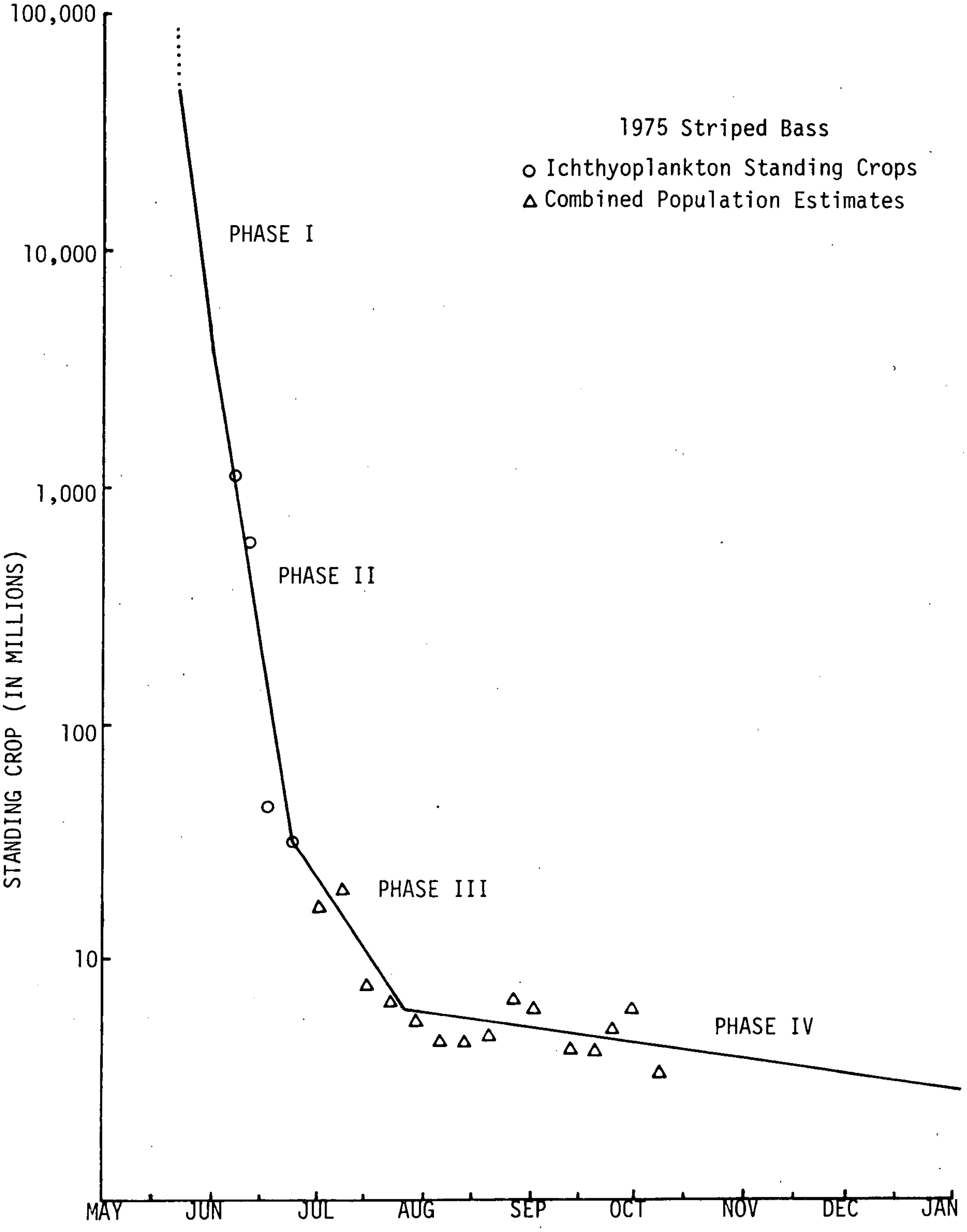

Figure 7.7-7 The Relationship between Population Size and Time for 1975 Year Class of Hudson River Striped Bass during First Year of Life

with the transition from the yolk sac to the post yoak-sac larval stage. Several authors (e.g., May 1974) suggest that the survival rate of many fish species during this "critical period" determines the subsequent size of that year class. During periods of high mortality, compensatory changes in mortality rates can have the greatest effect on the resultant population size (Section 10.6.5).

7.8 STRIPED BASS BEYOND THE YEARLING STAGE

7.8.1 INTRODUCTION

Striped bass beyond the yearling stage differ from the earlier life stages in that they leave the Hudson River, become subject to a sport and commercial fishery, and return to reproduce. A potential increase or decrease in the population can be predicted by studying the population parameters of these older reproducing-age groups. Parameters to be discussed in this section include rates of growth, natality, and mortality; age structure; and migrations. The Hudson River population is compared with other populations with respect to these parameters.

7.8.2 GROWTH RATES. A knowledge of growth rates is useful in determining the productivity of the Hudson River for striped bass and the age at which striped bass become available to the sport and commercial fisheries (legal size in New York is 16 in ~~[406 mm]~~ [407mm] fork length). As Ricker (1975:1) points out, the growth rate of fish is more variable than that of humans or many other organisms and may be a sensitive indicator of changes in the environment.

Two methods of growth measurement are used: direct measurement of mean size at a given age, and estimation of size by backcalculations from scale annuli (annual growth rings on the scale) measurements. In the first method, the size and age of each fish caught are determined and the mean size for each age group then calculated. In the second method, growth of a scale (as measured by the distance between annuli) is assumed to be a function of growth in body length; distances between annuli, therefore, can be used to determine the length at a given age (Ricker 1975:217-219). Both methods can give population growth rates, which will differ from individual growth rates if size-selective mortality occurs (i.e., fish of the same age but different sizes having different mortality rates). For example, larger fish may be caught by a commercial or sport fishery sooner than small fish of the same age, and the observed mean size for the age group thus would be less than it would have been had all the fish survived. Backcalculations can be used to compute both population and individual growth rates in order to determine whether size-selective mortality exists (Ricker 1975:219-220).

The rate of growth is expressed in two ways. The instantaneous growth rate for a population (G) is defined as:

$$G = \log_e W_2 - \log_e W_1 \tag{7-1}$$

where W_1 and W_2 are weights at two time periods. Growth rates are usually calculated over a 1-yr period. The incremental growth rate is defined as the increase in weight per year. Weights are calculated from data on fish length by:

$$W = a\,L^b \tag{7-2}$$

or

$$\mathrm{Log}_e W = \log_e a + b\,(\log_e L) \tag{7-3}$$

where a and b are constants and L is length derived from direct measurements or backcalculation.[*] Equation (7-1) can be rewritten as:

$$G = b\,(\log_e L_2 - \log_e L_1) \tag{7-4}$$

The constant b usually takes on values of approximately 3.

---

[*] For striped bass in the Hudson River the constants are $\log_e a = -11.96$, ~~$a = -5.194$~~, ~~$b = 3.117$~~ for males, and ~~$a = 5.595$~~, ~~$b = -3.223$~~ for females.
$\log_e a = 12.89$, $b = 3.223$
$b = 3.117$

7.8.2.1 Growth Rates for Hudson River Striped Bass. Female striped bass were significantly larger than males at a given age as measured by either backcalculation ($t = 3.51$; $P < 0.005$; Table 7.8-1) or observed mean size ($t = 3.59$; $P < 0.005$; Table 7.8-2). Since both methods include great sample variability and limited numbers of samples, a simple average of fork lengths calculated by the two methods was computed. Using this average the growth rate is about the same for males and females during the first 3 years of life, and again females were significantly larger than males ($t = 2.24$; $P \leq 0.05$) after the first 3 yrs (Fig. 7.8-1 and Table 7.8-3).

7.8.2.2 Comparisons with Other Striped Bass Populations. For comparisons, striped bass populations can be grouped into three types: landlocked or inland, west coast anadromous and east coast anadromous (Table 7.8-4). Landlocked populations grow faster than anadromous populations during the first 2 yr but slower during the next 3 yr (Table 7.8-5). However, inland populations still average 691 mm in total length compared with 555 mm for anadromous populations after five growing seasons and thus maintain the advantage they gained during the first 2 yr. Greater food availability and the more sheltered environment of inland waters may be responsible for the faster growth of inland populations. Most inland populations are recent introductions and may grow rapidly because their growth is not as limited by intraspecific competition. A comparison of all anadromous populations (Table 7.8-5), including the Hudson River population, reveals no significant difference between growth rates of East and West Coast populations (t = 0.29 ~~[1.50]~~ ~~0.85~~, P > [0.10] ~~0.05~~). The growth rate of the Hudson River population (Table 7.8-6) does not differ significantly from other East Coast anadromous populations (Friedman analysis of variance; χ_n^2 = [1.0] ~~1.5~~; P [= 0.80] $\geq$ ~~0.75~~). Within anadromous populations, males and females grow at approximately the same rate for the first 2-3 yr (Merriman 1941, Robinson 1960, Mansueti 1961c); after that females grow at a significantly faster rate and live to an older age. These findings agree with results for the Hudson River population.

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Table 7.8-1 Mean Fork Length (mm) of Hudson River Striped Bass at Time of Annulus Formation by Backcalculation

Age	1972		1973		Weighted Average*	
	Male	Female	Male	Female	Male	Female
(years)	(n=~~95~~) 52	(n=37)	(n=98)	(n=67)	(n=~~193~~) 150	(n=104)
I	110.8	102.1	103.1	104.9	105.7	102.7
II	232.8	214.5	233.7	238.0	233.0	218.8
III	323.1	281.3	349.1	369.2	330.2	281.3
IV	424.6	340.3	447.7	473.8	444.1	473.8
V	494.6	427.1	534.3	570.6	528.6	570.6
VI	538.0	509.4	611.9	658.7	603.2	658.7
VII	586.9	606.2	666.8	733.6	645.0	719.4
VIII	585.5	727.5	704.6	797.6	704.6	797.6
IX	609.4	792.3	689.1	844.3	689.1	844.3
X	623.5	742.4		886.1	623.5	828.6
XI		831.7		943.0	--	887.4
XII		859.8		827.7	--	827.7
XIII		885.9		881.2	--	885.9
XIV		1056.3				1056.3

*By sample size at each age

Table 7.8-2 Mean Fork Length (mm ± Standard Error and Sample Size) Based on Observed Size at Capture of Hudson River Striped Bass Collected during April and May 1972-75

Age	1972		1973		1974		1975		Average	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
II	210.7 ± 9.9 (12)	207.8 ± 13.2 (4)	216.3 ± 14.6 (4)	213.3 ± 13.4 (4)					212.1 ± 8.1 (16)	210.1 ± 8.8 (7)
III	307.0 - (1)	314.0 ± 38.0 (2)	363.0 ± 43.0 (2)		348.0 - (1)		435.0 - (1)	336.0 - (1)	363.2 ± 24.7 (5)	321.3 ± 23.1 (3)
IV	387.0 ± 54.0 (2)		425.9 ± 27.0 (8)	523.8 ± 10.2 (6)	437.6 ± 11.9 (16)	484.1 ± 16.6 (10)	451.7 ± 9.7 (15)	488.0 ± 10.0 (2)	438.0 ± 8.2 (41)	497.8 ± 10.6 (18)
V	542.0 - (1)		499.4 ± 26.2 (5)	597.2 ± 16.6 (8)	536.1 ± 13.7 (30)	548.7 ± 30.8 (7)	515.5 ± 13.8 (19)	506.1 ± 12.4 (2)	525.7 ± 9.2 (55)	534.6 ± 11.6 (36)
VI			574.0 ± 24.2 (13)		612.2 ± 24.4 (11)	654.0 ± 13.8 (7)	603.4 ± 16.0 (20)	605.0 ± 12.3 (25)	596.9 ± 11.8 (44)	615.8 ± 10.6 (32)
VII			697.4 ± 23.5 (14)	749.6 ± 36.2 (7)	665.2 ± 19.1 (13)	668.8 ± 27.8 (4)	622.8 ± 16.7 (5)	645.5 ± 23.6 (16)	672.7 ± 13.6 (32)	675.9 ± 18.9 (27)
VIII			736.6 ± 23.5 (14)	823.1 ± 13.9 (14)	736.4 ± 14.1 (19)	802.6 ± 8.6 (40)	798.2 ± 33.4 (4)	729.0 ± 37.8 (5)	743.3 ± 12.2 (36)	801.2 ± 7.9 (59)
IX			736.8 ± 24.0 (5)	861.0 ± 15.6 (14)	783.4 ± 11.0 (21)	841.5 ± 7.5 (38)	766.5 ± 23.9 (10)	822.3 ± 17.0 (28)	772.2 ± 9.9 (36)	838.2 ± 7.5 (80)
X		855.5 ± 41.5 (2)		905.7 ± 42.1 (3)	809.1 ± 12.7 (15)	867.1 ± 9.7 (42)	817.1 ± 17.6 (13)	876.0 ± 9.5 (32)	812.8 ± 10.5 (28)	871.9 ± 6.6 (79)
XI					873.4 ± 15.4 (5)	897.4 ± 15.8 (18)	794.6 ± 18.3 (7)	885.3 ± 10.7 (29)	827.4 ± 16.7 (12)	889.9 ± 8.9 (47)
XII				1060.5 ± 41.5 (2)	945.0 - (1)	910.5 ± 50.5 (4)	833.0 ± 89.0 (2)	922.1 ± 8.4 (15)	870.3 ± 63.5 (3)	933.1 ± 14.3 (21)
XIII							932.0 - (1)	922.0 - (1)	932.0 - (1)	922.0 - (1)
XIV				905.0 - (1)						905.0 - (1)
XV					892.0 - (1)			983.0 - (1)	892.0 - (1)	983.0 - (1)
XVI						972.0 - (1)				972.0 - (1)
XVII								1053.0 - (1)		1053.0 - (1)

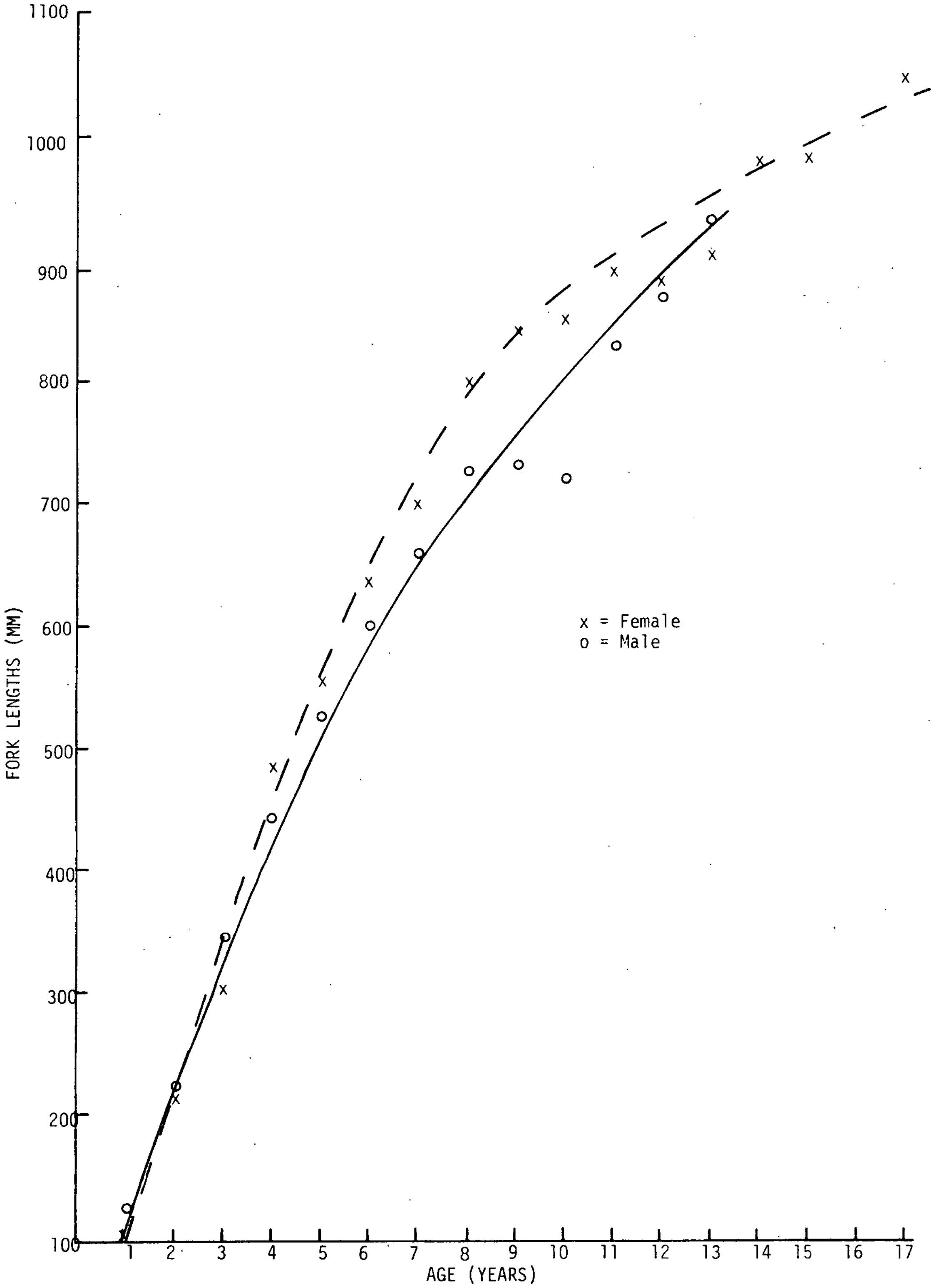

Figure 7.8-1 Growth of Hudson River Female and Male Striped Bass. (See Table 7.8-3)

12/12/77

(This is a replacement table for Exhibit 4, F.R.R. (McFadden NRC) page 7.145)

Table 7.8-3 Mean Fork Lengths (mm) and Annual Instantaneous Growth Rates of Hudson River Striped Bass Population Sampled from 1972-1975.

	Males			Females		
Age (Years)	Fork Length* (mm)	Incremental Growth Rates (mm)**	G†	Fork Length* (mm)	Incremental Growth Rates**	G†
II	223	117	2.32	214	111	2.28
III	347	124	1.38	301	87	1.06
IV	441	94	.747	486	185	1.49
V	527	86	.555	553	67	.402
VI	600	73	.404	637	84	.441
VII	659	59	.292	698	61	.285
VIII	724	65	.293	799	101	.421
IX	731	7	.030	841	42	.160
X	718	-13	-.056	850	9	.033
XI	827	109	.440	889	39	.140
XII	870	43	.158	880	-9	-.032
XIII	932	62	.214	904	24	.084
XIV				981	77	.255
XV				983	2	.006
XVI				972	-11	-.035
XVII				1053	81	.249

*Fork length can be converted to total length as follows: total length = 1.82 + 1.06 (fork length)

**From previous year

†Instantaneous population growth rate. A weight constant (b) of 3.117 was used with equation (7-4)

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Age (Years)	Fork Length* (mm)	Incremental Growth Rates (mm)**	$G^{\dagger}$	Fork Length* (mm)	Incremental Growth Rates**	$G^{\dagger}$
II	223	96	1.76	214	112	2.28
III	347	124	1.38	301	87	1.06
IV	441	94	.748	486	184	1.49
V	527	86	.555	553	67	.402
VI	600	73	.405	637	85	.439
VII	659	59	.292	698	60	.308
VIII	724	65	.293	799	102	.421
IX	731	7	.031	841	42	.159
X	718	-12	-.056	850	9	.034
XI	827	109	.439	890	40	.143
XII	870	43	.159	880	10	-.034
XIII	932	62	.215	904	24	.084
XIV				981	77	.256
XV				983	2	.006
XVI				972	-11	-.034
XVII				1053	81	.249

*Fork length can be converted to total length as follows: total length = 1.82 + 1.06 (fork length)

**From previous year

[†] Instantaneous population growth rate. A weight constant (b) of 3.117 was used with equation (7-4)

Table 7.8-4 Mean Fork Lengths (mm) of Landlocked and Anadromous Striped Bass (page 1 of 2)

Age (Years)	LANDLOCKED Average*	ANADROMOUS WEST COAST					
		California**		San Joaquin†		Oregon‡	
	Combined	Male	Female	Male	Female	Combined	Average
I	216	104	104				104
II	381	234	234				234
III	503	398	403	414	424	360	400
IV	607	493	504	485	523	480	497
V	691	568	595	561	624	580	586
VI	831	628	670	642	693	620	651
VII	935	668	741	711	751	700	714
VIII		710	789	739	806	720	753
IX		750	842	764	840	760	791
X		790	861		876	800	832
XI				863		850	856

*Wilson and Christenson 1965; Scruggs 1957; Stevens 1958; Mensinger 1971, Erickson et al. 1972, and Ware 1971, cited in Parsons 1974

**Robinson 1960

†Miller and Orsi 1969

‡Morgan and Gerlach 1950

(This is a replacement table for Exhibit 4, F.R.R. (McFadden NRC) page 7.146)

Table 7.8-4 Mean Fork Lengths (mm) of Landlocked and Anadromous Striped Bass (page 1 of 2)

Age (Years)	LANDLOCKED Average*	ANADROMOUS WEST COAST California**		San Joaquin†		Oregon‡	
	Combined	Male	Female	Male	Female	Combined	Average
I	216	104	104				104
II	381	234	234				234
III	503	399	403	414	424	360	400
IV	607	493	504	485	523	480	497
V	691	568	596	561	625	580	586
VI	831	629	671	643	693	620	651
VII	935	668	741	711	752	700	714
VIII		710	789	739	803	720	752
IX		750	842	765	841	760	792
X		790	861	785	876	800	822
XI				864	991	850	902

*Wilson and Christenson 1965; Scruggs 1957; Stevens 1958; Mensinger 1971, Erickson et al. 1972, and Ware 1971, cited in Parsons 1974

**Robinson 1960

†Miller and Orsi 1969

‡Morgan and Gerlach 1950

Replacement table for Table 7.8-4 (page 2 of 2)

		ANADROMOUS EAST COAST							EAST COAST ANADROMOUS	ALL ANADROMOUS
	Massachusetts*	Chesapeake**	Maryland***		New England‡	Maine‡	Hudson			
Age (Years)	Combined	Combined	Male	Female†	Combined	Combined	Male	Female	Average	Average
I	226	102	135	144	124	150			147	126
II	284	254	325	305	236	297	223	214	267	251
III	318	381	390	395	366	436	347	301	367	384
IV	381	470	436	445	450	498	441	486	451	474
V	447		479	583	531	588	527	553	530	558
VI	505		578	647	610	644	600	637	603	627
VII	556		704	724	686	674	659	698	672	693
VIII	587		749	760	749		724	799	728	740
IX	612		831	822	820		731	841	776	784
X	638		876	899			718	850	796	809
XI	658		926	910			827	889	842	872
XII	683			1039			870	880	868	868
XIII	699			993			932	904	882	882
XIV	709			1053				981	914	914
XV	716							983	850	850
XVI	721							972	847	847
XVII	744							1053	899	899
XVIII	785									
XIX	739									

*Fitzpatrick and Cookson 1958, cited in Parsons 1974

**Pearson 1938

***Mansueti 1961c

†And immature (unknown)

‡Davis 1966

Table 7.8-4 (Page 2 of 2)

		ANADROMOUS EAST COAST									ALL ANADRAMOUS
	Massachusetts*	Chesapeake**	Maryland***		New England†	Maine‡	Hudson				
Age (Years)	Combined	Combined	Male	Female	Combined	Combined	Male	Female	Average		Average
I	226	102	135	140	124	150			146		125
II	284	254	275	305	243	297	223	214	261		248
III	317	391	390	395	366	436	347	301	368		384
IV	381	470	436	444	500	498	441	486	457		477
V	447		478	544	531	588	527	553	524		555
VI	505		578	646	610	644	600	637	603		627
VII	556		704	724	686	674	659	698	642		678
VIII	587		749	760	749		724	799	728		740
IX	612		831	822	820		731	241	776		784
X	637		876	899			718	850	796		814
XI	658		926	910			827	890	842		849
XII	683			1033			870	880	866		866
XIII	699			993			932	904	882		882
XIV	709			1053				981	914		914
XV	716							983	849		849
XVI	721							972	846		846
XVII	744							1053	898		898
XVIII	785										
XIX	789										

*Fitzpatrick and Cookson 1958, cited in Parsons 1974

**Pearson 1938

***Mansueti 1961c

†Merriman 1941

‡Davis 1966

Table 7.8-5 Annual Incremental Growth Rates (mm) of Landlocked and Anadromous Striped Bass[*]

Age	Landlocked	Anadromous West	Anadromous East	Anadromous Average
I	216	104	146	125
II	165	130	115	122
III	122	166	107	146
IV	104	97	91	94
V	84	89	67	78
VI	224	65	79	72
VII	104	63	39	51
VIII		39	86	62
IX		38	48	43
X		41	20	30

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[*] See Table 7.8-4 for references.

(This is a replacement table for Exhibit 4, F.R.R. (McFadden NRC) page 7.148)

Table 7.8-5 Annual Incremental Growth Rates (mm) of Landlocked and Anadromous Striped Bass*

Age	Landlocked	Anadromous West	Anadromous East	Anadromous Average
I	216	104	147	126
II	165	130	120	125
III	122	166	100	133
IV	104	97	84	90
V	84	89	79	84
VI	140	65	73	69
VII	104	63	69	66
VIII		38	56	47
IX		40	48	44
X		30	20	25

*See Table 7.8-4 for references

(This is a replacement table for Exhibit 4, F.R.R. (McFadden NRC) page 7.149)

Table 7.8-6 Incremental Growth Rates of East Coast Striped Bass

Age	Maryland* Males	Maryland* Females	New England**	Maine[†]	Hudson Males	Hudson Females
II	190	161	112	147	117	111
III	65	90	130	139	124	87
IV	46	50	84	62	94	185
V	43	138	81	90	86	67
VI	99	64	79	56	73	84
VII	126	77	76	30	59	61
VIII	45	36	63		65	101
IX	82	62	71		7	42
X	45	77			-13	9
XI	50	11			109	39
XII					43	-9

*Mansueti 1961; back calculated and measured lengths are averaged

**Merriman 1941

[†] Davis 1966; back calculated and measured lengths are averaged

Table 7.8-6 Incremetal Growth Rates of East Coast Striped Bass

	Maryland*		New England**	Maine†	Hudson	
Age	Males	Females			Males	Females
II	162	166	110	147	96	112
III	65	90	132	112	124	87
IV	46	50	134	52	94	184
V	43	100	31	90	86	67
VI	49	102	79	55	73	85
VII	110	79	76	30	59	60
VIII	50	58	63		65	102
IX	77	64	71		7	42
X	45	43			-12	9
XI	31	36			109	40
XII					43	10

*Mansueti 1961; back calculated and measured lengths are averaged.

**Merriman 1941

† Davis 1966; back calculated and measured lengths are averaged.

7.8.3 NATALITY. The natality or birth rate of a population depends on the number of mature females and the fecundity or number of eggs per female. Female striped bass in the Hudson River population begin to mature at age IV and all are mature by age VIII (Table 7.8-7). Fecundity is approximately 80,000 ~~age~~ eggs lb^{-1} of fish (Table 7.8-7) and is more closely correlated with body weight than with age (Lewis and Bonner 1966).

Female Hudson River striped bass mature approximately 1-2 yr later than striped bass in the Chesapeake Bay (Vladykov and Wallace 1952:162) or in Connecticut waters (Merriman 1941:22). Although the reason is not clear, it may be related to the lower size limits and consequent higher exploitation for these. The legal size for striped bass in the Chesapeake Bay is only about 279 mm fork length, the size of most 2-yr old fish (Koo 1970). Since most striped bass caught in Connecticut water probably came from Chesapeake Bay, these fish might show the effect of the Chesapeake fishery. The age at maturity for such a population may decrease to compensate for a high exploitation rate. Such a process has been observed for other species of fish (section 10 and Miller 1949).

7.8.4 AGE COMPOSITION AND MORTALITY. Sources of mortality in fish populations are usually divided into two categories: natural mortality and fishing mortality. Natural mortality (expectation of natural death) includes causes of death over which man has little or no control (e.g., predation and disease). Fishing mortality (the fishing exploitation rate) is from man's sport or commercial fisheries. Actual total mortality (the fraction of fish present at the start of a year that die during the year) is simply the sum of the fishing exploitation rate, and the natural mortality rate:

$$A = u + v$$

where

Table 7.8-7 Age at Maturity and Fecundity of Hudson River Female Striped Bass Examined during April and May 1973-75

Age	Year	No. Examined	% Mature	Mean Fecundity	Standard Error	Sample* Size
II	1973	2	0	--	--	--
	1974	0	--	--	--	--
	1975	0	--	--	--	--
	Total	2	0	--	--	--
III	1973	1	0	--	--	--
	1974	0	--	--	--	--
	1975	1	0	--	--	--
	Total	2	0	--	--	--
IV	1973	15	0	--	--	--
	1974	0	--	--	--	--
	1975	2	50	408,593	--	1
	Total	17	6	408,593	--	1
V	1973	5	0		--	--
	1974	5	80	778,965	226,725	3
	1975	20	15	644,859	--	1
	Total	30	23	745,438	163,787	4
VI	1973	1	100	450,839	174,494	2
	1974	5	100	726,507	115,035	5
	1975	11	54	669,154	38,639	4
	Total	17	71	655,530	64,187	11
VII	1973	8	100	780,851	138,465	9
	1974	4	100	1,171,447	288,191	4
	1975	8	88	901,272	238,158	2
	Total	20	95	901,066	117,777	15
VIII	1973	14	100	1,548,715	125,464	14
	1974	17	100	1,250,154	86,175	15
	1975	3	100	949,342	227,249	3
	Total	34	100	1,352,573	77,238	32
IX	1973	9	100	1,563,872	155,272	9
	1974	18	100	1,497,703	120,367	17
	1975	10	100	1,551,659	199,722	9
	Total	37	100	1,528,592	84,915	35
X	1973	4	100	1,841,647	262,608	4
	1974	16	100	1,800,554	158,462	15
	1975	15	100	1,843,303	140,162	11
	Total	35	100	1,821,708	97,528	30
XI	1973	0	--	--	--	--
	1974	6	100	1,767,886	354,050	5
	1975	12	100	2,056,470	249,711	9
	Total	18	100	1,953,404	199,784	14
XII	1973	2	100	2,350,938	356,149	2
	1974	0	100	--	--	--
	1975	4	100	2,125,951	263,287	4
	Total	6	100	2,200,947	196,046	6
XIII	1973	0	--	--	--	--
	1974	0	--	--	--	--
	1975	0	--	--	--	--
	Total	0	--	--	--	--
XIV	1973	1	100	2,189,613	--	1
	1974	0	--	--	--	--
	1975	0	--	--	--	--
	Total	1	100	2,189,613	--	1
XV	1973	0	--	--	--	--
	1974	0	--	--	--	--
	1975	1	100	2,590,902	--	1
	Total	1	100	2,590,902	--	1

*Number of fish used to determine fecundity estimate.

A = total mortality rate
u = fishing exploitation rate
v = expectation of natural death

Expectation of natural death rates of Hudson River striped bass are not known. Chadwick (1968:241) computed annual rates for expectation of natural death (v) of 0.31 to 0.14 (depending on year) for striped bass in the Sacramento-San Joaquin River system. A preliminary estimate of an annual fishing exploitation rate for Hudson River fish of legal size (fork length, 407 mm and larger), calculated from the number of tags returned during TI movement studies (Section 7.8.7) (~~Section 7.8.4~~) was 0.07. If the upper range of Chadwick's estimates of expectation of natural death is assumed to apply to the Hudson River, then the annual total mortality rate of legal-size Hudson River striped bass would be about 0.40. In the absence of more precise data, this figure is used as a working approximation.

The age composition of the Hudson River population can be approximated by taking the mortality rate of 0.4 and calculating the numbers of survivors at a given age (Fig. 7.8-2). The type of age distribution shown would be typical of a stable population (Odum 1959:171-173). Such stability is rarely observed for fish populations such as striped bass which exhibit strong and weak year classes (Sections 7.9.2 and 7.9.3); an extremely large number of individuals spawned in a single year may dominate the fishery for many years that follow (Section 7.2). These strong year classes distort the uniformity of the idealized stable age distribution. Hence, a distribution such as shown in Figure 7.8-2 would not be expected in a sample of the fish population taken at some instant in time but might be approximated as a long-term average.

7.8.5 LIFE TABLE. A complete picture of a population's mortality and natality can be viewed in a life table, a statistical device for representing the number of individuals surviving in each age group. Its use can be extended to predict natality by adding the age at maturity and fecundity of each age group.

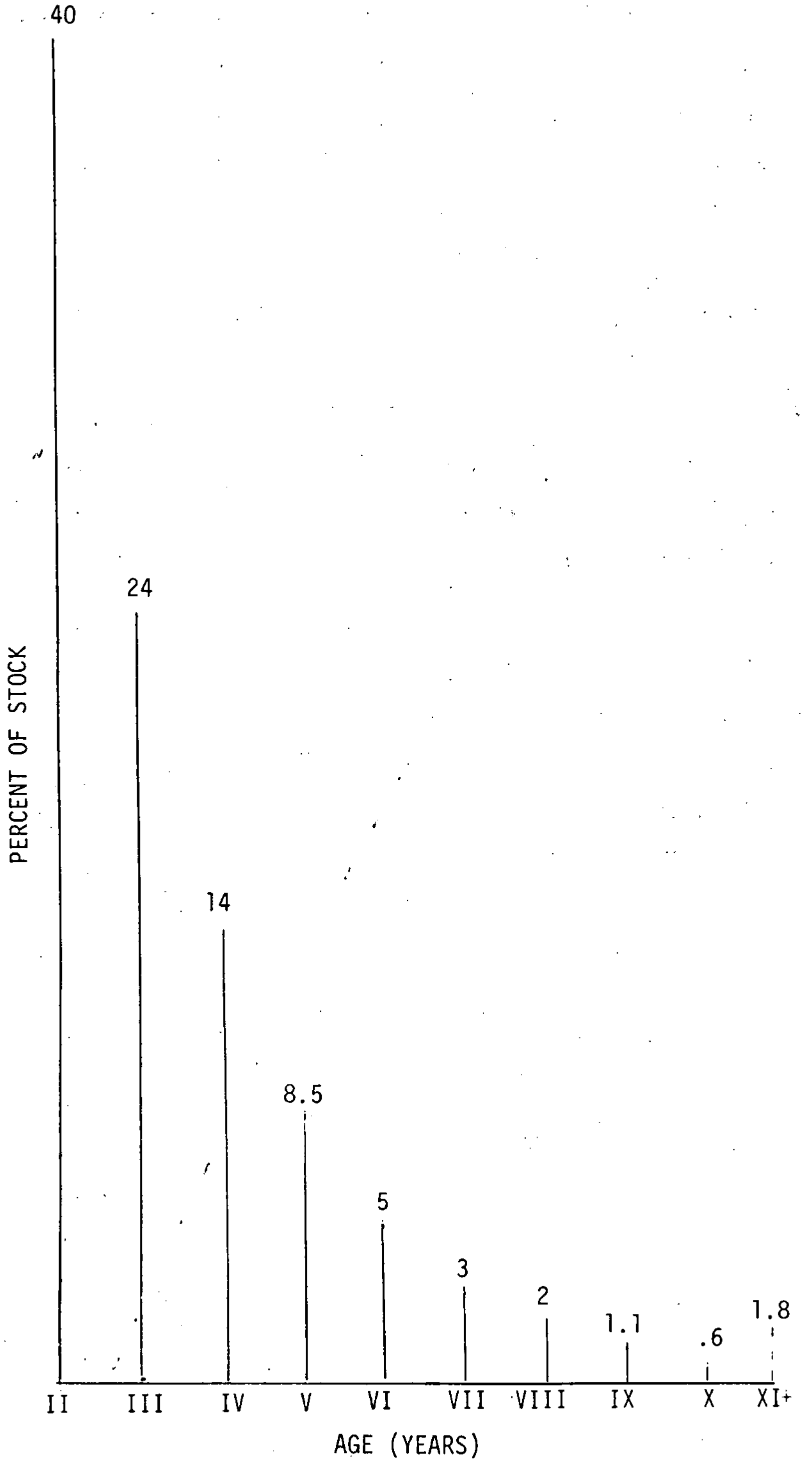

Figure 7.8-2 Age Composition of Hudson River Striped Bass, Assuming Mortality Rates of 0.4

A best approximation of the number of fish in the Hudson River spawning population can be calculated in the following manner. Using 6 x 10^6 age 0 striped bass (Section 7.9) and an annual mortality rate of 0.8 (Section 7.7) between ages 0 and I, there are about 1.2 x 10^6 yearling (age I) striped bass in the population. Assuming a mortality rate of 0.6 for yearlings, there would be 480,000 age II fish. If the sex ratio were 1:1, there would be approximately 240,000 age II females. Using an annual survival of 0.6 (mortality of 0.4, Section 7.8.4) for all age groups above II, the observed percentage of mature females in each age group, the calculated number of females in each age group (Section 7.8.4), and the age specific average fecundity, a spawning stock of 85,652 female striped bass produces 87.9 billion eggs (Table 7.8-8). Fish older than age X would produce only 13% of the eggs. The age at maturity is critical since an increase of 10% in the number of mature females at age V would yield about 12.8 billion eggs instead of 8.9 billion estimated in Table 7.8-8 for this age. However, due to the multiple age structure of this stock, it is unlikely that even a very strong year class would yield more than 20% of all eggs spawned in a given year. Mortality, from eggs to age II, is discussed further in Section 7.7.

7.8.6 CRITICAL AGE IN RELATION TO FISHERIES MANAGEMENT.

The effect on the population of exploiting a specific size fish can be predicted by using the population parameters, growth, and mortality just discussed. The critical age or size of fish in the population (Ricker 1975:18) is the point at which instantaneous growth (G) in weight is exactly balanced by instantaneous natural mortality (M). The critical age is the best average age at which to exploit a population if maximum yield is the goal of the fishery; exploitation at younger or older average ages would be less efficient.

A best approximation of the number of fish in the Hudson River spawning population can be calculated in the following manner. Using 6 x 10^6 age 0 striped bass (Section 7.9) and an annual mortality rate of 0.8 (Section 7.7) between ages 0 and I, there are about 1.2 x 10^6 yearling (age I) striped bass in the population. Assuming a mortality rate of 0.6 for yearlings, there would be 480,000 age II fish. If the sex ratio were 1:1, there would be approximately 240,000 age II females. Using an annual survival of 0.6 (mortality of 0.4, Section 7.8.4) for all age groups above II, the observed percentage of mature females in each age group, the calculated number of females in each age group (Section 7.8.4), and the age specific average fecundity, a ~~spawning~~ ~~[600,938]~~ 599,962 stock of ~~85,652~~ female striped bass produces 87.9 billion eggs (Table 7.8-8). Fish older than age X would produce only 13% of the eggs. The age at maturity is critical since an increase of 10% in the number of mature females at age V would yield about 12.8 billion eggs instead of 8.9 billion estimated in Table 7.8-8 for this age. However, due to the multiple age structure of this stock, it is unlikely that even a very strong year class would yield more than 20% of all eggs spawned in a given year. Mortality, from eggs to age II, is discussed further in Section 7.7.

7.8.6 CRITICAL AGE IN RELATION TO FISHERIES MANAGEMENT. The effect on the population of exploiting a specific size fish can be predicted by using the population parameters, growth, and mortality just discussed. The critical age or size of fish in the population (Ricker 1975:18) is the point at which instantaneous growth (G) in weight is exactly balanced by instantaneous natural mortality (M). The critical age is the best average age at which to exploit a population if maximum yield is the goal of the fishery; exploitation at younger or older average ages would be less efficient.

2-27-78

Transcript Changes
12/7/77
Pg. 145-147

Table 7.8-8 Life Table for Hudson River Striped Bass

No. Females*	Age	% Mature	Fecundity**	No. Eggs x 10^9	Percent of Stock
240,000	II	0	--	0	
144,000	III	0			
86,400	IV	6	400,000	2.1	2.4
51,840	V	23	750,000	8.9	10.2 ~~10.1~~
31,104	VI	71	650,000	14.4	16.6 ~~16.4~~
18,662	VII	95	900,000	16.0	18.4 ~~18.2~~
11,197 ~~11,974~~	VIII	100	1,350,000	15.1 ~~16.2~~	17.4 ~~18.4~~
6,718	IX	100	1,500,000	10.1 ~~16.1~~	11.6 ~~11.5~~
4,031	X	100	1,800,000	7.3 ~~7.2~~	8.4 ~~8.2~~
2,419	XI	100	2,000,000 ~~2,200,000~~	4.8	5.5
1,451	XII	100	2,200,000	3.2	3.7 ~~3.6~~
871	XIII	100	2,200,000	1.9	2.2
522	XIV	100	2,200,000	1.1	1.3 ~~1.2~~
313	XV	100	2,600,000	0.8	0.9
188	XVI	100	2,700,000	0.5	0.6
113 ~~112~~	XVII	100	2,800,000	0.3	0.3
68	XIII	100	2,900,000	0.2	0.2
41	XIX	100	3,000,000	0.1	0.1
24	XX	100	3,100,000	0.1	0.1
~~600,738~~ 599,962				~~87.9~~ 86.9	99.9

*Assuming 240,000 age II females and an annual mortality rate of 0.4 (see text).

**From Table 7.8-7.

Table 7.8-8 Life Table for Hudson River Striped Bass

No. Females*	Age	% Mature	Fecundity**	No. Eggs x 10^9	Percent of Stock
240,000	II	0	--	0	
144,000	III	0			
86,400	IV	6	400,000	2.1	2.4
51,840	V	23	750,000	8.9	10.1
31,104	VI	71	650,000	14.4	16.4
18,662	VII	95	900,000	16.0	18.2
11,974	VIII	100	1,350,000	16.2	18.4
6,718	IX	100	1,500,000	16.1	11.5
4,031	X	100	1,800,000	7.2	8.2
2,419	XI	100	2,200,000	4.8	5.5
1,451	XII	100	2,200,000	3.2	3.6
871	XIII	100	2,200,000	1.9	2.2
522	XIV	100	2,200,000	1.1	1.2
313	XV	100	2,600,000	0.8	0.9
188	XVI	100	2,700,000	0.5	0.6
112	XVII	100	2,800,000	0.3	0.3
68	XIII	100	2,900,000	0.2	0.2
41	XIX	100	3,000,000	0.1	0.1
24	XX	100	3,100,000	0.1	0.1
600,738				87.9	99.9

*Assuming 240,000 age II females and an annual mortality rate of 0.4 (see text).

**From Table 7.8-7.

The calculation of critical age may be made graphically (Fig. 7.8-3) by plotting the instantaneous rate of growth (G) for males and females by age (Ricker 1975:18). Since M was not known accurately for the Hudson River striped bass population, annual natural mortality rates of 0.30, 0.50, and 0.70 (corresponding to instantaneous natural mortality rates of 0.36, 0.69 and 1.20 respectively) were used. The intersections of G and M for these values of M led to the following critical ages:

Critical Age (Years)

M	Male	Female
1.20	3.25	3.75
0.69	4.25	4.50
0.36	7.0	6.50

If the mortality rate (M) of the Hudson River striped bass ~~populations~~ population is 0.69, then the critical age will be 4.5 yr. Taking fish at a younger age would represent harvest of a year class before its full potential for biomass growth had been realized. If Hudson River fish were taken at a mean age older than 4.5, the fishery would be harvesting the population during the phase of life when annual losses due to natural mortality exceed annual gains due to growth and the biomass of each year class consequently is steadily declining. Management of the fishery must, of course, take into account the necessity of maintaining an adequate spawning stock, the availability to the fishery and market value of striped bass of different ages, and other factors as well as critical size and age. However, the relationship of actual age distribution of the catch (which at present is not known) to critical size and age is important in assessing the potential for changes in the fishery that could offset possible decline in catch caused by power plant impact. For example, if the fishery turned out to be harvesting the stock in a suboptimal way at present, and the population were reduced by power plant impact to the disadvantage of the fishery, the loss might be counteracted by optimizing the fishery.

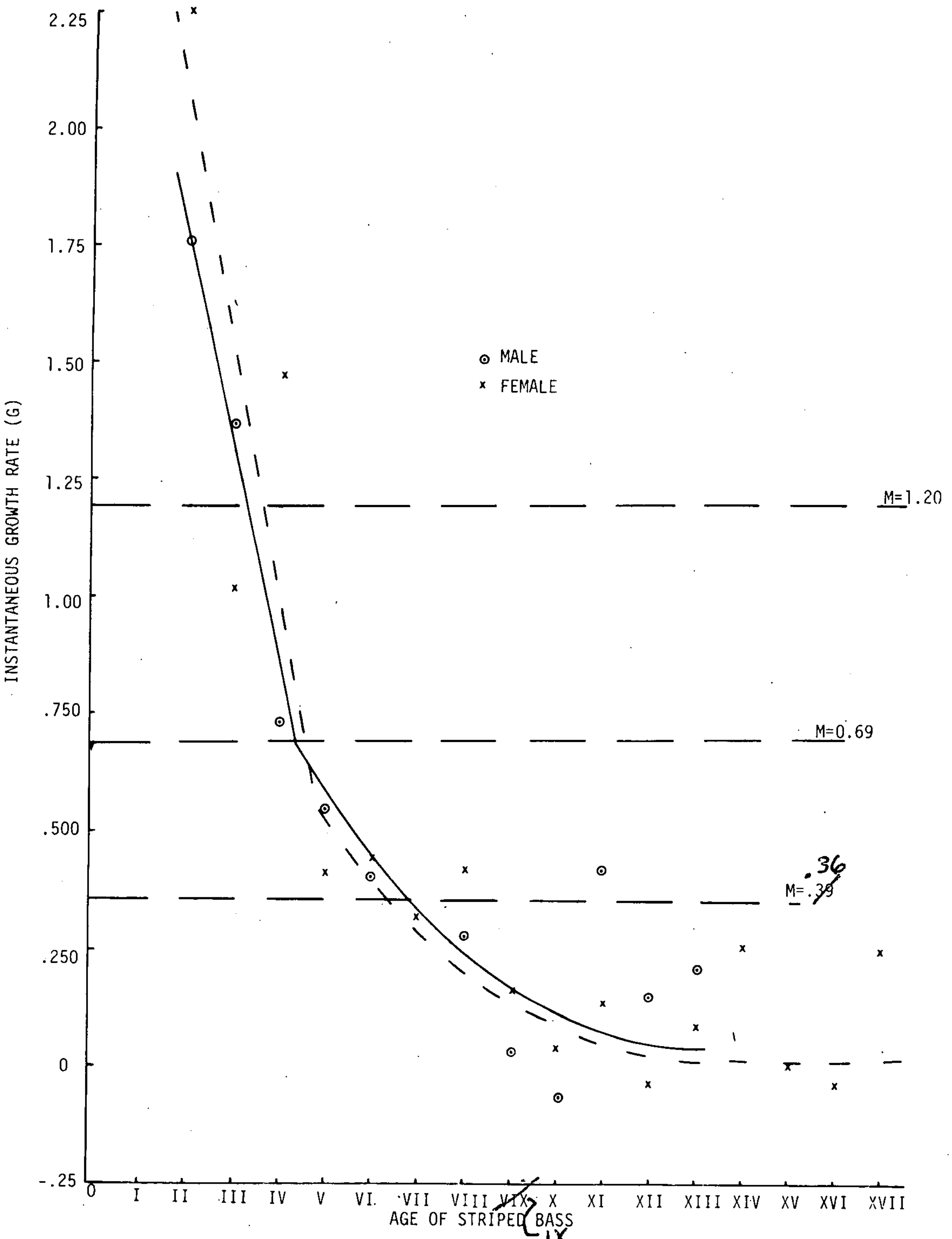

Figure 7.8-3 Critical Age for Hudson River Striped Bass at Three Levels of Instantaneous Natural Mortality Rates (M)

7.8.7 MOVEMENT. The majority of striped bass are rarely seen more than a few miles from shore (Raney 1954), tending to stay in the geographic area near the spawning river. Tagging studies outside the Hudson River (Vladykov and Wallace 1938, 1952; Merriman 1941; Raney 1952, 1957; Mansueti 1961c; Massman and Pacheco 1961; Nichols and Miller 1967) have shown that fish < 500 mm tend to be recaptured close to the release areas. However, large striped bass reportedly make extensive oceanic migrations (Chapotan and Sykes 1961, Schaefer 1968). There is a northward migration of older individuals along the Atlantic coast in late spring and a southward return migration in late fall (Merriman 1941, Vladykov and Wallace 1952, Raney et al. 1954, Massman and Pacheco 1961, Chapoton and Sykes 1961, Nichols and Miller 1967).

Early studies of striped bass in the Hudson River and vicinity suggested that they are relatively nonmigratory and generally restricted to the western end of Long Island Sound and off the southwestern end of Long Island (Neville 1940, Raney and deSylva 1953, Raney et al. 1954, Alperin 1966b). Subsequent tagging studies (Clark 1968, Clark and Smith 1969, TI 1976h) indicate more extensive migrations for some of the fish. There are two interpretations of these tagging data. Clark (1968) hypothesized the existence of three "contingents" of Hudson River striped bass or "groups of fish that engage in a common pattern of seasonal migration between feeding areas, wintering areas and spawning areas." He presented two of these groups as relatively nonmigratory: the Hudson Estuary Contingent and the Hudson-West Sound Contingent. He also hypothesized a third group, the Hudson-Atlantic Contingent, that moves greater distances away from the Hudson River. A second interpretation came from research conducted by Texas Instruments from April 1 1972 through December 31, 1975, in which many of the fish were tagged during the spawning season on a known spawning ground in the Hudson River (Table 7.8-9). Of the ~~65~~ 71 recaptured fish, return rates were higher for the larger fish; fish >400 mm in total length yielded a ~~9.7%~~ (10.0%) return rate (Tables 7.8-9 and 7.8-10):

Table 7.8-9 Length Distribution of Striped Bass Tagged and Released in Hudson River ~~(1972-75)~~ (April 1972 through June 1975) Between RM 12 and 152 (km 19 and 245)

Total Length (mm)	Winter (Jan-Feb-Mar)	Spring (Apr-May-Jun)	Summer (Jul-Aug-Sep)	Fall (Oct-Nov-Dec)	Total
≤100	0	93	1	31	125
101-200	0	341	~~159~~ 164	~~456~~ 451	~~957~~ 956
201-300	0	101	10	100	211
301-400	0	19	5	16	40
401-500	22	21	0	30	73
501-600	40	54	1	34	129
601-700	29	41	0	8	78
701-800	5	26	0	4	35
801-900	2	31	0	0	33
901-1000	0	50	0	0	50
>1000	1	15	1	0	17
Not Measured	0	0	2	43	45
Total	99	792	~~179~~ 184	~~723~~ 717	~~1,793~~ 1,792

Table 7.8-10 Release and Recovery Data for Recaptured Striped Bass Tagged in Hudson River, 1972-74 (Page 1 of 4)

Release Data				Recovery Data				
Date	Location (River)‡	Total Length (mm)	Age	Date	Location	Days at Large	Approximate Distance (km) from Tagging Site	Recapture Gear
1972								
Dec 28	54	555	---	5/1/73	Long Island Sound, Rye, NY	124	104	SF
	54	605	---	5/25/73	Long Island Sound, Greenwich, CT	148	112	SF
1973								
Jan 3	54	567	---	4/23/73	Hudson River Kilometer 54	110	<1	SF
	54	588	---	~~3/30/73~~ 3\31\73	Long Island Sound, Little Neck Bay, NY	87	80	SF
Mar 9	53	645	VI	4/23/73	Hudson River Kilometer 54	45	~~2~~ 1	SF
	53	570	V	4/27/73	Hudson River Kilometer 62	49	10	PS
	53	670	V	7/21/73	Long Island Sound, Mamaroneck, NY	134	95	SF
13	51	610	V	5/1/73	Hudson River Kilometer 62	49	11	PS
	51	650	V	6/20/73	Long Island Sound, Glen Cove, NY	99	104	SF
	51	650	V	7/27/73	Long Island Sound, Stamford, CT	136	112	SF
14	54	552	---	3/14/73	Hudson River Kilometer 54	0	<1	SF
15	53	870	VIII	7/5/73	Nantucket Sound, Nantucket, MA	112	400	SF
26	54	575	---	6/7/73	Great South Bay, R. Moses Bridge, NY	73	136	SF
	54	660	~~---~~ IV	9/5/74	Long Island Sound, Stamford, CT	528	112	SF

Table 7.8-10 (Page 2 of 4)

Release Data				Recovery Data				
Date	Location (River)	Total Length (mm)	Age	Date	Location	Days at Large	Approximate Distance (km) from Tagging Site	Recapture Gear
Apr 3	53	492	IV	4/13/73	Hudson River Kilometer 50	10	3	SF
19	96	903	VII	10/12/73	Block Island Sound, Montauk Pt., NY	176	296	SF
20	94	975	IX	6/19/73	Buzzards Bay, New Bedford, MA	60	389	SF
	91	1040	VIII	7/15/74	Boston Harbor Boston, MA	451	512	SF
26	94	745	VII	9/17/73	Lower NY Bay Rockaway Pt., NY	144	128	SF
Nov 12	62	645	VI	5/10/74	Stockport Creek, Tributary to Hudson River at Kilometer ~~193~~ 198	179	136	SF
1974								
Apr 23	67	~~908~~ 980	IX	5/2/74	Hudson River Kilometer 54	9	13	SF
24	22	120	I	8/1/74	Hudson River Kilometer 46	99	24	SF
30	88	808	---	6/15/75	Gravesend Bay Coney Island, NY	411	105	SF
May 16	67	1035	X	6/27/74	Cape Cod Bay Orleans, MA	42	416	SF
Jul 11	69	198	---	8/22/74	Hudson River Kilometer 198	42	130	SF
		196	---	9/17/74	Hudson River Kilometer 14	68	54	SF
Sep 18	46	145	---	10/29/74	Hudson River Kilometer 46	41	<1	PS
20	86	144	---	5/29/75	Hudson River Kilometer 86	251	<1	PS
Oct 9	56	238	---	6/23/75[†]	Hudson River Kilometer 19	257	37	SF
25	67	165	---	11/13/74	Hudson River Kilometer 67	19	<1	PS

Table 7.8-10 (Page 3 of 4)

Release Data				Recovery Data				
Date	Location (River)	Total Length (mm)	Age	Date	Location	Days at Large	Approximate Distance (km) from Tagging Site	Recapture Gear
Nov 4	64	174	---	11/15/74	Hudson River Kilometer 64	11	<1	PS
5	62	160	---	7/25/75	Hudson River Kilometer 62	262	~~0~~ <1	PS
12	67	145	---	10/17/75	Hudson River Kilometer 67	339	~~0~~ <1	PS
1975								
Apr 8	54	572	---	~~8/1/75~~ 8/10/75	Housatonic River, Stratford, CT	124	156	SF
15	56	578	---	4/29/75	Hudson River Kilometer 43	14	13	CF
16	56	607	VI	4/17/75	Hudson River Kilometer 56	1	<1	PS
16	56	591	VI	8/21/75	Atlantic Beach, Long Island, NY	127	98	SF
17	56	567	VII	4/18/75	Hudson River Kilometer 56	1	<1	PS
17	61	586	V	4/18/75	Hudson River Kilometer 61	1	<1	PS
17	61	661	VI	4/18/75	Hudson River Kilometer 61	1	<1	PS
17	~~55~~ 56	590	VI	4/29/75†	Hudson River Kilometer 45	12	11	SF
23	56	592	---	4/24/75	Hudson River Kilometer 56	1	<1	PS
29	56	624	VII	4/30/75	Hudson River Kilometer 43	1	13	CF
29	61	568	---	4/30/75	Hudson River Kilometer 43	1	18	CF

Table 7.8-10 (Page 4 of 4)

Release Data				Recovery Data				
Date	Location (River)	Total Length (mm)	Age	Date	Location	Days at Large	Approximate Distance (km) from Tagging Site	Recapture Gear
30	56	660	---	6/2/75	Long Island Sound, Mamaroneck, NY	33	99	SF
30	56	847	IX	6/22/75	Fallmouth Heights, MA	53	367	SF
May 1	61	846	X	5/2/75	Hudson River Kilometer 61	1	<1	PS
7	53	473	---	6/2/75	Block Island Sound, Shagwong Pt, NY	26	248	CF
14	67	535	---	6/10/75	Verrazzano Bridge Lower Bay, NY	27	78	SF
22	64	914	XII	7/5/75	Watch Hill, RI	44	272	SF
23	66	1002	---	~~7/7/75~~ 7/17/75	Jamestown, RI	45	322	SF
23	66	944	---	6/4/75	Cuttyhunk, MA	12	349	SF
27	64	174	---	6/10/75	Hudson River Kilometer 64	14	<1	PS
Jun 10	64	192	---	6/23/75	Hudson River Kilometer 64	13	<1	PS
10	64	194	---	6/30/75	Hudson River Kilometer 64	20	<1	PS
Sep 22	91	234	---	9/25/75	Hudson River Kilometer ~~70~~ 69	3	22	PS
29	54	178	---	10/7/75	Hudson River Kilometer 54	8	<1	PS
Oct ~~12~~ 1	64	148	---	10/24/75	Hudson River Kilometer 64	23	<1	PS
1	54	162	---	11/11/75	Hudson River Kilometer 54	41	<1	PS
1	91	142	---	10/28/75	Hudson River Kilometer 91	27	<1	PS
2	54	155	---	10/7/75	Hudson River Kilometer 54	5	<1	PS
3	53	148	---	10/22/75	Hudson River Kilometer 53	19	~~4~~ <1	PS
17	67	206	---	11/6/75	Hudson River	20	<1	PS

Length Group (mm)	Percent Return (%)
≤ 200	~~1.8~~ 2.3
201-400	~~1.2~~ 1.6
401-600	8.4
601-800	11.5
801-1000	10.8
> 1000	17.6

Of the ~~65~~ 71 returns, 24 ~~(37%)~~ (34%) were from outside the Hudson River and its tributaries (Fig. 7.8-4): nine from Long Island Sound, five from the south side of Long Island, and 10 from points east (Montauk, New York to Boston, Massachusetts). The most distant and also the largest recapture occurred in Boston Harbor, Massachusetts. Larger fish recaptured outside the Hudson River had a tendency to move greater distances. The 10 fish >800 mm in total length recovered outside the Hudson averaged 343 km in distance traveled; the 15 fish less than 800 mm in total length averaged ~~119~~ 120 km. The mean distance traveled was significantly different for these two size groups (t = ~~6.79,~~ 6.45 P <0.0005). Fish recovered outside the Hudson that had moved less than 200 km averaged 634 mm in total length, but those traveling more than 200 km averaged 900 mm. The mean sizes of these two groups were significantly different (t = 4.82, P <0.0005). These tag returns suggest that Clark's contingents may represent fish of different ages from the same genetic group, rather than different stocks. Thus, Clark's Hudson-Atlantic Contingent may represent large striped bass and the Hudson Estuary and Hudson-West Contingents may represent smaller and younger fish.

7.8.8 SUMMARY AND CONCLUSIONS. The striped bass population of the Hudson River may be characterized by faster growth rates for females after age III, as has been found in studies of non-Hudson River striped bass. There is no significant difference in growth rates between Hudson River striped bass and other anadromous groups. Landlocked populations grow faster than do anadromous populations. Female striped bass in the Hudson River population begin to mature at age IV and all are mature by age VIII, approximately

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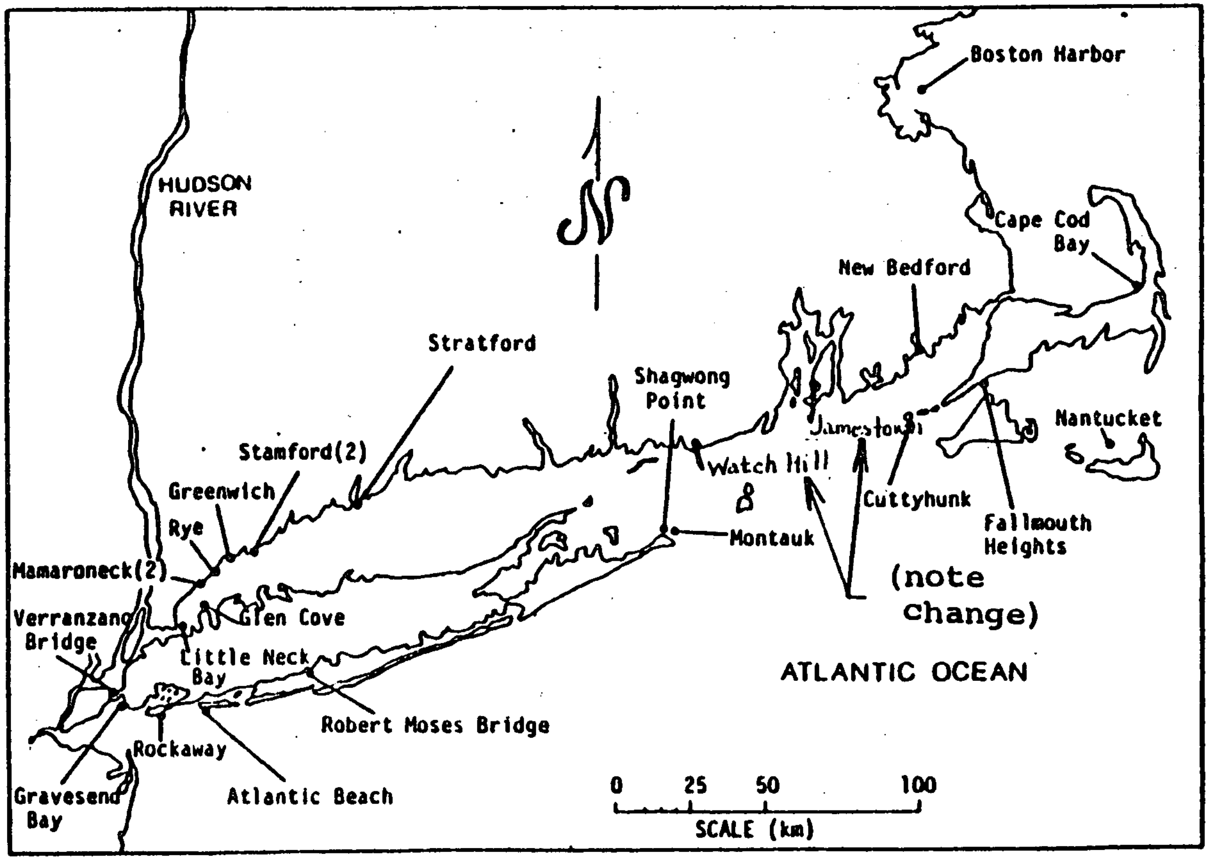
Figure 7.8-4 Returns of Striped Bass to Area Outside Hudson River and Its Tributaries during 1973, 1974, and 1975



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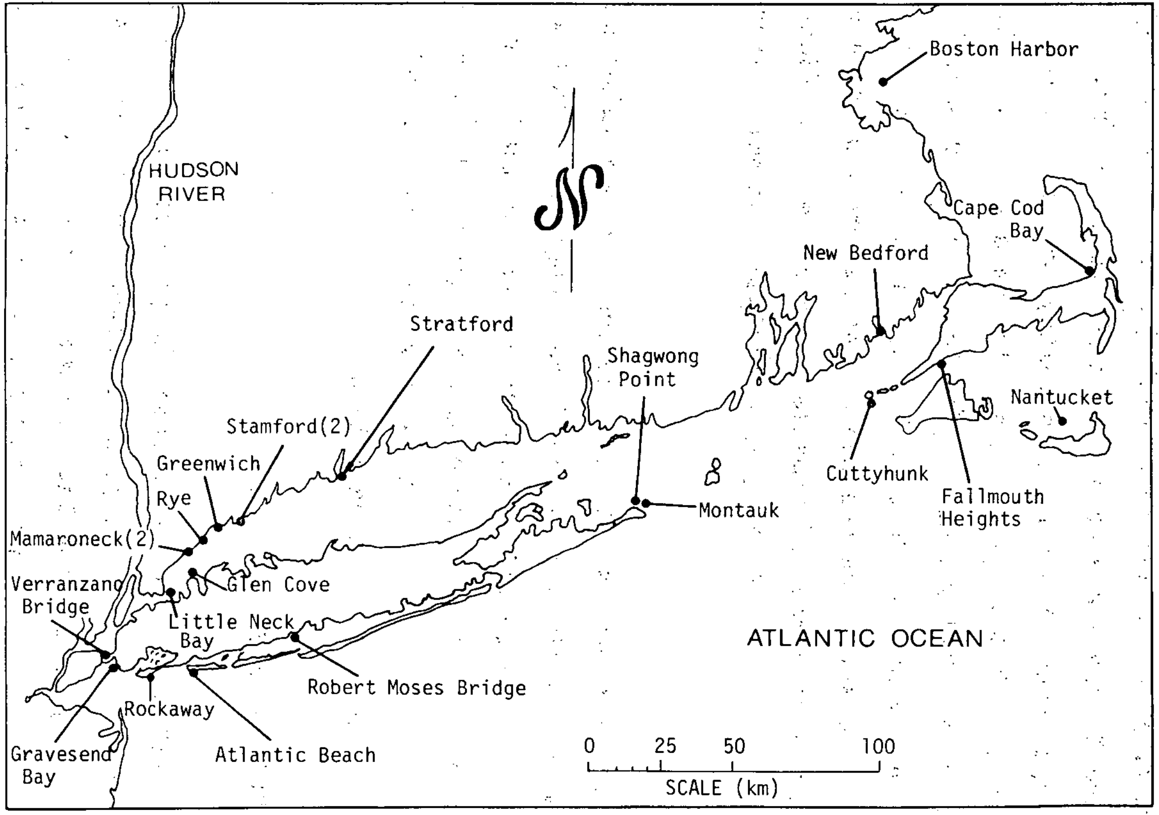

one to two years later than striped bass in the Chesapeake Bay or Connecticut waters. Total annual mortality rates for the Hudson are not known accurately, but may be approximately 0.4. Using 6 x 10^6 Age 0 striped bass (Section 7.9) and an annual mortality rate of 0.8 (Section 7.7) between ages 0 and I, there are about 1.2 x 10^6 yearling (age I) striped bass in the population. Assuming a mortality rate of 0.6 for yearlings, there would be 480,000 age II fish. If the sex ratio is 1:1, there would be approximately 240,000 age II females. Using an annual survival of 0.6, (mortality of 0.4, Section 7.8.4) in all age groups above II, as well as the observed percentage of mature females of each age group and the calculated number of females in each age group (Section 7.8.4), a spawning stock of 85,652 female striped bass would produce 87.9 billion eggs.

The critical age for the fishery is between 3.25 and 7 yr for males and 3.75 and 6.5 for females. Striped bass are seldom caught more than a few miles from the coast. Large (>800 mm) Hudson River striped bass tagged during the spawning season on known spawning grounds migrate to waters off New England. Smaller fish move to areas of western Long Island Sound and the southwestern shore of Long Island.

7.9 JUVENILE STRIPED BASS

7.9.1 POPULATION ESTIMATES. To understand the population dynamics of striped bass and to assess the effects of power plants on the species, a reliable estimate of the juvenile population size is essential. The strength of the year class (all Hudson River striped bass spawned in that year) is probably established before the end of August (see Section 7.9.2). After year class strength is determined, environmental conditions generally have less effect on population size and mortality rates decline. The population size after the establishment of year-class strength is the base on which all additional mortality (natural, fishing, and impingement) acts.

one to two years later than striped bass in the Chesapeake Bay or Connecticut waters. Total annual mortality rates for the Hudson are not known accurately, but may be approximately 0.4. Using 6 x 10^6 Age 0 striped bass (Section 7.9) and an annual mortality rate of 0.8 (Section 7.7) between ages 0 and I, there are about 1.2 x 10^6 yearling (age I) striped bass in the population. Assuming a mortality rate of 0.6 for yearlings, there would be 480,000 age II fish. If the sex ratio is 1:1, there would be approximately 240,000 age II females. Using an annual survival of 0.6, (mortality of 0.4, Section 7.8.4) in all age groups above II, as well as the observed percentage of mature females of each age group and the calculated number of females in each age group (Section 7.8.4), a ~~spawning~~ stock of ~~85,652~~ ~~[680,738]~~ 599,962 female striped bass would produce 87.9 billion eggs.

The critical age for the fishery is between 3.25 and 7 yr for males and 3.75 and 6.5 for females. Striped bass are seldom caught more than a few miles from the coast. Large (>800 mm) Hudson River striped bass tagged during the spawning season on known spawning grounds migrate to waters off New England. Smaller fish move to areas of western Long Island Sound and the southwestern shore of Long Island.

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Biases inherent in any single estimation procedure can be assessed by using more than one type of estimate. Usually sampling gear can not take a random sample of the whole population. All fishing gear have some degree of selectivity, usually for fish of a particular size. Fishing gear are also designed to sample effectively in specific habitats. Migration, diel (day/night) behavioral patterns, and environmental factors can introduce additional bias into a sampling program. Estimates made from catches in different gears are unlikely to have the same biases; thus, a comparison of estimates may show the direction of bias. When comparing population estimates, especially in a system as large as the Hudson River, some prior general knowledge of the fish and habitat is needed to determine which techniques provide reasonable estimates. By using several techniques, the severely biased ones can be identified and discarded or modified to reduce the bias. In this section, estimates of the size of the juvenile striped bass population obtained by the following methods are presented and discussed:

- mark/recapture methods
- beach seine catch extrapolations
- epibenthic sled and tucker trawl catch extrapolations
- commercial catch data

7.9.1.1 Population Estimates Based on Mark/Recapture Methods. Mark/recapture methods are often used to estimate fish populations. A sample of the population is captured, marked, and released. The proportion of marked animals in a later sample is an estimate of the proportion of the population that was marked. The whole population can be estimated from the number of animals marked and the estimate of the proportion of the whole population that was marked.

The Petersen method is best for estimating the population size of Hudson River striped bass. This single-census method requires only one release period and one recapture sample (Ricker 1958;84). The following are the assumptions necessary:

(1) Marked and unmarked fish have the same mortality rates.
(2) Marked and unmarked fish are equally catchable.
(3) Marked fish do not lose their marks.
(4) Equal recapture effort is applied to marked and unmarked fish.
(5) All recaptured fish are recognized and reported.
(6) Recruitment to the population is negligible during the recovery period.

The assumption of equal recapture effort for marked and unmarked fish is the most difficult assumption to meet for the Hudson River striped bass. This assumption can be satisfied best by allowing marked and unmarked fish sufficient time to mix before taking the recovery sample. The Petersen method was ~~choosen~~ chosen over other methods because it has great flexibility in selecting the time for the recovery sample.

Petersen estimates for the 1974 and 1975 year classes were ~~1,288,000~~ 1,308,000 and ~~1,024,000~~ 1,058,000 juveniles in the Hudson River (RM 12-153; km 19-245) in late October (Table 7.9-1). These estimates were based on fish marked in October and November and recaptured from March to June of the following year. The populations could not be estimated for August or September because too few fish marked in these months were recaptured in the spring (Table 7.9-2), thus a severe underestimate of the population size is likely (Robson and Regier 1964). The recapture period was not begun until March so that marked fish could mix with the unmarked fish. The recapture period was terminated in June to avoid problems with fin regeneration.

7.9.1.2 Population Estimates from Beach Seine Catch Extrapolation. The beach seine survey was designed to provide information on distribution, growth, movement, and abundance of Hudson River fish populations. Randomly selected beaches between RM 12 and 153 (km 19 and 245) were sampled with a 100-ft (30-m) seine weekly during July and August and every 2 wk from September to December. All fish caught were identified and counted. Beach-seine catch per unit effort (C/f) data were used to estimate the

This is a replacement Table.

Table 7.9-1 Petersen Mark/Recapture Estimates for 1974 and 1975 Striped Bass Year Classes

	1974	1975
Marking period	Oct-Nov 1974	Oct-Nov 1975
Recovery period	Mar-Jun 1975	Mar-Jun 1976
Recovery gear*	TI field sampling and Indian Point impingement	TI field sampling and Indian Point impingement
Number of marks available**	3281	5764
Number of fish in recovery sample	2790	2388
Number of marked fish recaptured	7	13
Estimated population size in late Oct	1,308,000***	1,059,000***
95% confidence interval	752,000-5,027,000	687,000-2,312,000

*Only sampling gear for which entire catch can be examined for marked fish by TI can be used for population estimates.

**The number of marks released was adjusted for observed 14-day mortality (TI 1975b, c) and for the number of fish recaptured in the release year to determine the number of marked fish available for recapture.

***Estimated population is rounded to nearest thousand.

Table 7.9-1 Petersen Mark/Recapture Estimates for 1974 and 1975 Striped Bass Year Classes

	1974	1975
Marking period	Oct-Nov 1974	Oct-Nov 1975
Recovery period	Mar-Jun 1975	Mar-Jun 1976
Recovery gear*	TI field sampling and Indian Point impingement	TI field sampling and Indian Point impingement
Number of marks available**	3281	5763
Number of fish in recovery sample	2747	2311
Number of marked fish recaptured	7	13
Estimated population size in late Oct	1,288,000***	1,024,000***
95% confidence interval	740,000-4,950,000	664,000-2,237,000

*Only sampling gear for which entire catch can be examined for marked fish by TI can be used for population estimates.

**The number of marks released was adjusted for observed 14-day mortality (TI 1975b, c) and for the number of fish recaptured in the release year to determine the number of marked fish available for recapture.

***Estimated population is rounded to nearest thousand.

THIS TABLE 7.9-1 DELETED IN FAVOR OF PRECEEDING TABLE

THIS IS A CORRECTED TABLE PER ERRATA SHEET

Table 7.9-2 Percent of Marked Striped Bass Recaptured in Year Following Marking

Marking Period	Number of Marks Available*	Number of Recaptures in Following Year**	Percent Recaptured
Aug-Sep 1974	~~4620~~ 4630	1	0.02
Oct-Nov 1974	3281	12	0.37
Aug-Sep 1975	7936	2	0.03
Oct 1975	3384	13	0.38
Nov 1975	2380	11	0.46

*The number of marks released was adjusted for observed 14-day mortality (TI 1975b, c) and for the number of fish recaptured in the release year to determine the number of marked fish available for recapture.

**Includes recaptures from TI field sampling, LMS field sampling, Indian Point and Bowline inpingement.

number of juvenile striped bass in the shore zone (areas <10 ft [3 m] deep). The area swept by each seine tow was assumed to be a constant (TI 1975b) so the catch per tow could be converted to number of fish per unit area. The catch per unit area was then multiplied by the area of the river <10 ft (3 m) deep. Separate estimates were made for each of 12 geographical regions to reduce bias from nonuniform distribution of the fish. The regional population estimates were summed to provide an estimate of the total river population.

Beach seine C/f was higher at night than during the day. Movement into shallower water at night was probably responsible for the higher C/f. The day/night C/f ratios were used to adjust day time estimates to nighttime estimates so that comparison could be made with shoal (10-20 ft; 3-6 m) populations which were sampled only at night.

On the basis of this estimation method, the 1974 and 1975 year classes reached peak abundance of approximately 5,000,000 in the shorezone in early or mid-September (Fig. 7.9-1) and declined rapidly to <2,000,000 by mid-October. The 1973 year class to which this estimation procedure can be applied, reached 20,000,000 in September and did not drop below 2,000,000 until November. All three year classes were <1,000,000 by late November. If year-class strength was already established by August, the differences in September peaks represented real year-class strength differences.

Decline in the population estimate after September was probably caused by movement away from the shorezone. The fish may have been moving into the channel where they were less efficiently sampled or to the lower estuary below the George Washington Bridge (RM 12; km 19). The latter hypothesis seems plausible since juvenile striped bass have been captured in the lower river and bays in September (Section 7.5).

7.9.1.3 Population Estimates from Extrapolation of Epibenthic Sled and Tucker Trawl Catches. The epibenthic sled and Tucker trawl sampling programs were designed to determine the abundance, movement, and distribution of eggs,

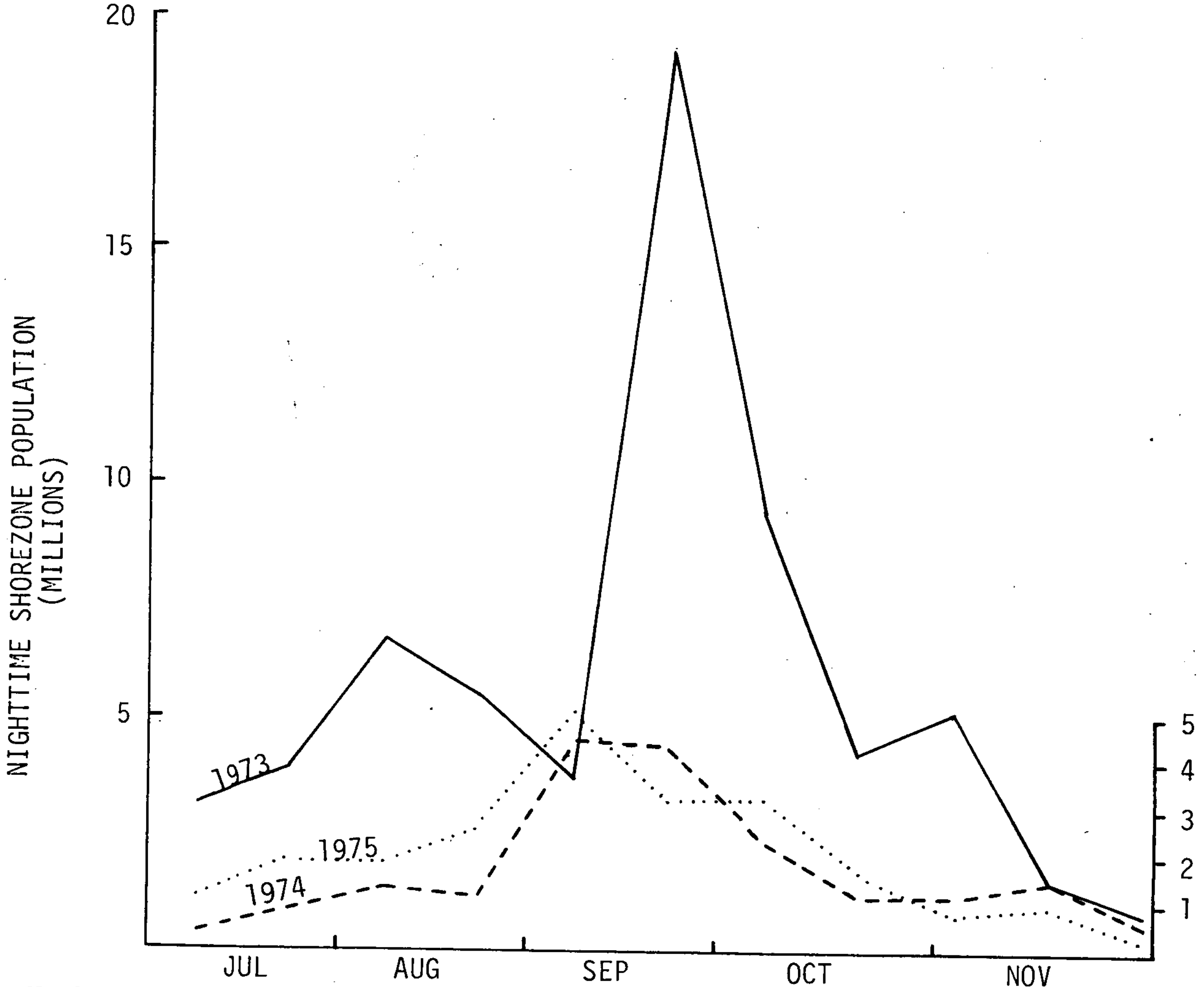


Figure 7.9-1 Number of Juvenile Striped Bass in Shorezone Based on Beach Seine Catch Extrapolations. (Estimates are corrected for nighttime C/f)

larvae, and juveniles, in the Hudson River. Sampling began in April and continued through December. Until mid-August, sampling with Tucker trawl and epibenthic sled extended from RM 14 to 140 (km 22 to 224); after mid-August, sampling was conducted with a modified epibenthic sled from RM 14 to 77 (km 22 to 123). Samples were generally taken from depths ≥10 ft (3 m). The epibenthic sled was deployed on the river bottom. Tucker trawls are used anywhere in the water column, but always >10 ft (3 m) above bottom. Density estimates (number of fish caught per unit volume of water passing through the net) in epibenthic sleds and Tucker trawls were extrapolated to produce population estimates of juvenile striped bass in (a) the shoals 10-20 ft (3-6 m) in depth; (b) in the channel from the surface to 10 ft [3 m] from the bottom in water >20 ft [6 m]; (c) and on the bottom 0-10 ft [0-3 m] above the bottom in water >20 ft [6 m] deep. The mean densities in each geographic region were multiplied by the volumes of the shoals, channel, and bottom in the region to obtain an estimate of the population. The regional estimates were summed to estimate the total river population. Channel sampling was discontinued in mid-August since very few juveniles are in the channel after this time. Population estimates in 1974 and 1975 showed peak abundance in early July, rapid decline until August, then a gradual decline with minor peaks through November (Fig. 7.9-2). The large estimates in early July were the result of late larvae that had not transformed to the juvenile stage.

7.9.1.4 Shoal, Channel, Bottom, and Shorezone Population Estimates Combined. Estimates of the 1974 and 1975 juvenile striped bass populations were developed through a combination of beach seine, epibenthic sled, and Tucker trawl catch extrapolation. These three gear permit the number of striped bass in the shore, shoal, channel, and bottom areas to be estimated.

The 1974 and 1975 year classes showed similar patterns: a population size of approximately 5,000,000-6,000,000 in late August, followed by a rapid decline and stabilization between 1,000,000 and 2,000,000 through October and November (Fig. 7.9-3). The 1975 year class deviated slightly from this pattern, apparently peaking again in early October due to 1 wk of large catches in the 10-20 ft (3-6 m) area.

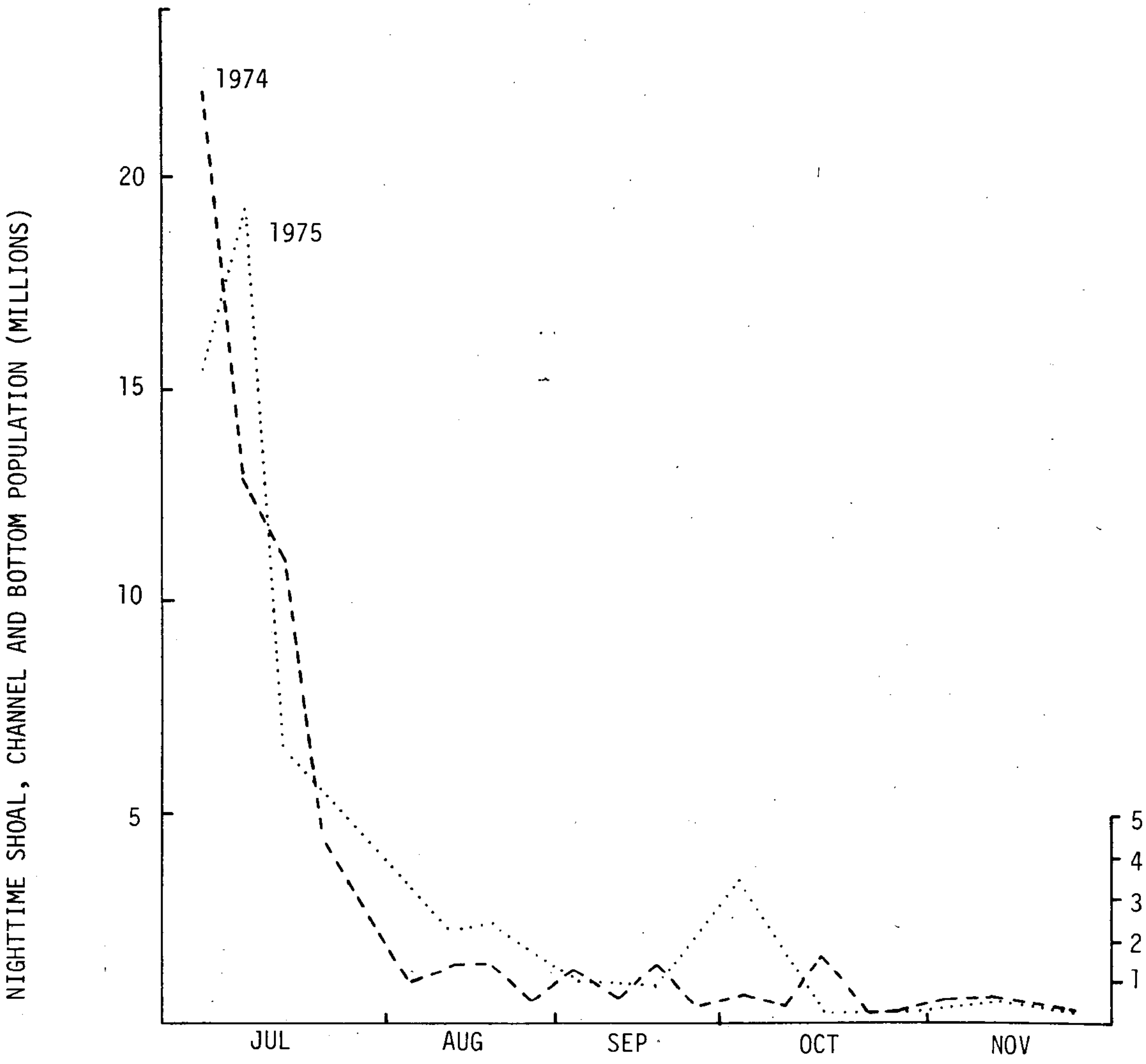


Figure 7.9-2 Number of Juvenile Striped Bass in Shoal, Channel, and Bottom Zones Based on Epibenthic Sled and Tucker Trawl Catch Extrapolations

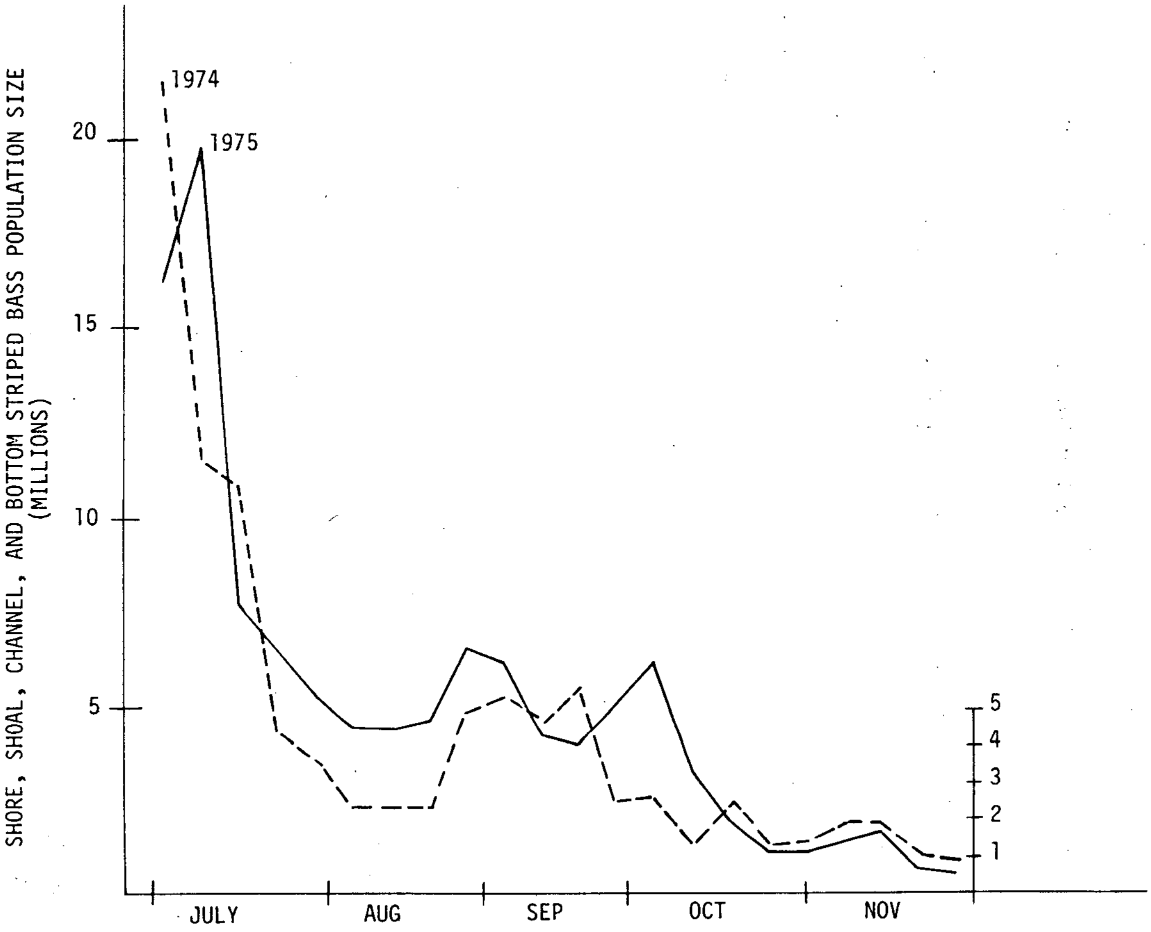


Figure 7.9-3 Striped Bass Juvenile Population Size Based on Beach Seine, Epibenthic Sled and Tucker Trawl Density Extrapolations

To explain the observed numerical decline from about 5,000,000 fish in late August to $\leq$1,500,000 in late October on the basis of natural mortality alone would require a postulated mortality of 45% mo^{-1}. This would be an extremely high mortality rate for fish that have already reached the juvenile stage (too high, in fact, to be readily accepted). The initial appearance of juvenile striped bass in the lower estuary in September (Section 7.5) suggests that emigration from the area encompassed by the population estimates is an additional major cause of the decrease in the river populations.

7.9.1.5 Estimates Based on Commercial Catch Extrapolations. Extrapolation of commercial catch statistics can provide a rough estimate of average year-class strength needed to sustain the commercial fishery, but this type of estimate can be used only to verify the population estimates derived by other methods for Hudson River striped bass. The commercial catch is reported in pounds, and essentially no information is available on the age structure of the catch or the number of fish caught. Thus, many assumptions are necessary to obtain an estimate of juvenile population size.

The mean annual commercial catch represents the average yield of a year class to the commercial fishery if the adult population size and age structure are stable. Each year's catch is comprised of fish from several year classes. When an exploited population's size and age structure are stable, the sum of the yields from each year class during 1 yr of fishing will approximate the yield from a single year class over the time it is vulnerable to fishing. The mean annual commercial catch (Section 7.2) of striped bass in the Hudson River over the past 15 yr has been 46,700 lb; this is assumed to be the average yield from a year class.

Population estimates of juveniles from commercial catch data are based on the assumption that 4-yr-old fish comprise one-half of the commercial catch by weight. Thus, 23,350 lb of the commercial catch would be attributed to 4-yr-old fish. If the mean weight of 4-yr-olds were 3.5 lb, the average number of 4-yr-olds caught would be 6,671. The commercial exploitation rate for 4-yr-olds is assumed to be 5%. The number of 4-yr-olds in the spawning run would then be 6671/0.05, or 133,420 fish. If the true exploitation rate were higher than 5%, the spawning run would be smaller.

Assumed and estimated age-specific survival rates (Sections 7.7, 7.8) were applied to the estimate of 4-yr-old fish in the spawning run to estimate the number of juveniles needed to produce that commercial catch. If actual survival rates were higher, fewer juveniles would be required to produce the commercial catch; conversely, lower survival rates would require a larger juvenile population. Age-specific survival rates of 0.20, 0.40, 0.50, and 0.60 for juvenile, yearling, 2-yr-old and 3-yr-old fish respectively have produced an estimated 5,559,000 juveniles as the average year-class strength (Fig. 7.9-4) over the last 15 years. Thus, if the actual survival parameters of the striped bass population and the accompanying exploitation rate do not vary substantially from those used in this assessment, then the juvenile populations of 5,000,000 to 6,000,000 which were estimated in Section 7.9.1.4 were capable of maintaining the average level of recruitment to the fishery observed over the past 15 yr.

7.9.1.6 Summary. All estimation techniques indicated that normal striped bass year-class strength in late August was about 5,000,000 or 6,000,000 based on the 1974 and 1975 year classes. Based on beach seine catch extrapolations alone, the 1973 year class was almost 20,000,000. The apparent fourfold variation in year-class strength is not unusual for fish populations. The close agreement of the shore-shoal-channel-bottom estimates and commercial catch extrapolations for early fall and shore-shoal-bottom and mark/recapture estimates for late fall suggests that none of the methods are severely biased (Fig. 7.9-5).

The rapid decline in population size in September was probably due to a combination of movement out of the primary sampling areas and natural

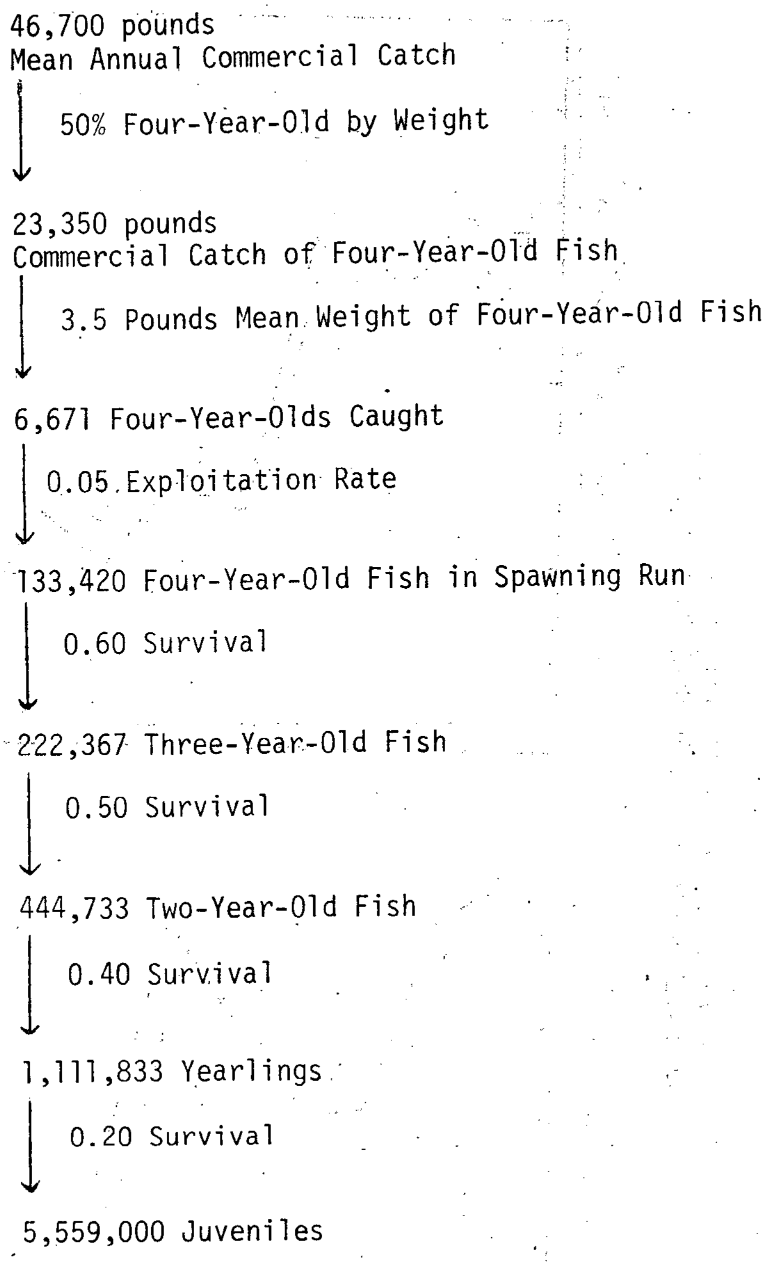


Figure 7.9-4. Striped Bass Population Estimates Based on Commercial Catch Data

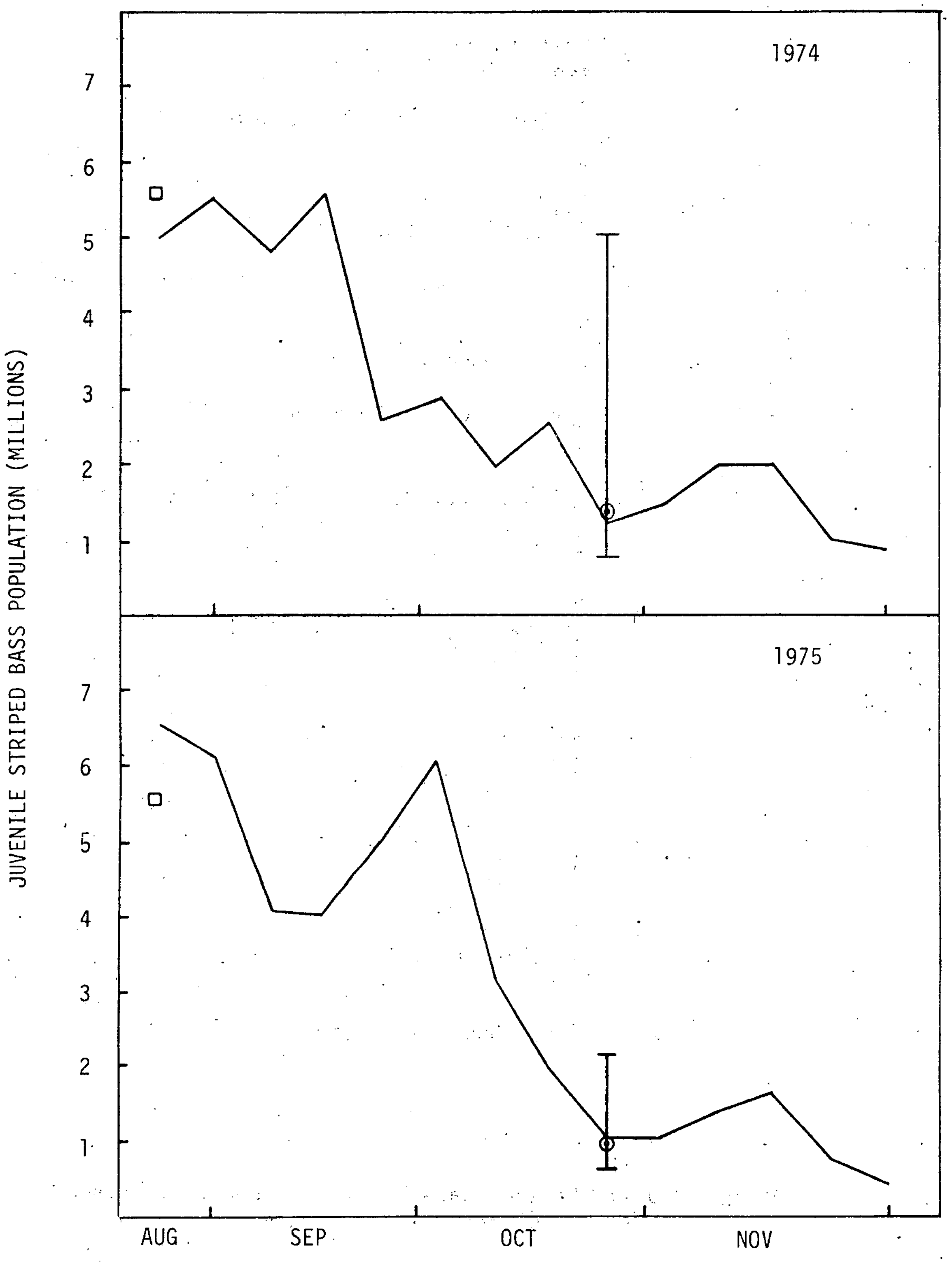


Figure 7.9-5 Juvenile Striped Bass Population Size Based on Shore, Shoal, and Bottom Catch Extrapolations (——), Commercial Catch Extrapolation (▭), and Mark/Recapture Methods with 95% Confidence Interval (⊙) →DELETE

(Φ) →ADD

mortality. The appearance of juvenile striped bass in the lower bays at that time (Section 7.5) supported the emigration hypothesis. Recaptures of marked fish showed no substantial downstream movement (Fig. 7.5-2 and 7.5-3); however, the relatively small amount of sampling effort below the Tappan Zee Bridge, the large size of the regions, and concentration of sampling in shallow water made detection of emigration difficult, especially if the fish were moving out through the channel.

There was no evidence of mortality rates high enough (45% of the population over 1 mo) to explain the disappearance of 4,000,000 to 5,000,000 juvenile striped bass. Emigration was a much more likely explanation of the decline.

Striped bass that had not emigrated by mid-October remained in the shallow-water areas until late November (Fig. 7.9-1). In all 3 yr, the size of the population remaining in the shallows in late fall was between 1,000,000 and 2,000,000, which represents the part of the population that has not emigrated. The spring recapture percentages of fish marked in October and November (Table 7.9-2) suggest that many of those fish remained in the river all winter.

The population size of striped bass that should be used as a base for assessing exploitation and impact was the late summer population size. The population at that time was approximately 5,000,000 or 6,000,000 fish but could have been much larger in some years. Smaller populations might also be seen if more years of data were available.

The catch extrapolation estimates may represent minimal estimates because they are based on the number of fish caught in the area or volume sampled. No correction was made for fish that were in the water sampled but managed to avoid capture. The efficiency of each gear in capturing the fish in the sampling area changes during the year, and substantial differences exist between gears. Thus, the fish are sampled with a different degree of efficiency when they are in the shoals than when they are in the shorezone. Apparent changes in population size could be attributable in part to movements to habitats where the sampling efficiency is greatly different from the prior habitat.

7.9.2 FLUCTUATIONS IN ABUNDANCE. Using the available data from the Hudson River estuary, a yearly index of juvenile striped bass abundance was developed which will be correlated in Section 7.9.3 with different environmental factors to determine if a relationship exists. Hudson River sampling gear useful in developing abundance indices included ichthyoplankton gear, bottom trawls, and seines. A previous study of juvenile striped bass abundance in the Hudson River estuary (TI 1975b:39) used the July-August riverwide beach seine survey as a basis for comparisons with environmental factors. After an index was selected, an attempt was made to verify that it was indicative of real fluctuations in population abundance, rather than an artifact of sampling variability.

7.9.2.1 Selection of Abundance Index. To determine the "best index" of juvenile abundance, the data base provided by several types of sampling gear was reviewed. This included ichthyoplankton gear, which sample eggs and larvae; bottom trawls, which sample areas away from the shorezone; and beach seines, which sample areas near shore. Qualities desired in a "best index" included an ability to sample a majority of the young-of-the-year population, a sampling sequence that used consistent gear over the years studied, and an index representing a time period after year-class strength had been established (an index directly related to the number of new fish eventually entering the fishery and eventually available for spawning). Sampling techniques that failed to fulfill these criteria adequately were eliminated as a possible base for a juvenile striped bass abundance index.

Ichthyoplankton data (collected during May and June) were available for a 6 yr period within any given river region. Sampling gear varied over this time period, with changes in sampling location, types of gear used for the sampling, methods of operating the gear. This was complicated by the short durations of the larval stages and the dramatically altered susceptibility to different gear types from one stage to the next. Also, year-class strength may be determined at the end of the larval period or later (Sommani 1972:49-51). All of these considerations indicated that an adequate juvenile striped bass abundance index could not be derived from ichthyoplankton data.

Gear changes and population distribution also made the 10 yr of bottom trawl data (1965-75 excluding 1971) difficult to use for an abundance index. Comparisons among years were hampered by differences in towing speed, trawling location, and net mesh size. An even more serious problem involved the distribution of juvenile striped bass in summer and early fall. Young-of-the-year striped bass were seldom caught in bottom trawls during June, since they were still too small to be captured by the gear. During July, the percent of the standing crop in depths >20 ft (6 m) decreased from 97.1 to 12.7% in 1974 and from 81.0 to 10.1% in 1975 (Section 7.9); similarly, during August, the percent of the standing crop in depths <10 ft deep (3 m) averaged 54.2% in 1974 and 48.2% in 1975, and these percentages increased both years during the months of September and October (Section 7.9). Depths <10 ft are not sampled by the bottom trawl, so it can sample the majority of the juvenile population only during July, when most of the population is migrating out of deeper water into the shorezone not sampled by this gear type. Since the majority of the juvenile population was available to bottom trawls for < 1 mo this gear could not provide an adequate abundance index.

Beach seine surveys had been taken over a 10-yr period (1965-75 excluding 1971); however, June, July, and August were the only months during which sampling had occurred every year of surveying. Since juvenile striped bass are seldom caught by beach seine in June, an index covering all 10 yr could be derived only for July and August. Effort during those months varied greatly over the 10 yr period (Table 7.9-3). Both the area of the river included in the annual survey and the amount of effort in each region had substantially increased in the past 3 yr. Earlier surveys concentrated their sampling in the Indian Point region (RM 43; km 69). The 1969 studies by NYU and Raytheon, the 1970 study by Raytheon, and the 1972 TI study are the most restricted in this respect.

Sampling which is restricted to a small portion of the total river may present a biased abundance index if the striped bass are not evenly distributed throughout the river. Striped bass in the Hudson River estuary

Table 7.9-3 Comparison of River Area Sampled and Total Surface Area Swept by Beach Seine during July and August (Day Only), 1965-75

Study	Year	River Area Sampled (RM)	River Area Sampled (km)	Total Surface Area Swept (Jul-Aug) $(Ft)^2$	Total Surface Area Swept (Jul-Aug) (m^2)
NYU	1965	27-87	43-139	167,500	15,578
NYU	1966	27-105	43-168	512,850	47,695
NYU	1967	27-96	43-154	311,250	28,946
NYU	1968	27-105	43-168	464,700	43,217
NYU,RAY	1969	35-87	56-139	136,483	12,693
RAY	1970	35-47	56-75	489,244	45,500
TI	1972	32-43	51-69	358,850	33,373
TI	1973	12-153	19-245	2,359,340	218,490
TI	1974	12-153	19-245	2,891,868	268,940
TI	1975	12-153	19-245	4,417,728	410,851

appear to be unevenly distributed, and the location of the greatest percentage of the population changes from month to month (Sections 6.1 and 7.5). Restricting the index to those stations and the time periods common to all surveys (standard stations) should at least standardize the bias, but the index might not accurately reflect the abundance of river population as a whole. A riverwide index including all stations uses the broadest data base available and should reflect the abundance of the entire river population, but biased estimates would remain for those years with restricted sampling.

To compensate for this, a ratio of total river abundance to standard station abundance in July and August was derived for 1973-75. The catch-per-effort (C/f) values of those sampling programs restricted to the Indian Point area (1969, 1970, and 1972) were then multiplied by the resulting fraction (0.37). This adjustment scaled the 1969, 1970, and 1972 values to approximate those of a more comprehensive survey (Table 7.9-4). All of the bias, however, would be eliminated only if juvenile striped bass distribution in 1969, 1970, and 1972 were approximately the same as in 1973-75.

Table 7.9-4 Riverwide Beach Seine Catch per Unit Area (CPUA), 1965-75

1965	1966	1967	1968	1969	1970	1972	1973	1974	1975
3.6	5.9	3.2	1.1	27.0*	14.8*	8.5*	29.4	7.2	16.8

*Adjusted by multiplying times an average riverwide abundance/standard-station abundance ratio (1/2.7) = (0.37).

Although July-August was the only time period consistently sampled each year, it would be more useful as an index if it accurately represented abundance fluctuations after year-class strength had been determined. Sommani (1972:49-51) stated that year-class strength in the San Francisco Bay estuary was determined when the juveniles reached 1.5 in (TL). Since this length was reached in the Hudson River during July (Section 7.7), the July-August index should represent subsequent population abundance levels, including the period of recruitment to the fishery.

Further examination of the Hudson River data base also indicated that year-class strength was established by the time of the July-August abundance index. One check for this hypothesis was to compare indices derived from later months or combinations of months (September, October, and August-September) for those years for which they were available. All of these indices followed the same trend, with 1969 and 1973 consistently being shown as large year classes (Fig. 7.9-6). Another check on whether the July-August estimate was representative of year-class strength was to compare it with corresponding commercial C/f. Assuming that the commercial fishery in the Hudson is dominated by 4-yr-old fish (an assumption supported by preliminary age and length analysis), then the relative abundance of July-August juveniles and the commercial C/f 4 yr later should follow similar patterns, which they do (Fig. 7.9-7).

7.9.2.2 Analysis of Variance. Striped bass abundance is known to fluctuate considerably from year to year (Turner and Chadwick 1972:444-445, and Schaefer 1972a); however, the statistical significance of yearly differences is not often tested because of the need for a substantial number of observations, extensive geographical coverage, and highly comparable data. Such a data set was not available for the riverwide abundance index because of the years of restricted sampling, but data from four comparable standard stations did exist over a 6 yr period. Even though these stations may not have represented the entire river population, a statistical analysis of their fluctuations in abundance may help to determine the validity of the riverwide index.

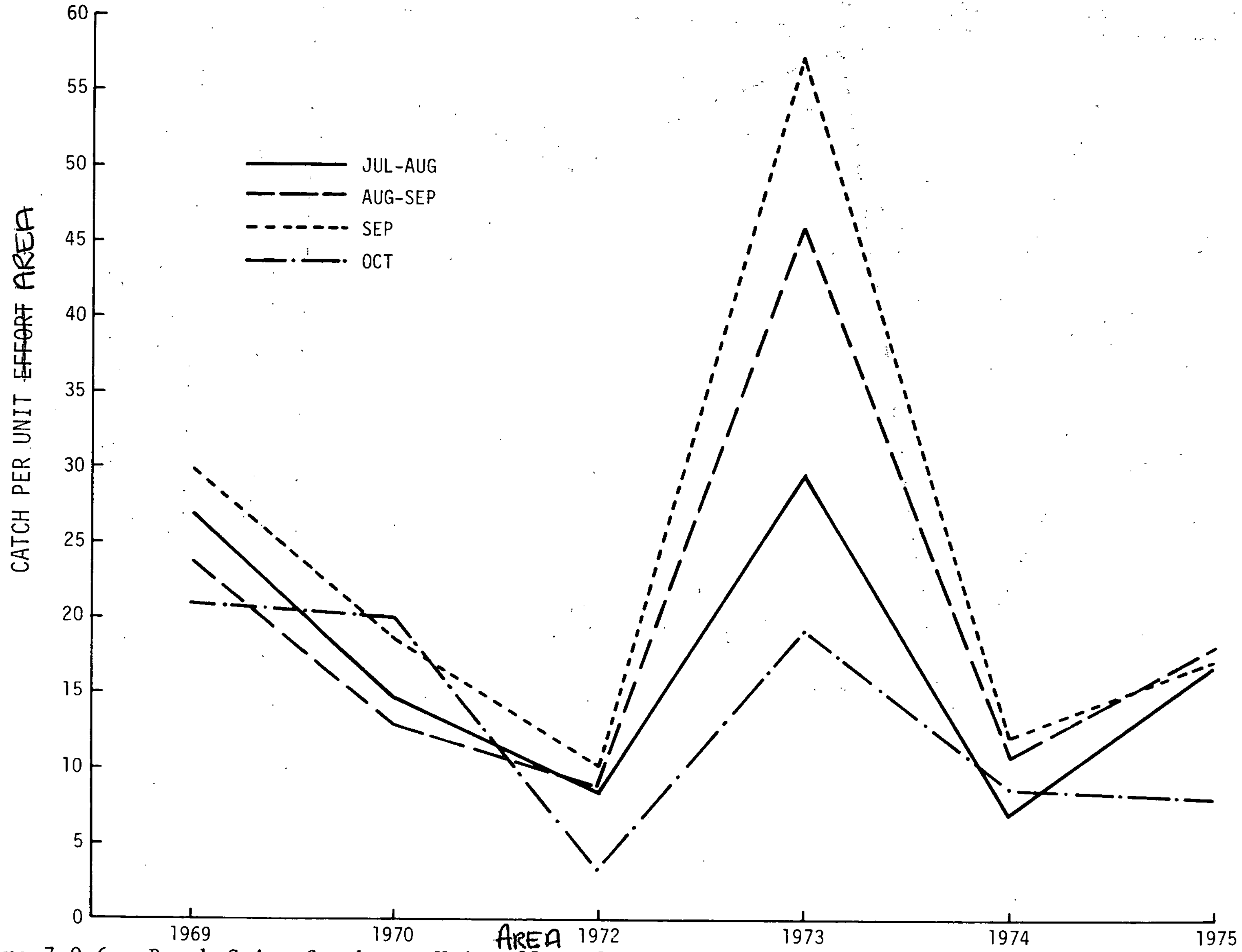


Figure 7.9-6 Beach Seine Catch per Unit ~~Effort~~ AREA for Juvenile Striped Bass in July-August, August-September, September and October

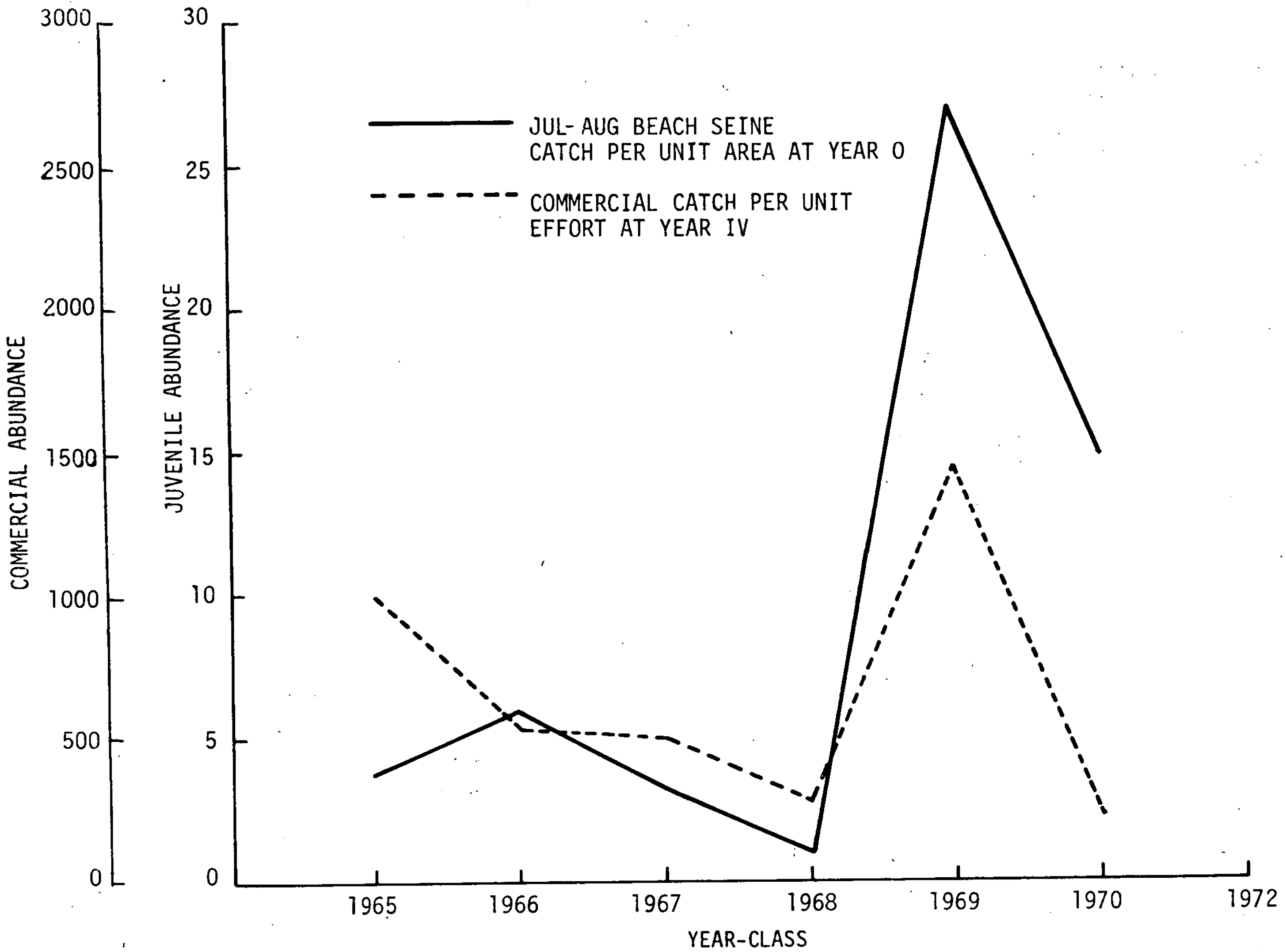
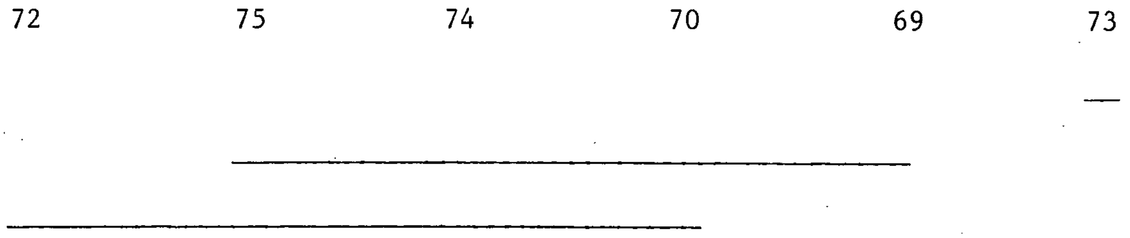


Figure 7.9-7 Abundance of Striped Bass Year Classes Represented by Beach Seine Catch per Unit Area at Year 0 and Commercial Fishery Catch per Unit Effort at Year IV

Beach seine sampling was conducted for 6 yr (1969-75 excluding 1971) at the same four stations in the vicinity of Indian Point (Table 7.9-5). Raytheon stations 34,35,36, and 38 coincided with TI stations 8,9, 10, and 11. Seine size (100 ft; 31 m) was comparable for all 5 yr except August 1-September 10, 1969, when Raytheon used 75-ft (23-m) seines; however, catches made with the 75 ft seines were converted to the equivalent of 100-ft seine catches by a ratio of areas swept (TI 1975b). Seine deployment was comparable for all 5 yr (TI 1975b). Data used were mean catch per unit effort for day samples taken during 12 consecutive weeks starting with the first complete week of August. For the analysis of variance, the 12 weeks were partitioned into three groups, i.e., the first 4 wk, the second 4 wk, and the third 4 wk, which are approximately equivalent to August, September, and October respectively.

An initial analysis of variance revealed an interaction between months and years ($p < 0.05$). To determine the source of this interaction, a Newman-Keuls multiple comparison test was made (Winer 1971). At an α level of 0.05, there were significant differences among years during August but not during September or October. The August differences can best be summarized with the use of the following segmental line graph in which year classes are ranked in order of size, from smallest (left) to largest (right):



The lines connect those years which had no statistically significant abundance differences. Therefore, 1973 was significantly larger than all other years and 1969 significantly larger than 1972 while 1970, 1974, 1975, and 1972 could not be separated from one another statistically. Using an α level of 0.1 did not change these results. This test agreed with the

Table 7.9-5 Total Number of Beach Seine Hauls (Day Only) during August, September, and October at Comparable Indian Point Region Standard Stations

Study	Year	Stations	No. of Tows Aug, Sep, Oct
Ray	1969	34, 35, 36, 38	38
Ray	1970	34, 35, 36, 38	60
TI	1972	8, 9, 10, 11	67
TI	1973	8, 9, 10, 11	59
TI	1974	8, 9, 10, 11	46
TI	1975	8, 9, 10, 11	47

July-August riverwide index (Table 7.9-4), which also showed 1973 and 1969 to be ranked first and second respectively and to be considerably larger than the other year classes in the index.

The large differences in the August mean abundance values (standard stations) were apparent when graphed with mean abundance values from September and October (Fig. 7.9-8). The 1973 year class size was much larger than other years, with 1969 also being high. All values tended to converge in September and October, as indicated by the lack of significant differences among means in those months. This convergence could have been caused by an increasing mortality rate with increasing abundance (density-dependent mortality) or by density-associated migration away from the beach areas or downstream out of much of the survey area in September and October. If the decrease in abundance of larger year classes were caused by mortality (or if the migration was downstream and out of the region), then the Hudson would appear to have a carrying capacity that confines abundance in the river to a narrow range. The migration hypothesis seems to be favored by distribution data (Sections 6.2 and 7.5). It should be noted that such density-dependent emigration may subject the migrants to higher levels of mortality from predation by other sources in the marine environment. Thus, density-dependent emigration can lead to density-dependent mortaltiy.

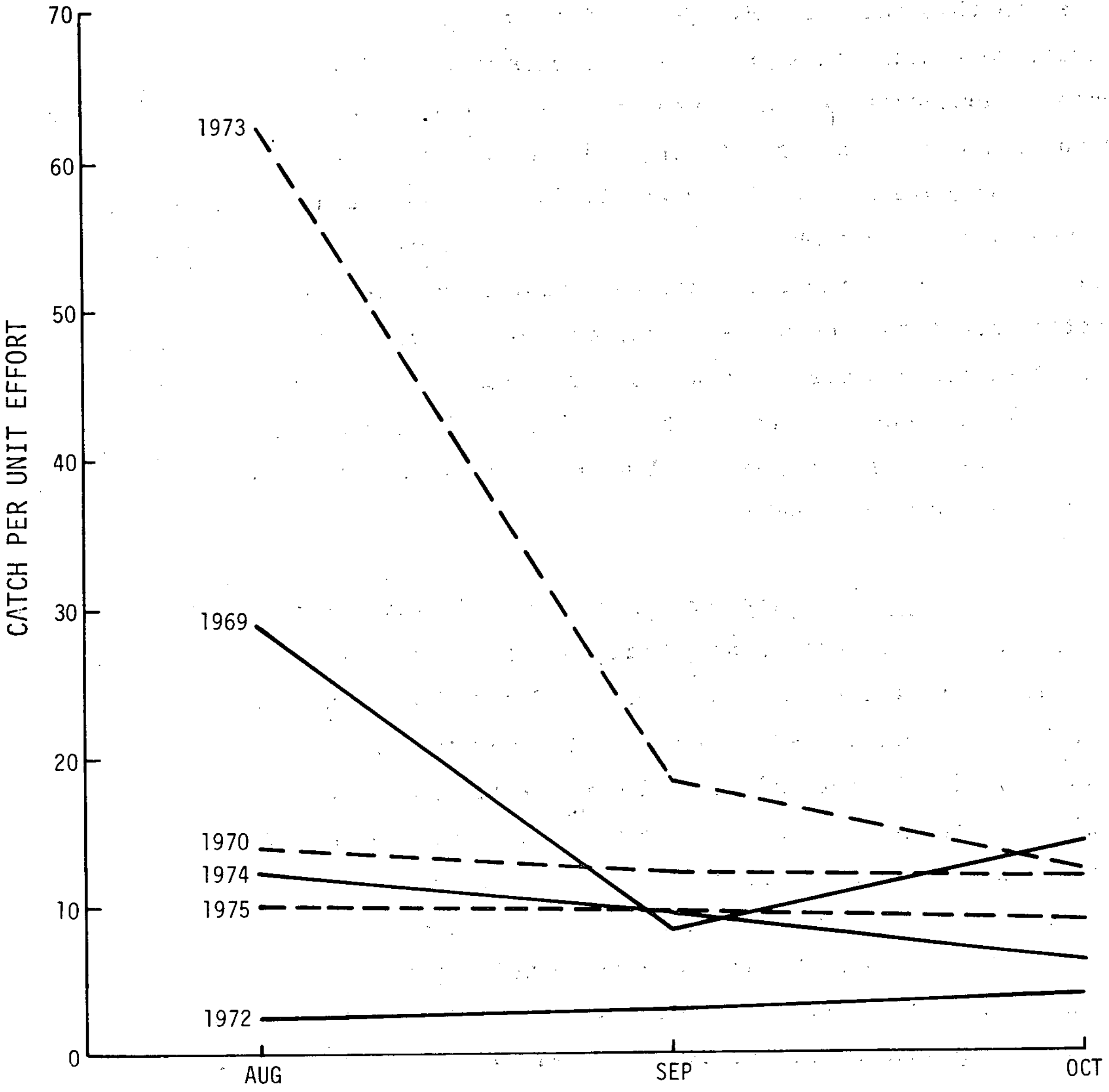


Figure 7.9-8 Standard Station Beach Seine Mean Catch per Unit Effort for Juvenile Striped Bass, August, September, and October, 1969-75 (Excluding 1971)

7.9.3 ENVIRONMENTAL FACTORS INFLUENCING YEAR CLASS ABUNDANCE.

The relationship between variations in juvenile striped bass abundance (Section 7.9.2) and a variety of potentially important environmental factors is examined in this section. By identifying those variables that significantly influence year-class strength, their effects can be differentiated from changes in abundance of fish caused by power plant impact, and future striped bass abundance under an assortment of different conditions can be estimated. Guidelines recommended by Ricker (1975:278-279) have been used in selecting from among the large number of environmental factors available. These guidelines give preference to factors likely to affect the species directly (as determined from previous studies) and to factors for which accurate quantitative measurments are available over all 10 yr of the juvenile striped bass abundance index (Section 7.9.2). Factors selected as important were tested by multiple linear regression analysis for their influence on juvenile abundance.

7.9.3.1 Selection of Environmental Factors. Freshwater flow has been noted as important in determining striped bass abundance (Sommani 1972: 55-59, Turner and Chadwick 1972). Hudson River flow data were available in biweekly segments for all months of the year (based on USGS records of mean daily freshwater inflow at Green Island Dam, Troy, New York), but only the months November (of the previous year) through June were considered to have a possible effect on July-August juvenile abundance. Flow variables were selected by the principal components technique (Morrison 1967); this technique determines which portion of a data set contains most of the variance, then makes that portion a new variable (principal component 1) and repeats the same process with the remaining variance to produce principal component 2, etc. The resulting variables were a weighted average flow (November-June) and the difference between spring flow (April-June) and winter flow (November-March) using weighted averages (Table 7.9-6).

The literature also frequently mentions temperature as influencing striped bass reproduction (Talbot 1966:42, Farley 1967:34-36, Bayless 1972:44-48). With a July-August abundance index, pertinent temperature effects

Table 7.9-6 Variables Used in Latent Root Regression Analysis. (Flow and predation variables were chosen by the Principal Components Method [Morrison 1967])

Year	PC-1* Flow	PC-2** Flow	Temperature Change Number of Days (12°-16°C)	Temperature Change Number of Days (16°-20°C)	Power-Plant Withdrawal Index ($m^3 \times 10^3 day^{-1}$)	Egg-Production Index	PC-1*** Predation
1965	-26145.83	-1390.29	0.210	0.182	3217	2010	-1.5616
1966	-9895.88	-4515.00	0.222	0.267	3217	2217	-1.9210
1967	-13487.36	5299.94	0.154	0.364	3786	2091	-1.8235
1968	-3417.68	-1904.63	0.222	0.167	3786	2327	-1.8413
1969	912.70	6134.98	0.235	0.286	4604	2706	-1.7788
1970	-7140.71	3475.75	0.200	0.182	5258	3052	-0.9707
1972	19388.93	20784.49	0.444	0.095	5258	3190	1.4356
1973	22335.10	11262.12	0.114	0.500	12094	3014	-0.3554
1974	8121.44	-5659.89	0.182	0.154	14188	2997	4.2682
1975	9329.58	-10963.26	0.444	0.444	17682	2963	4.5486

* Standardized weighted average flow (November-April)

** Standardized weighted difference of flows, Spring (April-June) minus Winter (November-March)

*** Standardized weighted average of bluefish and yearling and older striped bass catch-per-unit area are probably limited to April, May, and June. Simple linear regressions showed no significant relationship between year class abundance and biweekly mean temperatures during that period. However, if maximum spawning activity always occurs within the same narrow temperature range (Calhoun et al. 1950:141-143, Talbot 1966:42, Farley 1967), then rate of temperature change or duration of temperature within a certain range could be the important factor (Bannister et al. 1974:35, Pinus 1974:83). Since most eggs and yolk-sac larvae were caught during 12-20°C temperature range, the rate of temperature change was calculated for two intervals: 12-16°C and 16-20°C (Table 7.9-6). The former temperature range included the maximum catch per unit effort for eggs and the latter includes the maximum catch per unit effort for yolk-sac larvae (Section 6.2).

Power plant cooling water withdrawal was used as an indicator of potential entrainment and impingement mortality. Volumes used were maximum combined daily water withdrawal by all operating units at Bowline (RM 37; km 60), Lovett (RM 41; km 66), Indian Point (RM 43; km 69), Danskammer (RM 66; km 106), and Roseton (RM 65; km 105), assuming the volume of water withdrawn was directly proportional to capacity (Table 7.9-6).

Cannibalism might regulate juvenile striped bass population levels should the distribution of the different age groups overlap. In the Sacramento-San Joaquin River system of California, cannibalism by both yearlings and adults was demonstrated to be an important cause of mortality for young-of-the-year striped bass (Stevens 1966, Thomas 1967). There is a paucity of data on other predators of juvenile striped bass in the Hudson River. One predator that does occur is the bluefish, an active piscivore (Bigelow and Schroeder 1953:383-389). Abundance indices for bluefish and yearling and older striped bass were based on the same beach seine survey during July and August from which the juvenile striped bass abundance index was derived (Section 7.9.2). The model used here considered cannibalism to be a special type of predation and bluefish and yearling and older striped bass to be part of a predator complex. The combined predation index was determined by the principal components technique (Morrison 1967) (Table 7.9-6).

Size of the spawning stock is related to young-of-the-year abundance for many fish species, including some populations of striped bass (Sommani 1972:37-51, and this report, Section 10.6). This relationship may be positive or negative, depending on the particular species and the range of population size. An egg production index for the Hudson River spawning stock was derived from commercial fishery catch per unit effort data (Table 7.9-6). This egg production index utilized estimates of mortality, fecundity, and percent maturity for all ages of Hudson River striped bass in the spawning stock in order to estimate relative egg production. As Ricker (1975) pointed out: "...it is likely that the effect of parental stock density upon recruitment is usually exerted *via* the density of the eggs or larvae they produce,...".

7.9.3.2 *Analysis and Results*. A relationship was sought between the juvenile striped bass abundance index and the seven factors described in Section 7.9.3.1:

- Weighted average freshwater inflow (Nov-Jun) (Green Island Dam, Troy, New York)
- Weighted average spring freshwater inflow (Apr-Jun) minus (-) weighted average winter flow (Nov-Mar)
- Rate of warming of surface water, 12-16°C
- Rate of warming of surface water, 16-20°C
- Maximum combined daily power plant water withdrawal
- Juvenile bluefish and yearling and older striped bass combined predation index
- Egg production index (derived from spawning stock).

The juvenile striped bass abundance index was regressed upon the seven factors using a modified backward elimination type of linear regression procedure (Webster, Gunst, and Mason 1974). This procedure is referenced as latent root regression analysis. It assessed whether a strong linear dependence existed among ~~among~~ the independent variables that produced little or no change in the dependent variable (striped bass abundance)

(Webster, Gunst, and Mason 1974). Normal estimates of the parameters in a multiple linear regression model are known to suffer severe distortion when such a dependence exists (Gunst, Webster, and Mason 1976). A linear dependence did exist among the independent (environmental) variables, but this linear dependence produced change in the dependent variable, making the dependence predictive and of value. Therefore, the latent root procedure performed a stepwise backward elimination of variables using the ordinary least squares method.

The latent root regression analysis resulted in eliminating all the variables except three: predator index, egg production index, and rate of temperature change over the interval 16-20°C (Table 7.9-7). All three of the variables significantly influence the abundance of juvenile striped bass, the predation index at the $\alpha < 0.10$ level and the other two at $\alpha < 0.05$. In combination, they explain 78.8% of the variability in young-of-the-year abundance. Striped bass abundance was not significantly influenced by power plant water withdrawals.

7.9.3.3 <u>Discussion</u>. Various mechanisms by which predation, egg production of the spawning stock, and rate of temperature rise (16-20°) can affect juvenile abundance have been examined. Comparions with other systems are often informative; however, each of these factors must be viewed in the context of the Hudson River estuary. Some of the effects of these factors may be indirectly expressed through another variable (such as temperature rise controlling a food organism's productivity cycle). Only about 20% of the variation in abundance is not explained by the three variables.

7.9.3.3.1 Predation. Yearling and older striped bass abundance (a cannibalism index) was weighted lightly by the principal components technique. Striped bass catch per unit area are multiplied by a weighting factor of 0.2233 as opposed to 0.9747 for bluefish. Therefore cannibalism does not contribute as much to the predation index as does bluefish predation. Stevens (1966) and Thomas (1967) report that cannibalism is important in the Sacramento-San Joaquin estuary of California; however, Thomas (1967) demonstrated that striped bass are

Table 7.9-7 Results of Latent Root Regression Analysis of Predation Index, Egg Production Index, and Rate of Temperature Rise from 16-20°C Against Juvenile Striped Bass Abundance

	Degrees of Freedom	Sum of Square	Mean Square	F	R^2
Regression	3	707.3	235.68	7.43050	0.788
Error	6	190.30	31.72		
Total c.f.m.	9	897.33			

Regressor	Modified T Statistic	Probability of Chance Occurrence
Predation Index	1.994	< .10
Egg Production Index	3.543	< .05
Rate of Temperature rise (16-20°)	3.185	< .05

The ordinary least squares prediction equation is

$$\hat{Y} = 11.75 - 14.536 \frac{X_1}{7.6187} + 25.783 \frac{X_2 - 2656.7}{1349.3} + 17.978 \frac{X_3 - 0.2641}{0.4026}$$

where

$\hat{Y}$ is the predicted striped bass juvenile abundance

X_1 is Predation Index

X_2 is Egg Production Index

X_3 is Rate of Temperature Rise (16-20°C) opportunistic predators, and only where large concentrations of adults and juveniles overlap do the juveniles form a major portion of the adult diet. In the beach seine and trawling surveys designed to estimate juvenile abundance, older striped bass were infrequent, suggesting a possible lack of sufficient spatial overlap between the different age classes for a high cannibalism rate.

The amount of bluefish predation on young-of-the-year striped bass is highly variable and influenced by a large complex of factors, among which are bluefish abundance and distribution, striped bass abundance and distribution, and the abundance and distribution of alternate prey species. Since bluefish spawn in the ocean and the juveniles migrate into the estuary, their abundance is probably influenced by factors different from those affecting striped bass. Adult bluefish are seldom caught in the estuary, and juvenile bluefish are generally restricted to the region below RM 50 (km 81)(TI 1975b:39-42). The 2 yr of feeding studies available on bluefish in the Hudson River were not enough to determine the overall importance of striped bass in their diet. Although limited 1973 data showed that bluefish do consume juvenile striped bass, more extensive studies in 1974 (TI 1976a) found less evidence of bluefish predation on striped bass, even though bluefish were abundant. In 1973, however, striped bass juveniles were extremely abundant (Section 7.9.2), while being low in abundance and concentrated father upstream in 1974 (TI 1975b:39-42). Therefore, striped bass juveniles were much less accessible to bluefish in 1974. Conditions needed for bluefish to prey heavily on juvenile striped bass would thus include a relatively high population level for both species and a summer concentration of juvenile striped bass below RM 50 (km 81).

7.9.3.3.2 Spawning Stock. A positive correlation exists between the spawning stock and juvenile abundance indices. It is entirely possible that the linear model employed here is not an appropriate representation of the biological relationships being examined. However, spawning stock reproductive potential could positively influence juvenile abundance over certain density ranges in a variety of ways. The relationship could be a direct one, with an increase in the number of eggs increasing July-August juvenile abundance. An indirect mechanism could involve a more abundant population spawning over a longer time period; e.g., if strong year classes occurred when maximum abundance of post yolk-sac larvae coincided with the maximum density of a prey organism as postulated by Cushing (1974:411), then a longer spawning period would increase the chance for this type of synchronization. The number of juveniles surviving any mortality factor that operates on a fixed percentage of the population will also increase directly with the number of egg spawned.

7.9.3.3.3 Temperature. Since the 16-20°C temperature range includes the maximum catch per unit effort for yolk-sac larvae (Section 7.4), the rate of temperature rise through this range will affect the duration of the yolk-sac stage. In laboratory experiments, yolk-sac larvae absorbed approximately as much yolk in 72 h at 23.9°C as in 144 h at 16.7-17.8°C (Albrecht 1964:108). Optimum survival of larvae occurred between 19.4 and 20.6°C, but larvae survived well at temperatures of 12.8-23.9°.

The positive relationship between rate of temperature increase and year-class abundance observed for striped bass is the opposite of temperature-juvenile abundance correlations noted for some oceanic species; for the latter, low temperatures and a slow rate of warming are positively correlated with large year classes (Bannister, et al. 1974: 35, Pinus 1974:83-85). For tiulka (*Clupeonella delicatula*), Pinus states that years when the water remained between 15 and 18°C for 18 to 22 days had large year classes, while years of rapid warming (about 10 days duration for the 15-18°C range) resulted in low ~~abundace~~ abundance; however, 15-18° is the optimum temperature range for tiulka egg survival, and Pinus postulated that a warming beyond this range would increase egg mortality. Bannister et al. (1974:35) postulated reduced predation intensity at low temperatures, or a better synchronization of larvae with food-organism cycles.

For larval striped bass in the Hudson, the data indicate that rapid warming increases growth (Section 7.7) and shortens the developmental period. This may act to reduce exposure to predation and increase larval survival. Optimum survival occurs at temperatures in the upper portion of the 16-20°C range, and survival rates do not decline greatly until after 24°C (Bayless 1972:46-68). The shortest duration of the 16-20°C temperature range during the 10 yr studied was 8 days, while the yolk-sac stage lasted only ~~46~~ 4-6 days at 21°C (Section 7.4). Therefore, there is little chance that the water could warm so rapidly that it could reach temperatures harmful to the larvae. Thus, temperature increase simply results in more rapid growth, shorter exposure time to certain predators, and a higher survival rate.

7.9.3.3.4 Summary. Juvenile striped bass abundance (in July-August) was significantly related to three environmental variables ($R^2 = 0.788$): predation ($\alpha < 0.10$), egg production ($\alpha < 0.05$), and rate of temperature increase between 16 and 20°C ($\alpha < 0.05$). According to this model, large year classes should result from years with large spawning stock, low bluefish abundance, and a rapid rise in temperature between 16 and 20°C. The temperature increase probably affects abundance by increasing the growth rate and shortening the developmental period and the accompanying exposure to predation. The regression equation's predictive capability is limited to the range of variables actually used in the regression. If spawning stock should increase beyond the maximum value used in the regression, for instance, the amount of change in juvenile abundance predicted by the equation in Table 7.9-7 would no longer be valid, since a different mechanism may operate at that level.

7.10 RELATIVE CONTRIBUTION OF HUDSON RIVER STRIPED BASS STOCK TO ATLANTIC COASTAL FISHERY

7.10.1 INTRODUCTION. Striped bass (*Morone saxatilis*) is an important sport and commercial fish in the estuaries and coastal waters of the Atlantic seaboard from Maine to North Carolina (Koo 1970). Recruitment to the striped bass fishery is from various stocks (i.e., genetically isolated populations) of striped bass, the individuals of which are spawned and developed in the rivers and estuaries along the Atlantic coast. Recapture locations of tagged striped bass suggest that individuals from all spawning areas north of Cape Hatteras, North Carolina, utilize much of the Atlantic coast north of their respective spawning areas during a northward migration in the spring and a southern migration in the fall (Merriman 1941:36-42, Raney et al. 1954:385-395, Alperin 1966a:105-106, Schaefer 1968:13-37, Florence 1974, TI 1975e:IX). The major spawning areas that potentially contribute individuals to the fisheries operating during the northward and southward migrations are the tributaries of the Chesapeake Bay system and the Roanoke, Delaware, and Hudson Rivers. Although tagging data have not led to quantitative estimates of relative contribution of the major stocks to the coastal striped bass fishery, they have led to conflicting ideas as to which stock predominates in the fishery: the Hudson stock or the Chesapeake stock.

Studies on striped bass migratory behavior have generally concluded that the Chesapeake Bay system is the major contributor to the striped bass fisheries north of Chesapeake Bay (Merriman 1941:47-52, Valdykov and Wallace 1952:172-177, Alperin 1966a:~~96105~~ 96-105, 110; Porter and Saila 1969: 4-5; Raney 1972:10-13). These studies have indicated movements of striped bass between Chesapeake Bay and coastal waters of New England ~~and New England~~ and relationships between exceptionally good production of young-of-the-year fish in Chesapeake Bay in 1934, 1958, and 1961 and the occurrence of dominant year classes of striped bass in northern waters >2 yr later. Clark (1972:4) and Goodyear (1974), however, have taken exception to the conclusion that the Chesapeake stock is the major contributor to the middle Atlantic striped bass fishery (primarily New York and New Jersey). Although tagging studies showed that a few 2-yr-olds left the bay, studies by Merriman (1941:26) and Schaefer (1968:38) showed that 2-yr-olds dominated collections from New York and Connecticut waters in 1936 and 1963. Clark and Goodyear decided that the number of striped bass, especially 2-yr-olds, tagged in Chesapeake Bay and recaptured outside the bay was too low to indicate a large contribution of Chesapeake stock to that fishery. Therefore, because of apparent inconsistencies in the tagging studies and the closer proximity of the Hudson River to middle Atlantic and New England fisheries, they concluded that the striped bass stock of the Hudson River is the major contributor to the coastal fishery from New Jersey to Massachusetts.

Estimates of the impact of power generating plants of the Hudson River on this fishery require quantitative estimates of relative contribution of the major stocks. Due to the lack of such estimates, the U.S. Nuclear Regulatory Commission (USNRC 1975b:~~VI-66~~ V-166 to ~~VI-78~~ V-178), in its impact statement, assumed 90% Hudson contribution to the waters of the Hudson River, the western half of Long Island Sound, and the New York Bight ("inner zone") and 10 and 50% to the remaining waters extending from Maine to Cape May, New Jersey ("outer zone"). However, the controversy still existed as to which stock predominated.

Therefore, reliable estimates of the relative proportion of the major stocks in the fishery were needed to settle the controversy of which stock predominates and to provide a basis for making meaningful estimates of plant impact on the Atlantic fishery for striped bass. Texas Instruments conducted a study to obtain such estimates using innate tags, i.e., inherited traits or environmentally produced characteristics specific to the river of origin. A previous study (TI 1975d:iii) demonstrated the feasibility of using innate tags to distinguish between Hudson and Chesapeake spawning stocks with approximately 80% accuracy.

7.10.2 OVERVIEW. In order to estimate stock composition in oceanic waters, it was first necessary to identify the origin of each striped bass collected in the ocean. Meristic counts (e.g., fin ray counts), morphometric measurements (e.g., snout length), and enzyme characters act as "innate tags" and were therefore used as potential indicators of the origin of each fish. Since it was assumed that mature striped bass migrate from the ocean to their natal stream to spawn, representative samples of the spawning stocks of the Hudson River, Chesapeake Bay system, and Roanoke River were collected in those rivers during the spawning season and meristic counts and morphometric measurements were taken on each specimen. A statistical procedure called discriminant analysis then used this data to determine functions which classified each fish as to area of origin (i.e., Hudson River, Chesapeake Bay system, or Roanoke River). Liver samples were also taken on each specimen and processed for two enzymes, which were investigated for additional discriminative potential.

The ability of the discriminant functions to separate spawning stocks and accurately estimate stock proportions was assessed. Specimens from the spawning-stock collections were classified by the functions and the percentage of fish correctly classified was obtained, since specimens from these collections were of known origin. Estimated stock proportions were also obtained and compared to the known stock proportions. Since misclassification of specimens can bias estimated stock proportions, especially when one stock predominates in the sample, estimated stock proportions were revised by two procedures to reduce bias. A simulation study was then conducted to determine which of three estimates was most accurate (i.e., least biased).

The Atlantic coastal fishery from Cape Hatteras, North Carolina to Maine was then sampled. Observations for the same characters used in the discriminant functions were then taken and the resulting data entered into these functions. The oceanic specimens were then classified by these functions as to area of origin, and estimates of relative contribution of the Hudson, Chesapeake, and Roanoke stocks to the Atlantic coastal fishery were obtained.

7.10.3 INNATE TAGS. Innate tags (inherent characters that can identify individuals or populations) rather than conventional tagging methods were used to obtain relative contribution estimates since inherent traits provide a means with which to "tag" all striped bass in the Atlantic coastal fishery. Conventional mark/recapture methodology was rejected since it would be necessary to simultaneously tag and release striped bass from each major stock contributing to the fishery and to know the proportion of each stock tagged; such an undertaking would have been costly and logistically infeasible.

Meristic (countable), morphometric (measurable), and enzyme characters act as innate tags and thus are potential indicators of the origin of each individual. Meristic characters such as numbers of scales, fin rays, and gill rakers are determined during embryonic development and are partially influenced by the environment during that stage. Morphometric characters such as the ratios of measurements of various body parts and of scale annuli are indirectly affected by environment over a longer period of time and therefore appear to be more "acute" indicators of differences in striped bass stocks than do meristic characters (Lund 1957:7). Enzyme characters are the optimal innate tags: they express inheritable traits at the level of the gene itself and, because of the 1:1 relationship between an enzyme and the gene that determines the structure and specificity ~~specificalty~~ of the enzyme (Srb et al. 1965:294, 311), the activity of the enzyme can identify alleles, which are paired members of paternal and maternal origin within each gene, at the gene locus (i.e., location). Enzymes that reveal several variant alleles (i.e., polymorphisms) can be used to demonstrate genetic differences among striped bass stocks.

Since individual meristic, morphometric, and enzyme characters exhibited only small differences between striped bass stocks, simultaneous analysis of many characters was essential if there was to be adequate separation among stocks. A multivariate (many character) statistical technique known as quadratic discriminant analysis (Kendall and Stuart 1968:322) provided this capability for meristic and morphometric characters by creating functions that simultaneously used all characters to classify individuals from a mixed sample into their respective stocks. However, since the analysis made certain assumptions that could not be met by the enzyme characters, these characters were used univariately to reclassify specimens after the discrimination procedure (Section 7.10.8).

7.10.4 ESTABLISHMENT AND EFFECTIVENESS OF DISCRIMINANT FUNCTIONS.

The discriminant functions were based on the spawning segment of each stock since it was assumed that mature striped bass collected on the spawning grounds of a river during the spawning season originated from that river, i.e., that striped bass, like salmon and other anadromous fishes, home to their natal stream to spawn. Although young-of-the-year and yearling fish were also considered to have originated in the rivers in which they were collected (Raney and deSylva 1953:496), spawning stock collections from many year classes were used to determine the discriminant functions since estimation of relative contribution necessitated sampling from the ocean where the striped bass were $\geq$2 yr old.

The choice of meristic and morphometric characters for segregating spawning stocks of striped bass followed three stages of statistical analysis: correlation analysis between each character and fork length; analysis of the effects of sex and age on each character; and stepwise discriminant analysis. Analysis involved only those specimens for which there were observations of all meristic counts and morphometric and scale-annulus measurements.

To verify that character differences among stocks were caused by racial differences and not by differences in length distributions among stocks that can result from variations in year class strength and gear selectivity, each character was correlated with length. Each of the five meristic and morphometric characters listed in Table 7.10-1 satisfied the criterion for lack of correlation with fish length in each stock, i.e., $r < 0.316$, with the exception of the snout length/internostril width ratio for the Roanoke stock. Nevertheless, this character was retained because it had the least population overlap of all characters, thus making it a potentially good discriminator.

Table 7.10-1 Meristic and Morphometric Characters Used To Classify Striped Bass

Character Description
Lateral line scale count
Character index*: sum of rays on left pectoral, right pectoral, second dorsal, and anal fin
Upper-arm gill-raker count including rudimentary rakers
First to second annulus/focus to first annulus measure ratio
Snout length/internostril width ratio

*Raney and deSylva (1953)

Multivariate statistical tests among year classes and between sexes were made to determine the effect of sex and age on the characters used to determine the discriminant functions. Since one assumption of discriminant analysis is that each stock is a homogeneous group, large differences in the character values due to differences among ages or between sexes may indicate distinct subgroups within each stock. This, in turn, may reduce the effectiveness of the functions to discriminate among stocks. Results of these tests indicated that only the Hudson stock was homogeneous in the characters among ages and between males and females. Significant differences among ages and between sexes were found in the Chesapeake spawning stock and among ages in the Roanoke spawning stock. The differences found in the Chesapeake spawning stock may have resulted from the pooling of collections from its four major tributaries. However, Texas Instruments (1975d:iii) found that this pooling was necessary for adequate discrimination between Hudson and Chesapeake stocks. Although the differences found could be partially explained, their effect on the ability of the discriminant functions to distinguish among stocks needed assessment.

Stepwise discriminant analysis (Dixon 1970:214a-214t) was applied to data on spawning stock specimens to determine the subset of characters that best separated the spawning stocks. This statistical procedure evaluated the discriminative potential of subsets of characters by including or excluding each character of interest in a linear function that attempted to classify striped bass as to their natal stocks. Once the subset of characters best separating the spawning stocks was determined, the character set was used to obtain quadratic functions because such functions made fewer assumptions on the statistical distribution of the character set. Therefore, a measure of the effectiveness of the discriminant functions to separate stocks using a subset of characters was needed so that the "best" character set could be selected.

One measure of the effectiveness of the discriminant functions to separate stocks is the percentage of spawning-stock individuals correctly classified; this can be obtained from spawning-stock samples since these samples are of known origin. Based on these samples, 76.8% of the Hudson stock, 67.7% of the Chesapeake stock, and 85.9% of the Roanoke stock were correctly classified using the five characters listed in Table 7.10-1; this closely agreed with results obtained by Raney and deSylva (1953:506) and Raney et al.(1954:394). Most of the misclassifications occurred between the Hudson and Chesapeake spawning stocks, as indicated by overlaps (i.e., measures of the probabilities of misclassification) of 24.1, 4.4, and 10.9% between the pairs of Hudson-Chesapeake, Hudson-Roanoke, and Chesapeake-Roanoke spawning stocks respectively.

An independent measure of the effectiveness of the discriminant functions was obtained by a cross-validation procedure in which the collections from each spawning stock were randomly divided in half and specimens from one-half used to determine new discriminant functions. These functions were then applied to the specimens from the other half of the collections to estimate percentages of correct classification. The quadratic discriminant functions determined from the randomly sampled specimens correctly classified 73.2% of the remaining specimens in the collections, which was near the ~~75.9%~~ 77.1% correct classification of the specimens used to determine these functions and the 74.4% correct classification of the total collections (Table 7.10-2). Although there was close agreement in these correct-classification percentages, it was necessary to evaluate the ability of the discriminant functions to estimate relative contribution accurately, since obtaining these estimates was the major objective of the study.

The discriminant functions were first used to provide estimates of classification percentages of relative contribution set forth in the Report on Relative Contribution of Hudson River Striped Bass to the Atlantic Coastal Fishery (TI 1976h). These estimates are referred to as the "as-classified" estimates. The use of the discriminant functions to classify the oceanic collections is described in Section 7.10.8.

Table 7.10-2 Correct Classification Percentages of Collection Sets of Spawning Stocks Based on Quadratic Discriminant Functions

Collection Set	Hudson	Spawning Stock Chesapeake	Roanoke	Overall
Function set*	81.0	69.8	87.8	~~75.9~~ 77.1
Independent set**	72.6	68.1	86.0	73.2
Total set ***	76.8	~~67.1~~ 67.1	85.9	74.4

*Randomly sampled half of total spawning stock collections used to determine quadratic functions for cross-validation.

**Remaining half of spawning stock specimens classified by quadratic functions obtained from function set.

***All specimens from spawning stock collections; percentages obtained from quadratic functions based on total set.

In order to improve the ability of the discriminant functions to estimate accurately the relative contribution of striped bass to the Atlantic coastal fishery, further statistical analysis was performed to reduce bias (i.e., difference between the estimates and the true value) inherent in the as-classified estimates. Fukuhara et al.(1962:40) reported that in an analogous attempt to classify sockeye salmon from Asian and North American stocks, misclassifications tended to cancel when each of the stocks in the mixture was equally represented. Furthermore, as stock proportions become more disproportionate, as in the case where one stock predominates, bias increases.

Since the as-classified estimates showed that the Chesapeake stock predominated (TI 1976h), it appeared likely that the as-classified estimates of stock contribution might be significantly biased. At this point it was not known whether minimizing the bias would increase or decrease the estimate of the percentage contribution of the Hudson River.

7.10.5 ADJUSTED ESTIMATE OF RELATIVE CONTRIBUTION.

The first method used to minimize bias is called the adjusted estimate. This was based on a technique generalized by Worlund and Fredin (1962) and developed by Fukuhara et al.(1962) for the two population case. The methodology developed by Schuermann and Curry (1973) was also applied.

The adjusted estimate was derived by first applying the discriminant functions to samples of known origin (spawning stock) to obtain percentages of misclassification. Those percentages were applied to the as-classified estimates to obtain the adjusted estimates. Adjusted estimates of contribution ($\hat{M}_C$, $\hat{M}_H$, $\hat{M}_R$) were obtained by solving the following equation for M_C, M_H, M_R:

$$P_{CC}M_C + P_{HC}M_H + P_{RC}M_R = N_C$$

$$P_{CH}M_C + P_{HH}M_H + P_{RH}M_R = N_H$$

$$P_{CR}M_C + P_{HR}M_H + P_{RR}M_R = N_R$$

where

P_{CC} = probability of classifying Chesapeake fish as Chesapeake

P_{HC} = probability of classifying Hudson fish as Chesapeake

P_{RC} = probability of classifying Roanoke fish as Chesapeake

P_{CH} = probability of classifying Chesapeake fish as Hudson

P_{HH} = probability of classifying Hudson fish as Hudson

P_{RH} = probability of classifying Roanoke fish as Hudson

P_{CR} = probability of classifying Chesapeake fish as Roanoke

P_{HR} = probability of classifying Hudson fish as Roanoke

P_{RR} = probability of classifying Roanoke fish as Roanoke

M_C = true number of Chesapeake fish

M_H = true number of Hudson fish

M_R = true number of Roanoke fish

N_C = as-classified number of Chesapeake fish

N_H = as-classified number of Hudson fish

N_R = as-classified number of Roanoke fish

7.10.6 ITERATIVE ESTIMATE OF RELATIVE CONTRIBUTION. In order to verify the adjusted estimate of relative contribution, a second procedure for reducing bias was employed, called the iterative estimate.

In the iterative procedure the discriminant functions were reapplied several times to refine the as-classified estimates. First, the functions were applied to a spawning stock sample (known origin) to determine the proportion of the sample which fell into each of the three origin groups. The determination of origin can be adjusted for the probability that a fish belongs to a particular origin group. The first calculation assumed equal probabilities for the three groups. The results of the first calculation were then used as input probability values in a second application of the discriminant functions to the same sample to produce a new estimate of the proportions falling into each group. Those new proportions were then used as input probability values for a third calculation, or iteration. The iteration can be carried out through any number of stages.

In developing the method used for the three population case, such iterations were performed on samples of known spawning stock to determine the number of iterations which would produce an estimate which deviated least from the actual proportions in the population. As a result of these studies, it was determined that the use of the results of the third iteration would give the smallest deviation from actual stock proportions. In using the iterative method on actual ocean samples this number of steps was used.

7.10.7 SIMULATION STUDY. The effectiveness of the adjusted and iterative procedure in accurately estimating stock proportions was investigated in a simulation study. Discriminant functions from the cross-validation study were used to classify a subset of specimens from the independent half of the spawning stock collections, and each of the three types of estimates of relative proportion was obtained and compared to the known stock proportions. For proportions of Hudson stock ranging from 0.0 to 0.90, the difference between each estimated Hudson proportion and the known proportion of Hudson specimens in the subsample was obtained as a measure of the bias in the estimate.

Results of the simulation study on the bias of the as-classified, adjusted, and iterative esimates of relative contribution indicated that the iterative procedure provided the best estimate of the relative contribution of Hudson River stock (Table 7.10-3). On the average, the third iteration (i.e., stage) resulted in estimates of relative proportion of Hudson River stock closest to the true proportions. For 15 of the 18 proportions of Hudson spawning stock specimens considered, iterative estimates of Hudson stock proportions were closer

Table 7.10-3 Mean and Standard Deviation of Absolute Bias* of Estimated Relative Percentage of Hudson River Stock in Replicated Random Samples from Spawning Stock Collections**

	Estimates of absolute bias					
Known percentage of Hudson River stock	As-classified		Iterative		Adjusted	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
90***	23.0	2.40	4.3	2.97	14.4	5.73
80	20.2	5.14	7.4	8.82	14.3	7.78
75	17.6	3.47	8.4	~~3.81~~ 3.82	12.8	5.00
70	13.0	3.32	4.7	4.52	7.3	4.80
65	10.8	3.11	3.3	~~2.97~~ 2.98	~~8.0~~ 7.5	~~4.69~~ 4.07
60	9.0	3.21	5.3	~~2.83~~ 2.84	~~7.9~~ 6.8	~~5.28~~ 5.00
55	7.5	2.95	~~4.7~~ 4.8	3.52	7.4	4.02
50	5.5	1.99	4.2	2.66	4.7	3.44
45	2.2	2.17	~~3.4~~ 3.5	1.85	4.7	2.14
40	1.2	1.04	3.2	3.44	~~4.2~~ 4.3	~~4.29~~ 4.21
35	2.2	1.45	4.2†	2.09†	4.4	2.87
30	5.9	3.18	3.3	2.43	3.4	1.79
25	7.8	3.07	4.0	2.25	4.2	3.27
20	9.5	2.26	~~2.5~~ 2.8	~~1.64~~ 1.72	1.8	0.99
15	12.1	4.19	3.5	3.24	3.3	2.62
10	15.1	3.80	4.5	~~3.35~~ 3.36	5.0	3.61
5	17.4	4.03	4.5	3.72	~~2.8~~ 4.3	~~3.17~~ 3.85
0	18.1	2.53	2.5	1.73	1.5	1.69
Overall mean	11.0		~~4.3~~ 4.4		6.2	

*Absolute value of the difference between the true relative percentage of Hudson River stock in the subsample and the estimated relative percentage based on nine replicates of varying Chesapeake and Roanoke proportions in the subsamples.

**Estimates were based on random samples from half of spawning-stock collections which were classified as to area of origin by quadratic functions obtained from the other half of the collections.

***Based on two replicates.

†Based on eight replicates.

to the true proportions than the as-classified estimates. For 14 of 18 proportions of Hudson spawning-stock specimens considered, the iterative estimate was less biased than the adjusted estimate. The variation in the bias of the iterative estimate was also less than the variation in the bias of the adjusted estimate for the majority of the proportions of Hudson spawning stock specimens considered. Therefore, the simulation study indicated that the iterative estimate is a better estimate of relative contribution of Hudson River stock than the as-classified and adjusted estimates.

7.10.8 CLASSIFICATION OF OCEANIC AND OVERWINTERING COLLECTIONS.

Assessing the relative contribution of various stocks of striped bass to the Atlantic coastal fishery requires a sampling scheme that provides samples from the entire coastal fishery and considers the migratory nature of striped bass. To fulfill these objectives, a geographically and temporally stratified sampling design was used. The geographical stratification consisted of 10 strata from southern Maine to Cape Hatteras, North Carolina, with two to four substrata within each stratum to obtain more precise estimates of stock composition in the strata (Fig. 7.10-1); the Rhode Island stratum was not subdivided because of its small size. Temporally, the year was divided into six 2-mo periods to obtain more precise estimates of the composition of each stratum at various times of the year and to demonstrate potential changes in composition throughout the year. Since the assessment of contribution to the coastal fishery required that the individuals actually be part of the fishery, collections of striped bass of sublegal size and those overwintering in the Hudson River were analyzed separately.

Iterative and adjusted estimates of the relative contribution of the Hudson, Chesapeake, and Roanoke stocks to the Atlantic coastal striped bass fishery were calculated for those geographical and temporal strata with collections of more than five individuals. These estimates of the composition in strata from southern Maine to Cape Hatteras, North Carolina, during the six 2-mo periods indicated that the Chesapeake

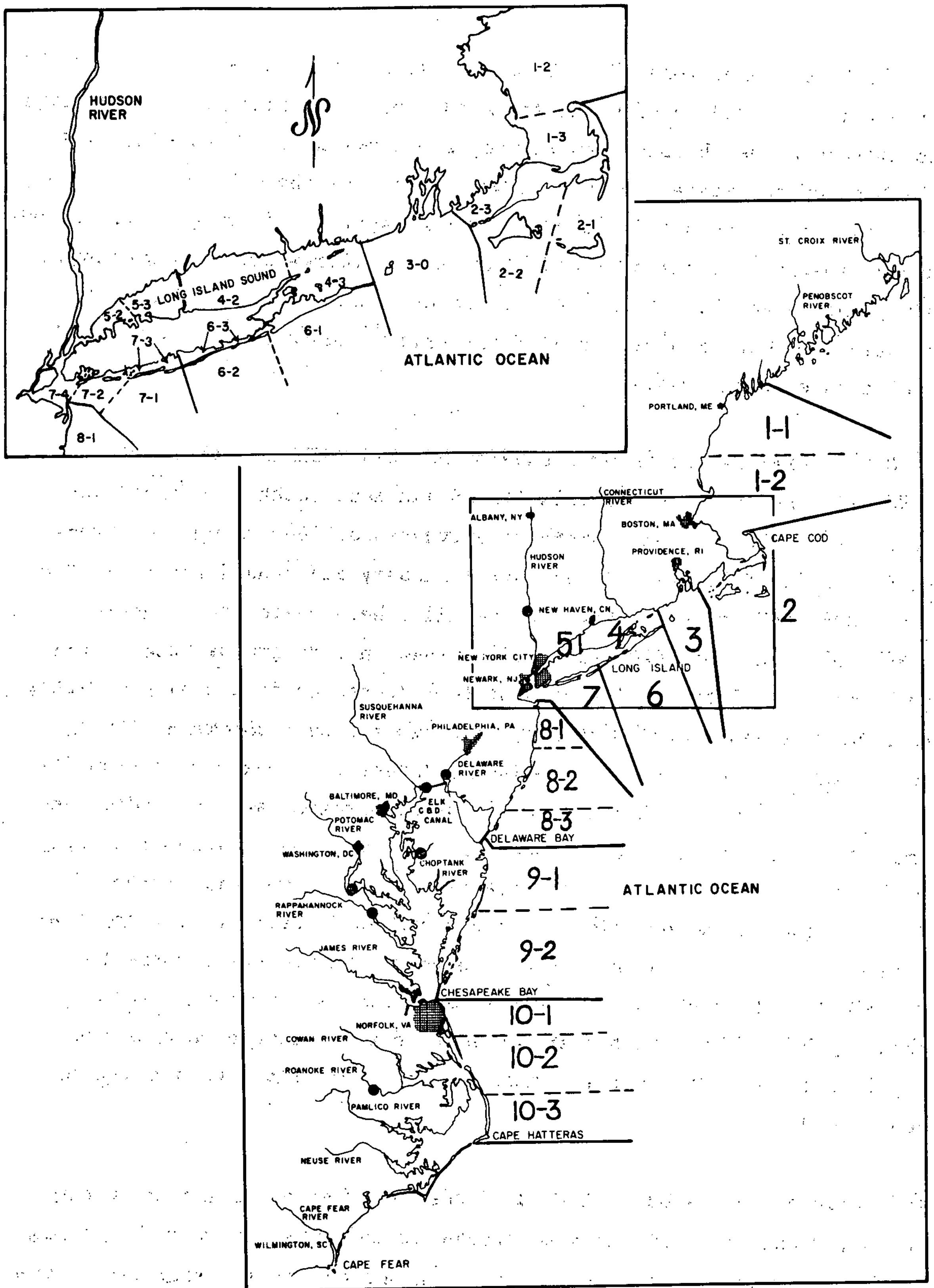


Figure 7.10-1 Geographical Stratification and Substratification of Collection Regions for Atlantic Coastal Fishery. (Collection sites for spawning-stock specimens indicated by dots on source rivers)

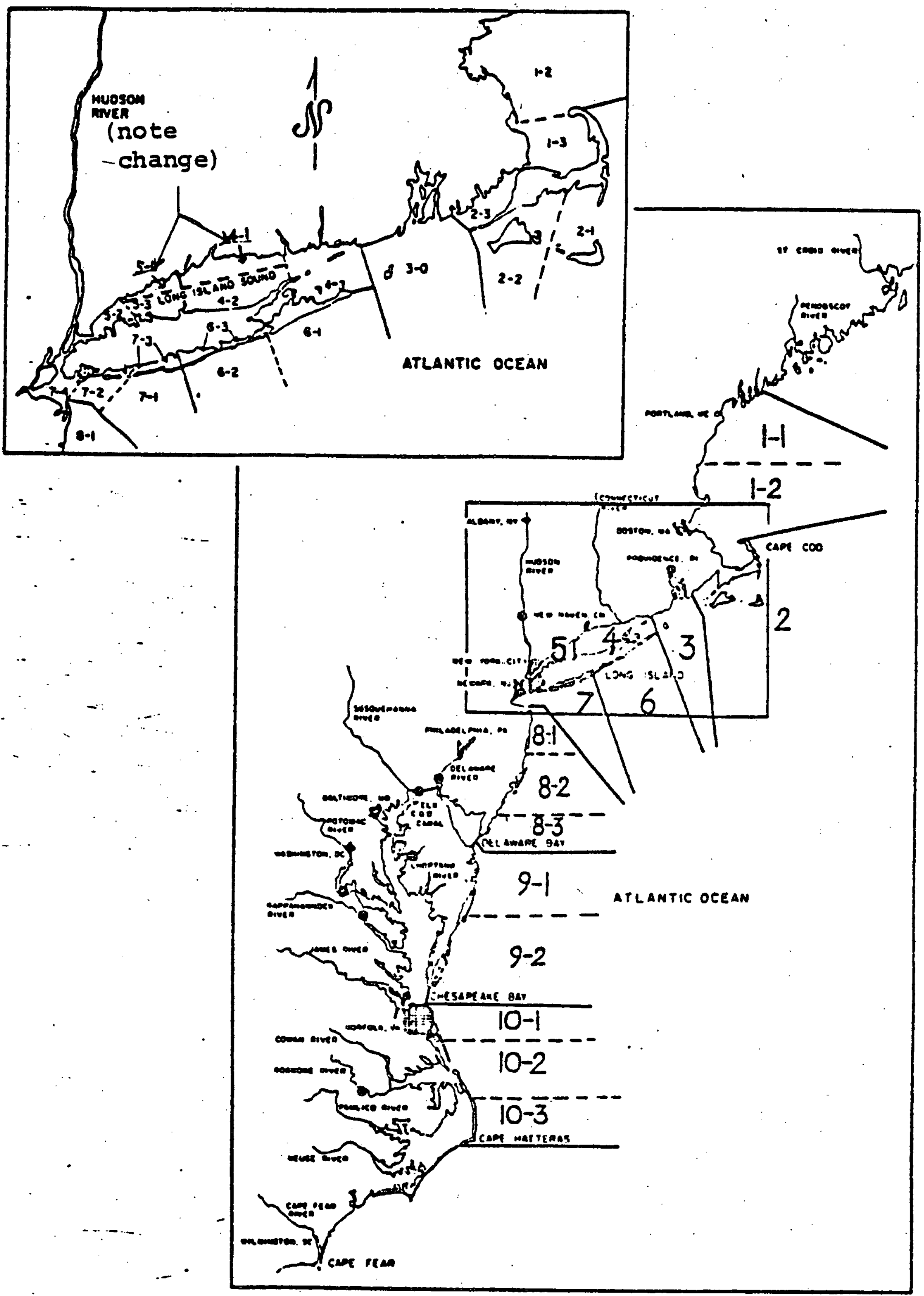


Figure 7.10-1 Geographical Stratification and Substratification of Collection Regions for Atlantic Coastal Fishery. (Collection sites for spawning-stock specimens indicated by dots on source rivers)

stock predominated in 34 of the 35 strata (Table 7.10-4). The highest iterative estimate of contribution of the Hudson stock occurred in western Long Island Sound (stratum 5) and the New York Bight (stratum 7), with values exceeding 25% during some months. However, iterative estimates of 0.0% Hudson contribution were common in strata south of northern New Jersey and north of southern Massachusetts.

Comparison of the iterative estimate of Hudson contribution with the adjusted estimate indicated close agreement between the two estimates for the 35 geographical and temporal strata studied (Table 7.10-4). The largest difference between the estimates was 10.6 percentage points, but in 80% of the strata the difference was less than 5 percentage points. The adjusted estimates therefore substantiate the low contribution of the Hudson stock to the coastal striped bass fishery from Massachusetts north to Maine and from New Jersey south to North Carolina.

The iterative estimate of approximately 4% Hudson stock off Cape Hatteras, North Carolina, in February 1975 must be viewed cautiously because of the small sample size involved and the age structure (age VIII+) of the sample. The discriminant function for the Roanoke stock was determined from the character set of spawning stock specimens (all but two) having a fork length <800 mm; however, all but two specimens collected from Cape Hatteras had fork lengths >800 mm. Since the snout length/internostril width ratio (i.e., the best discriminatory character) had a negative correlation with length for the Roanoke spawning stock, there was a potential for misclassifying large Roanoke fish off Cape Hatteras as Hudson fish. Additionally, adult striped bass tagged in the Hudson River during the spawning season have not been recaptured south of northern New Jersey (TI 1975e:ix); therefore, unless tagged striped bass from the Hudson River are recaptured in southern waters, caution must be taken in interpreting this low estimate of Hudson contribution as representing the true Hudson contribution.

Table 7.10-4 Estimates of Relative Contribution of Hudson, Chesapeake, and Roanoke Stocks of Legal-Sized Striped Bass to 1975 Oceanic Collections by Period and Spatial Strata Using Quadratic Discriminant Functions*

Period	Stratum	Sample Size**	Hudson			Chesapeake			Roanoke		
			As-Classified	Iterative	Adjusted	As-Classified	Iterative	Adjusted	As-Classified	Iterative	Adjusted
Jan-Feb(1)	10	27	25.9	3.7	6.7	63.0	92.6	90.7	11.1	3.7	2.6
Mar-Apr(2)	5	38	52.6	57.9	54.2	42.1	42.1	45.8	5.3	0.0	0.0
	7	30	23.3	3.3	0.0	73.3	96.7	100.0	3.3	0.0	0.0
	8	34	23.5	8.8	0.8	67.6	88.2	99.2	8.8	2.9	0.0
	9	71	8.5	0.0	0.0	77.5	97.2	98.9	14.1	2.8	1.1
May-Jun(3)	1	82	11.0	0.0	0.0	68.3	90.2	88.5	20.7	9.8	11.5
	2	91	14.3	0.0	0.0	71.4	95.6	96.4	14.3	4.4	3.6
	3	60	30.0	3.3	13.9	60.0	96.7	84.5	10.0	0.0	1.6
	4	96	21.9	1.0	0.0	69.8	99.0	100.0	8.3	0.0	0.0
	5	14	35.7	28.6	23.0	57.1	71.4	77.0	7.1	0.0	0.0
	6	89	25.8	5.6	5.4	65.2	93.3	94.6	9.0	1.1	0.0
	7	58	41.4	25.9	33.7	51.7	70.7	66.3	6.9	3.4	0.0
	8	113	23.9	0.0	1.5	67.3	100.0	98.5	8.8	0.0	0.0
Jul-Aug(4)	1	58	19.0	0.0	0.0	67.2	94.8	95.4	13.8	5.2	4.6
	2	90	7.8	0.0	0.0	72.2	96.7	90.8	20.0	3.3	9.2
	3	43	30.2	2.3	10.3	65.1	97.7	89.7	4.7	0.0	0.0
	5	15	26.7	0.0	5.1	66.7	100.0	94.9	6.7	0.0	0.0
	6	102	22.5	7.8	1.6	63.7	88.2	92.7	13.7	3.9	5.7
	7	93	33.3	15.1	13.4	65.6	84.9	86.6	1.1	0.0	0.0
	8	28	21.4	0.0	0.0	71.4	100.0	100.0	7.1	0.0	0.0
Sep-Oct(5)	1	74	13.5	0.0	0.0	77.0	98.6	100.0	9.5	1.4	0.0
	2	82	12.2	0.0	0.0	58.5	85.4	76.0	29.3	14.6	24.0
	3	56	25.0	3.6	7.5	58.9	94.6	83.3	16.1	1.8	9.2
	4	140	16.4	0.7	0.0	64.3	94.3	88.6	19.3	5.0	11.4
	5	89	41.6	40.4	37.2	46.1	57.3	56.5	12.4	2.2	~~6.3~~ 6.4
	6	86	15.1	0.0	0.0	73.3	96.5	99.8	11.6	3.5	0.2
	7	120	23.3	1.7	2.9	63.3	95.0	91.8	13.3	3.3	5.2
	8	73	16.4	0.0	0.0	76.7	98.6	100.0	6.8	1.4	0.0
	9	6	16.7	0.0	0.0	66.7	100.0	92.2	16.7	0.0	7.8
Nov-Dec(6)	4	99	21.2	0.0	0.0	66.7	98.0	96.9	12.1	2.0	3.1
	6	106	16.0	0.0	0.0	69.8	99.1	95.9	14.2	0.9	4.1
	7	124	21.0	4.8	0.0	76.6	95.2	100.0	2.4	0.0	0.0
	8	117	21.4	0.0	0.0	72.6	100.0	100.0	6.0	0.0	0.0
	9	100	8.0	0.0	0.0	80.0	99.0	100.0	12.0	1.0	0.0
	10	24	12.5	0.0	0.0	62.5	83.3	82.0	25.0	16.7	18.0

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[*] Not included are <406.5 mm fork length striped bass from New York waters.

[**] Samples having five specimens or less not included.

Although the iterative (and adjusted) estimates of relative contribution of the Hudson stock in the region from Massachusetts to Maine (strata 1 and 2) was zero, this did not necessarily indicate an absence of Hudson River striped bass from that area. The simulation study has shown that iterative (and adjusted) estimates of zero contribution may be obtained in situations in which the true contribution is not exactly zero but is quite low; in fact, data on adult striped bass tagged in the Hudson River during spawning season and recaptured in waters as far north as Boston Harbor, Massachusetts have suggested a northern migration of a portion of the Hudson stock (TI 1975e:ix). Thus, while the Hudson contributes some fish to this area, the relative contribution of the Hudson stock must be low.

To assess the contribution of the stocks to the sport and commercial fishery along the Atlantic coast for all of 1975, estimates of relative contribution within geographical and temporal strata were averaged and these unweighted estimates then compared to estimates of the stock composition within the 1975 commercial landings weighted by the proportion of poundage landed in each stratum. Mean iterative (and adjusted) estimates of 6.5% Hudson stock (6.6% adjusted), 90.8% Chesapeake stock (90.2% adjusted), and 2.7% Roanoke stock (3.2% adjusted) were obtained by averaging the estimates over geographical strata within periods and then averaging the mean estimates over the six periods (mean as-classified estimates for the Hudson, Chesapeake, and Roanoke stocks were 23, 66, and 11% respectively). Stock composition for the 1975 commercial landings was estimated by weighting the estimated stock proportions from each spatial and temporal stratum by the corresponding proportion of the periodic commercial poundage landed within the stratum and by the proportion of the yearly poundage landed within the period.* Weighted mean iterative (and adjusted) estimates (Table 7.10-5)

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*Commercial poundage data were obtained by month, state, county, gear, and water from the National Marine Fisheries Service (NMFS), Statistics and Market News Division, Washington, D.C. and Easton, Maryland.

Table 7.10-5 Estimates of Relative Contribution of Hudson, Chesapeake, and Roanoke Stocks to Commercial Landings (Poundage) by Period and Overall Year

Period	Sample Size*	Weight**	Hudson			Chesapeake			Roanoke		
			As-Classified	Iterative	Adjusted	As-Classified	Iterative	Adjusted	As-Classified	Iterative	Adjusted
Jan-Feb(1)	27	0.1592	0.259	0.037	0.067	0.630	0.926	0.907	0.111	0.037	~~0.206~~ 0.026
Mar-Apr(2)	135	0.0605	0.142	0.024	0.002	0.747	0.953	0.992	0.111	0.023	0.007
May-Jun(3)	589	0.1720	0.269	0.064	0.095	0.639	0.923	0.897	0.091	0.013	0.008
Jul-Aug(4)	414	0.1965	0.281	0.076	0.078	0.654	0.912	0.905	0.064	0.012	0.017
Sep-Oct(5)	637	0.1568	0.188	0.012	0.020	0.665	0.954	0.922	0.147	0.034	0.058
Nov-Dec(6)	570	0.2550	0.164	0.002	0.000	0.708	0.958	0.953	0.128	0.040	0.047
Cumulative Weighted Proportion†			0.223	0.036	0.046	0.669	0.937	0.924	0.108	0.027	0.030

*Stratum 5 has no commercial fishery, so its sample size is not included. In addition, samples having five specimens or less are not included.

**Periodic proportion of yearly total poundage.

†Sum of weighted contributions for year.

of 3.6% Hudson stock (4.6% adjusted), 93.7% Chesapeake stock (92.4% adjusted), and 2.7% Roanoke stock (3.0% adjusted) indicated little difference from the unweighted mean estimates. The weighted estimates of contribution were based primarily on New York and New Jersey landings, which comprised 57% of the annual commercial poundage landed in coastal waters from southern Maine to North Carolina, ~~including~~ excluding the Hudson River, Delaware Bay, Chesapeake Bay, Albermarle Sound, Pamlico Sound, and coastal waters of North Carolina south of Cape Hatteras.

Although the mean iterative (and adjusted) estimate of the Hudson stock contribution in 1975 was <7%, its contribution to western Long Island Sound and the New York Bight (Table 7.10-6) was >7% during most periods, thus indicating a higher yearly Hudson contribution within the strata adjacent to the Hudson River (i.e., inner zone) and a lower contribution elsewhere (i.e., outer zone). The yearly contribution of the Hudson River and elsewhere was estimated and compared to the estimates used by the USNRC (1975b:V-166 to V-178). Strata 5, 7, and 8, substratum 1 (Fig. 7.10-1), were pooled to form a stratum for western Long Island Sound, the New York Bight, and northern New Jersey comparable to the NRC's "inner zone"; and strata 1 to 4, 6, and 8, substrata 2 and 3, were pooled to form the remaining stratum from Maine to New Jersey comparable to the NRC's "outer zone". Mean estimates of relative contribution for the year were calculated for the inner and outer zones by averaging the estimates obtained for the five periods from March through December. The mean iterative (and adjusted) estimates of relative contribution of the Hudson River stock to the inner and outer zones were 16.0% (15.0% adjusted) and 2.8% (0.0% adjusted) respectively for the year (Table 7.10-6). The iterative estimate of 16% Hudson contribution for the inner zone was higher than its mean contribution (7%) to the entire Atlantic coastal fishery; however, it was substantially lower than the 90% contribution used by the NRC. Likewise, the iterative estimate of Hudson contribution for the outer zone was less than the 10 and 50% contribution used by the NRC. Although the Chesapeake stock was the predominant contributor to both the inner and outer zones, the Hudson stock's contribution exceeded that of the Roanoke stock in the inner zone but was less than that of the Roanoke stock in the outer zone.

Table 7.10-6 Estimates of Relative Contribution of Hudson, Chesapeake, and Roanoke Stocks for Legal-Sized Striped Bass to 1975 Oceanic Collections within USNRC Zones by Period Using Quadratic Discriminant functions*

III-F

Period[**]	Zone[†]	Number of Specimens	Hudson			Chesapeake			Roanoke		
			As-Classified	Iterative	Adjusted	As-Classified	Iterative	Adjusted	As-Classified	Iterative	Adjusted
Mar-Apr(2)	Inner	68	39.7	33.8	28.5	55.9	66.2	71.5	4.4	0.0	0.0
	Outer	35	22.9	8.6	0.0	68.6	88.6	100.0	8.6	2.9	0.0
May-Jun(3)	Inner	112	37.5	17.0	25.7	56.2	~~81.2~~ 81.3	74.3	6.2	1.8	0.0
	Outer	491	20.0	1.6	0.0	67.8	95.7	97.2	12.2	2.6	2.8
Jul-Aug(4)	Inner	136	30.1	10.3	8.8	66.9	89.7	91.2	3.0	0.0	0.0
	Outer	293	18.4	3.1	0.0	67.2	93.5	94.8	14.3	3.4	5.2
Sep-Oct(5)	Inner	252	28.6	15.1	12.2	59.5	82.1	83.8	11.9	2.8	4.0
	Outer	468	16.0	0.6	0.0	67.1	94.2	92.1	16.9	5.1	7.9
Nov-Dec(6)	Inner	161	22.4	3.7	0.0	75.8	96.3	100.0	1.9	0.0	0.0
	Outer	285	18.6	0.0	0.0	69.5	98.9	98.1	11.9	1.1	1.9
Mean[‡]	Inner	729	31.7	16.0	15.0	62.9	83.1	84.2	5.5	0.9	0.8
	Outer	1572	19.2	2.8	0.0	68.0	94.2	96.4	12.8	3.0	3.6

[*] Not included are <406.5 mm fork length striped bass from New York waters.

[**] Only one striped bass collected in inner zone during Jan-Feb (period 1).

[†] U.S. Nuclear Regulatory Commission inner zone corresponds to study strata 5, 7, and 8, substratum 1; outer zone corresponds to study strata 1-4, 6, and 8, substrata 2 and 3.

[‡] Average of periodic estimates of relative contribution.

Aside from demonstrating that the Chesapeake stock was the major contributor to the Atlantic coastal fishery in 1975, this study provided additional information on the importance of dominant year classes of striped bass. Part of the rationale that investigators of striped bass migratory behavior have used in concluding that the Chesapeake Bay system is the major contributor to the Atlantic coastal fishery has been the relationship between good production of young-of-the-year fish in Chesapeake Bay and the occurrence of dominant year classes of striped bass in the northern waters ≥ 2 yr later (Section 7.10.1). Schaefer (1972a) stated that the production of young-of-the-year striped bass in Chesapeake Bay during 1970 was the largest ever recorded and, if survival remained high and migration followed normal patterns, this year class should provide excellent fishing in New York waters for 6 to 8 yr after recruitment; this appears to have occurred since approximately 52% of the specimens collected from the coastal fishery in 1975 were from the 1970 year class and 77% of this year class were classified with discriminant functions as Chesapeake fish. The presence of this dominant year class of Chesapeake fish confirms the rationale of a predominance of Chesapeake stock in the coastal fishery. A summary of the occurrence of dominant year classes in the Atlantic coastal fishery has been given by Schaefer (1968:38-40).

The proportion of sublegal-sized striped bass (fork length <406.5 mm) classified into the Hudson stock exceeded the proportion classified into the Chesapeake and Roanoke stocks in western Long Island Sound (stratum 5) and the New York Bight (stratum 7), but the opposite was true in eastern Long Island (stratum 6) during most periods (Table 7.10-7). The estimated proportions of sublegal-sized fish classified into the Hudson stock in western Long Island Sound (primarily in Little Neck Bay) and the New York Bight in the late spring-early fall months were at least 80%.

Table 7.10-7. Estimates of Relative Contribution of Hudson, Chesapeake, and Roanoke Stocks of Sublegal-sized Striped Bass to New York Waters in 1975 by Period and Spatial Stratum Using Quadratic Discriminant Functions*

Period	Stratum	Sample Size**	Hudson			Chesapeake			Roanoke		
			As-Class.†	Iter.‡	Adj.‡‡	As-Class.	Iter.	Adj.	As-Class.	Iter.	Adj.
May-Jun (3)	5	42	92.9	100.0	100.0	7.1	0.0	0.0	0.0	0.0	0.0
	6	8	12.5	0.0	0.0	50.0	62.5	64.3	37.5	37.5	35.7
	7	11	81.8	81.8	100.0	18.2	18.2	0.0	0.0	0.0	0.0
Jul-Aug (4)	5	85	88.2	100.0	100.0	11.8	0.0	0.0	0.0	0.0	0.0
	6	17	41.2	35.3	39.2	41.2	58.8	47.4	17.6	5.9	13.4
Sep-Oct (5)	5	10	80.0	80.0	100.0	20.0	20.0	0.0	0.0	0.0	0.0
	6	19	26.3	15.8	20.8	36.8	47.4	41.9	36.8	36.8	37.3

*Sublegal refer to <406.5 mm fork length striped bass from New York waters.

**Samples having five specimens or less are not included.

† As-Classified estimate.

‡ Iterative estimate.

‡‡ Adjusted estimate.

In addition to dominating collections of sublegal-sized striped bass in strata adjacent to the Hudson River, the Hudson stock predominated in collections of specimens overwintering in Croton Bay on the Hudson River. Iterative estimates of 97.4% (95.7% adjusted; 76.3% as-classified) Hudson contribution and 2.6% (4.3% adjusted; 23.7% as-classified) Chesapeake contribution to the stock overwintering in the Hudson were obtained for the 76 legal-sized striped bass collected. The three sublegal-sized specimens collected were classified as Hudson fish.

7.10.9 ENZYME ANALYSIS. Polymorphic enzymes (i.e., enzymes produced by structurally and functionally different alleles) can be used to demonstrate genetic differences among striped bass stocks provided their allelic frequencies vary among the stocks. In a previous study, Texas Instruments (1975d) reported that out of 45 serum protein, hemoglobin, and enzyme systems investigated, only the two enzymes isocitrate dehydrogenase (IDH) and α-glycerophosphate dehydrogenase (α-GPDH) showed usable polymorhpisms indicating that striped bass are a genetically homogeneous species. For 2 yr of data, the allelic frequencies of IDH and α-GPDH indicated a low level of variation among Hudson, Chesapeake, and Roanoke stocks on a north to south cline, with the exception of collections from the Hudson River after May 23, 1975. Striped bass collected in the Hudson River through May 23 had an allelic frequency for IDH and α-GPDH similar to that of the 1974 collections from the Hudson spawning stock and collections of striped bass overwintering in the Hudson River (Table 7.10-8); after May 23, however, allelic frequencies for both IDH and α-GPDH within the Hudson spawning stock were similar to the southern spawning stocks, especially the Roanoke.

The changes in allelic frequencies of IDH and α-GPDH in the spawning stock collections from the Hudson River after May 23 indicated that those collections included individuals from either a southern spawning stock or a unique late breeding segment of the Hudson stock. The

Table 7.10-8 Gene Frequencies for Alleles of α-GPDH and IDH within Hudson, Chesapeake, and Roanoke Stocks and Striped Bass Overwintering in Hudson River

Region/Date	Sample Size	α-GPDH*		IDH**		
		A	B	A	B	C
Hudson						
1974	192	0.12	0.88		1.00	
Dec 1974-Mar 1975	71	0.12	0.88		1.00	
May 14-23, 1975	73	0.10	0.90		1.00	
May 24-Jun 5, 1975	44	0.03	0.97	0.08	0.91	0.01
Chesapeake						
1974	688	0.04	0.96		0.96	0.04
1975	~~189~~ 190	0.03	0.97		0.97	0.03
Roanoke						
1975	92	0.01	0.99	0.03	0.95	0.02

*α-glycerophosphate dehydrogenase

**isocitrate dehydrogenase

hypothesis that southern migrants entered the Hudson River during the latter portion of the spawning run was plausible for two reasons. First, the 44 striped bass from collections made in the Hudson River after May 23 represented <12% of all Hudson River specimens analyzed for IDH and α-GPDH, and this small sample could be influenced easily by an influx of southern migrants. The remaing 88%, which included striped bass from the 1974 and early 1975 spawning runs and from the overwintering population (demonstrated by meristic and morphometric characters to be primarily of Hudson River origin) were genetically representative of a single stock. Second, multivariate analysis (Anderson 1958:101-125) indicated significant differences ($\alpha = 0.05$) in the mean values of the meristic and morphometric characters between the early (through May 23) and late (after May 23) segments of the spawning run in the Hudson River, thus supporting the hypothesis for southern migrants. However, when discriminant functions were determined for specimens collected before May 23 and applied to specimens collected after May 23 all fish except two were classified as they had been by the discriminant functions based on all Hudson collections. Therefore, the early and late spawning striped bass collected from the Hudson River were similar enough in their values of the meristic and morphometric characters to be classified as a single stock. Equally plausible was the alternative hypothesis of a unique "late breeding" segment of the Hudson stock that appeared similar to the major segment in its mean values for the meristic and morphometric characters but different in its allelic frequencies for the two enzymes.

The discriminative power of the enzyme characters was assessed using two techniques, but no significant improvement in correct classification resulted. One technique incorporated both enzyme characters into a multivariate discrimination procedure based on methodology developed by Krzanowski (1975). Each combination of observed values from IDH, α-IDH, and upper-arm gill-raker count was investigated for adequate sample size using the data from the Chesapeake, Roanoke, and early and late Hudson spawning stock collections. Discriminant functions based on the remaining four characters (i.e., lateral line count, character index, snout length/internostril width ratio, and scale ratio) were obtained for the two categories with large sample sizes (representing more than three-fourths of the spawning-stock specimens). An overall correct classification of 75.6% was obtained for these categories, which was similar to the overall percentage of 74.4 (Table 7.10-2) obtained using only the five meristic and morphometric characters for the total spawning stock collections. When the remaining specimens were classified by the original quadratic functions, 73.3% of the specimens were correctly classified. The remaining categories were not analyzed because of the small sample sizes involved.

In the other technique, only one enzyme character, IDH, was used to reclassify some of the spawning stock specimens that had been misclassified by the original discriminant functions based on five meristic and morphometric characters. Under hypothesis A, the assumption was that only the B allele of IDH occurs in the Hudson stock. Chesapeake and Roanoke specimens with the C allele of IDH that had been misclassified as Hudson in origin could be reclassified as "non-Hudson"; likewise, Roanoke specimens with the A allele of IDH that had been misclassified as Chesapeake or Hudson in origin could be reclassified as "non-Hudson non-Chesapeake." Reassigning these specimens resulted in a 2% increase in correct classification for spawning-stock collections. Under hypothesis B, however, the assumption was that the A, B, and C alleles of IDH all occurred in the Hudson stock; therefore, there would be no change in the percentage of correct classification for the spawning-stock collections.

The reclassification of striped bass specimens from oceanic collections using hypothesis A decreased the relative proportion of specimens classified as Hudson stock; the use of hypothesis B increased the estimated relative proportion of Hudson stock specimens. Under hypothesis A, coastal water specimens with an A or C allele were "non-Hudson"; also, those with an A allele were "non-Chesapeake" since the A allele did not occur in spawning stock specimens from the Chesapeake Bay system. When they violated these assumptions, striped bass classified as Hudson or Chesapeake fish were reclassified. As a result, the use of hypothesis A decreased the relative percentages of specimens classified into the Hudson and Chesapeake stocks and increased that of the Roanoke stock (or that of another southern stock not investigated in this study). ¶ Under hypothesis B, specimens from the coastal waters with an A or C allele were potentially Hudson; however, those with an A allele were still "non-Chesapeake."

The majority of those specimens with an A allele classified into the Chesapeake stock may be of Hudson origin for two reasons: first, the A allele occurred in 16% of the Hudson spawning stock specimens collected after May 23 but ~~but~~ only 5% of the Roanoke spawning stock specimens in the 1975 spawning runs; second, the overlap between Hudson and Chesapeake spawning stocks

¶ = New paragraph

was double that between Roanoke and Chesapeake spawning stocks. Therefore, all coastal water specimens with an A allele classified as Chesapeake fish were reclassified to be of Hudson origin. As a result, the use of hypothesis B increased the realative percentage of specimens classified into the Hudson stock without influencing that of the Roanoke stock.

Although the relative proportion of specimens classified into the Hudson stock using hypothesis A or B differed from the original as-classified estimate, the difference on the average was slight. The yearly estimates of Hudson contribution, obtained by averaging strata within periods and then averaging the periods, were 22.1% ~~22.0%~~ for hypothesis A, 23.0% as-classified, and 25.7% ~~25.6%~~ for hypothesis B. Iterative and adjusted estimates obtained by the procedure detailed in Section 7.10.4 were not further modified using hypothesis A or B because the effect of these hypotheses on the as-classified estimates was minimal.

Although 10-16 percentage point differences (Table 7.10-9) among the as-classified estimates using hypothesis A and B occurred during the summer for Massachusetts (stratum 2), Rhode Island (stratum 3), eastern Long Island (stratum 6), and New Jersey (stratum 8), differences of this magnitude occurred in <12% of temporal and geographical strata investigated.

7.10.10 CONCLUSIONS. The following are the major conclusions drawn from the study:

- The Chesapeake stock is the major contributor to the Atlantic coastal striped bass fishery from southern Maine to Cape Hatteras, North Carolina.
- The Chesapeake stock is also the major contributor of legal sized striped bass in the vicinity of the Hudson River (western Long Island Sound and the New York Bight).

Table 7.10-9 Comparison of Estimated Relative Percentages of Legal-Sized Striped Bass of Hudson River Stock Obtained with IDH Assumption A and B and Results from Use of Quadratic Functions[*]

Period	Stratum	Sample Size	Case A[**]	As-Classified	Case B[***]
Jan-Feb(1)	10	27	25.9	25.9	29.6
Mar-Apr(2)	5	38	50.0	52.6	52.6
	7	30	23.3	23.3	23.3
	8	34	23.5	23.5	26.5
	9	71	8.5	8.5	~~8.5~~ 11.3
May-Jun(3)	1	82	6.1	11.0	14.6[†]
	2	91	12.1	14.3	14.3
	3	60	~~28.3~~ 30.0	30.0	~~33.3[†]~~ 35.0[†]
	4	96	19.8	21.9	27.1[†]
	5	14	35.7	35.7	42.9[†]
	6	89	23.6	25.8	27.0
	7	58	37.9	41.4	43.1[†]
	8	113	23.0	23.9	24.8
Jul-Aug(4)	1	58	17.2	19.0	20.7
	2	90	5.6	7.8	15.6[‡]
	3	43	23.3	30.2	39.5[‡]
	5	15	26.7	26.7	26.7
	6	102	~~18.6~~ 19.6	22.5	~~32.4[‡]~~ 33.3 ‡
	7	93	33.3	33.3	37.6
	8	28	21.4	21.4	32.1[‡]
Sep-Oct(5)	1	74	~~12.2~~ 13.5	13.5	~~16.2~~ 17.6
	2	82	12.2	12.2	12.2
	3	56	25.0	25.0	25.0
	4	140	15.7	16.4	18.6
	5	89	~~38.2~~ 40.4	41.6	~~41.6~~ 42.7
	6	86	15.1	15.1	15.1
	7	120	23.3	23.3	25.0
	8	73	15.1	16.4	16.4
	9	6	16.7	16.7	16.7
Nov-Dec(6)	4	99	21.2	21.2	21.2
	6	106	~~15.1~~ 16.0	16.0	16.0
	7	124	20.2	21.0	21.8
	8	117	20.5	21.4	~~23.1~~ 22.1
	9	100	8.0	8.0	8.0
	10	24	12.5	12.5	12.5

[*] Not included are <406.5 mm fork length striped bass from New York waters.

[**] Case A assumes IDH classifications of AA, AB, BC, or CC to be non-Hudson.

[***] Case B assumes IDH classifications of AA, AB, BC, or CC to be Hudson and AA or AB, when fish are misclassified as Chesapeake, to be Hudson.

[†] Variation between 5 and 10% between cases A and B.

[‡] Variation >10% between cases A and B.

- Sublegal-sized striped bass collected in the vicinity of western Long Island Sound and the New York Bight are predominantly of Hudson origin.
- Striped bass overwintering in the Hudson River are predominantly of Hudson origin.

The relative contribution of the Hudson, Chesapeake, and Roanoke stocks to the Atlantic coastal striped bass fishery in 1975 was estimated to be 7, 91, and 3% respectively.

SECTION 8

ENTRAINMENT OF STRIPED BASS

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SECTION 8

ENTRAINMENT OF STRIPED BASS

8.1 INTRODUCTION

The early life stages of striped bass (eggs, yolk-sac larvae, post yolk-sac larvae, and early juveniles) are susceptible to entrainment by power plant cooling water circulating systems, the degree of susceptibility depending largely on the fish's size and location relative to the power plant cooling water intake. As the fish grows larger, its motility and nervous sensory systems develop and it becomes increasingly capable of detecting and avoiding currents created by plant withdrawal, although it may still be smaller than the opening of the intake screens (generally 3/8 in [9.5 mm]). With the development of mobility, striped bass begin to move in search of prey and preferred habitat. Depending on circumstances, such movement may enhance or, if the movement is to protected areas, reduce susceptibility to entrainment.

Upon passage through a cooling water circulating system, some of the organisms entrained may be killed by exposure to various mechanical stresses and elevated temperatures. The portion of the organisms surviving entrainment is an important factor in determining impact on the striped bass population.

Direct measurements of striped bass ichthyoplankton at the plants and at river transects in front of the plant intakes provide a data base that can be incorporated into the real-time life-cycle model to predict entrainment impact under different conditions of plant operation and standing crops in the river (Section 12.2). The data base developed from field data can also be used directly to calculate total entrainment of striped bass ichthyoplankton. Sections 8.4 through 8.10 present direct calculations of entrainment for Indian Point and other plants in the central part of the estuary. No entrainment data are available for the Albany plant, which is located at the upriver extreme of the lower Hudson well above the major spawning ground of the striped bass. Results of empirical calculations and model predictions are compared in Section 8.11.

8.2 STRIPED BASS CHARACTERISTICS THAT DETERMINE SUSCEPTIBILITY TO ENTRAINMENT

8.2.1 SIZE. To be entrained, striped bass must be smaller in two dimensions than the mesh of the screens that are installed at power plant intakes to prevent large particles from entering the condenser cooling system. The mesh is typically 9.5 mm^2 (Section 2.3.3.3), or 13.4 mm on the diagonal. Thus, striped bass eggs that average 3.4 mm in diameter (Section 7.3.1) and yolk-sac larvae that are typically <6.0 mm in length (Section 7.4) are readily entrainable. Although the length of older (larger) post yolk-sac larvae is >13.4 mm (Section 7.4), the physical flexibility of this life stage under conditions of intake turbulence and suction may result in entrainment of essentially all individuals unable to avoid the screens. While the length of all juveniles exceeds the dimensions of the intake screen mesh (Section 7.5), the depth (distance from dorsal to ventral surface) of some individuals in this life stage is smaller than the mesh dimensions; therefore, the entrainability of juveniles is a function of the fish's orientation in relation to the screen mesh, as well as its body dimensions. As already described in Section 7.5, this length-depth ratio for juveniles is approximately 5:1; therefore, the maximum lengths entrainable are 46-65 mm. Extendable fins probably reduce this range by several millimeters. For practical purposes, juvenile striped bass longer than 40 mm are probably too large to be susceptible to entrainment.

8.2.2 LIFE-STAGE DURATION. Depending on the size of the organisms (Section 8.2.1), striped bass are susceptible to entrainment during the period of growth between spawning and metamorphosis into young fish >40 mm in length. The duration of a given life stage (Section 7.3 through 7.6) is a function of the growth rate of that life stage; the growth rate depends on a number of environmental factors including water temperature, salinity, dissolved oxygen, and pollutant concentrations. Biotic factors such as disease, food availability, and development of the necessary organs at the time of yolk-sac absorption also influence the growth rate of the fish. Thus, the duration of a life stage can be expected to vary, even within a population and increase with age as follows:

Eggs	2.00-2.75 days
Yolk-sac larvae	4-6 days
Post yolk-sac larvae	20-30 days
Early juveniles	20-30 days

The persistence of a life stage at a location in the river, while related to duration is dependent also on the temporal distribution of spawning, downstream transport, and active migration. Because of the combined effects of these variables, two or more life stages are generally found at the same time in a given river section and may occur for a period of time longer or shorter than the typical duration of a life stage.

8.2.3 AVOIDANCE CAPABILITY. Withdrawing water from the Hudson River for a power plant's condenser cooling system results in the formation of a zone of increasing water velocity leading to the system's intake. Turbulence also may occur, depending on intake design. The ability of entrainable striped bass to avoid the zone of withdrawal and the intake is a function primarily of their sensitivity and response to velocity gradients and turbulence; and of their swimming speed and endurance (Sections 7.3 through 7.6).

Striped bass eggs are nonmotile and cannot actively avoid entrainment. As indicated in Section 7.7, the post-hatch life stages become increasingly motile and more capable of avoidance as they develop. Yolk-sac larvae are weakly motile: they drift in a head-up position and make short, irregular swimming motions that result, if sustained, in vertical movement of probably

$<1\ \mathrm{m\ min}^{-1}$. Due to the irregular nature of the movement, actual distance traveled per minute is probably <0.5 m in still water. This swimming speed, duration, and orientation makes unlikely the avoidance of or escape from the zone of withdrawal by organisms at this life stage.

Post yolk-sac larvae are capable of active, directed movement of several minutes' duration. Most striped bass in this life stage appear capable of swimming against a current of 12 cm sec^{-1} for at least 4 min or approximately 20 m in 4 min. This degree of motility, plus development of feeding behavior, suggests concurrent development of the nervous sensory system; i.e., post yolk-sac larvae are presumed to have the capacity to sense and respond to pressure oscillations and velocity gradients, thus making detection, avoidance, and escape at this life stage possible, at least in the periphery of the withdrawal zone.

Early juvenile striped bass are stong swimmers that can maintain position against a current of approximately 30 cm sec^{-1} for 10 min or travel 180 m in 10 min. Detection, avoidance, and escape from the zone of withdrawal, therefore, is a greater possibility for early juveniles than for post yolk-sac larvae.

8.2.4 SPATIAL DISTRIBUTION LATERALLY. Since the intakes of most power plants on the Hudson River are located at or near the shoreline (Section 2.3.3.3), the lateral distribution of entrainable striped bass affects their availability for entrainment. For example, if 75% of the standing stock of a particular life stage were to occur in the middle third of a lateral transect of the river, 12.5% would be available for entrainment on either side of the river, assuming equal distribution in both nearshore fractions. Availability can be reduced further if the zone of withdrawal includes less than the full extent of the nearshore third. Recent studies by LaSalle Hydraulic Laboratory (LaSalle 1976) indicated that the zone of withdrawal at Indian Point is narrow (much less than one third of the river's width).

Distribution studies in the Cornwall region (RM 56; km 90) of the Hudson River (approximately 10 mi [16 km] upstream from Indian Point) indicate that the lateral distribution of striped bass eggs varies with depth in the water column as well as with longitudinal location; on the average, eggs are more abundant in the middle and west sectors of the river, but this pattern is strongly influenced by the distribution in one longitudinal sector. In other Cornwall study sectors and in the Indian Point study (RM 42; km 68), the opposite tendency has been observed but is generally not statistically significant (Section 7.3). The lateral distribution of striped bass eggs is likely a function of the hydrodynamics of a river sector and of localized spawning activity. Consequently, the lateral distribution of striped bass eggs is expected to vary from one longitudinal sector to another and to change through time.

The lateral distribution of yolk-sac striped bass varies with depth in the water column and with longitudinal location as well as with sampling date. As noted for the eggs of this species, there is a tendency toward greater abundance in the middle and west sectors of the river, but lateral differences are generally not statistically significant (Section 7.4). The lateral distribution of yolk-sac stage is probably a function of the hydrodynamics of a river sector.

The east/west distribution of post yolk-sac larvae in the Cornwall study was highly complex, varying with time of day, depth in the water column, longitudinal location, and sample date. In general, however, post yolk-sac larvae are more abundant in the west sector or the east sector than in the middle sector. On one of the dates analyzed, lateral differences in abundance were statistically insignificant; on the other, they were significant and extremely complex, with vertical/diurnal distribution patterns impossible to separate from lateral distribution. Observations suggest that the lateral distribution of post yolk-sac larvae is influenced by the hydrodynamics of the river and modified by temporal/spatial variations in vertical/diurnal distribution (Section 8.2.5).

As described in Section 7.5, juvenile striped bass in the Hudson River generally move shoreward and downstream during summer and fall. Recently transformed juveniles apparently inhabit depths >20 ft (6 m) but move to the shore zone as the river warms and becomes more saline. East/west patterns vary with location and time; in the Indian Point area, for example, juveniles are significantly more abundant, on the average, in open water to the west and on east-shore beaches.

Overall then, lateral distributions of eggs, yolk-sac larvae, and to some extent post yolk-sac larvae appear to be influenced primarily by river hydrodynamics: velocity of flow, current patterns, and turbulent mixing. The vertical/diurnal distribution of the post yolk-sac stage may influence lateral distribution. Since lateral distributions of eggs, yolk-sac, and post yolk-sac larvae appear to vary with longitudinal location and possibly with tidal stage, the influence of these distributions on entrainment cannot be generalized. Juveniles tend to prefer nearshore zones, a phenomenon that may result in their being protected to some degree from the influence of the rivers' hydrodynamics and plant withdrawals.

8.2.5 SPATIAL DISTRIBUTION VERTICALLY. Since power plants do not withdraw water equally from the upper and lower portions of the water column, (Section 8.3.4), the vertical distribution of entrainable striped bass affects their susceptibility to entrainment.

As noted earlier, striped bass eggs are nonmotile and their vertical distribution therefore is primarily a function of their specific gravity and current speed and turbulence. In rapidly flowing water, the eggs are pelagic, i.e., found throughout the water column; in areas of low velocity, they tend to settle and concentrate near the bottom. As described in Section 7.3, studies in the Cornwall and Indian Point regions indicate that eggs are usually significantly more abundant in the bottom layers of the water column than in the surface layers.

Striped bass yolk-sac larvae, despite their weak swimming ability, are capable of diurnal migration (Section 7.3). Statistical analyses of distribution data indicate a general upward movement and dispersion through the water column at night in both the Cornwall and Indian Point regions. This life stage is many times more abundant in bottom waters than in surface waters during daylight hours.

Post yolk-sac striped bass exhibit similar diurnal migration behavior (Section 7.4), but day/night distribution patterns vary with location and, in some instances, day values are significantly greater on the average than night values, suggesting that diurnal migration may be lateral as well as vertical at some locations.

Vertical migration patterns for striped bass yolk-sac and post yolk-sac larvae were calculated from the Indian Point and Cornwall studies analyzed in Section 7 as well as from transects in the Bowline (RM 37; km 60), Lovett (RM 41; km 66), and Roseton/Danskammer (RM 65-66; km 105-106) regions sampled during 1975. The results, shown in Table 8.2-1, are remarkably similar at all of the transects sampled and are consistent with the notion of vertical/diurnal migration. At all the transects and for both life stages, the fraction of organisms in the lower layer (mid-depth to bottom) is greater during the day than at night. The average values shown in Table 8.2-1 for the yolk-sac and post yolk-sac stages were input to the real-time life-cycle model to define the vertical migration phenomenon.

As described earlier (Section 7.5), juvenile striped bass presumably move upward and laterally toward the nearshore zone during darkness. The smaller lengths of juveniles collected at night in the nearshore zone suggest that vertical/lateral migration is an early juvenile behavior pattern and that other, larger fish in this life stage may respond primarily to tidal stage.

Table 8.2-1 Relative Fractional Distributions of Yolk-Sac and Post Yolk-Sac Striped Bass Larvae in Lower Hudson River

		Yolk-Sac Larvae		Post Yolk-Sac Larvae	
Location	Time	Lower Layer	Upper Layer	Lower Layer	Upper Layer
Bowline	Day	0.7421	0.2579	0.8299	0.1701
	Night	0.3812	0.6188	0.5264	0.4736
Lovett	Day	0.7574	0.2426	0.5929	0.4071
	Night	0.4395	0.5605	0.3154	0.6846
Indian Point	Day	0.8518	0.1482	0.6986	0.3014
	Night	0.4130	0.5870	0.5675	0.4325
Roseton/ Danskammer	Day	0.8538	0.1462	0.8071	0.1929
	Night	0.5936	0.4064	0.5145	0.4855
Cornwall	Day	0.7977	0.2023	0.8988	0.1012
	Night	0.4194	0.5806	0.6053	0.3947
Mean	Day	0.8006	0.1994	0.7655	0.2345
	Night	0.4493	0.5507	0.5058	0.4942

8.2.6 MOVEMENT. The lateral and vertical distributions described in the preceding sections are considered here in conjunction with longitudinal distribution to develop a qualitative model of the movement of entrainable striped bass.

Striped bass eggs are at the mercy of the currents in the river. While net downstream movement is a function of net downstream water flow, upstream movement occurs during flood tide. Therefore, the entrainable striped bass in a particular water mass may be exposed more than once to a power plant's withdrawal zone; the frequency of exposure is a function of the tidal dynamics and freshwater flows in the river and is limited by the duration of the egg stage. In 2-3 days, eggs transform into yolk-sac larvae, which continue to drift with the currents. This life stage migrates diurnally in the water column, and longitudinal distribution thus is reordered on a daily basis by vertical differences in currents for the 4-6 day duration of the yolk-sac stage and for the following 20-30 days of the post yolk-sac phase. However, during this time, lateral migration behavior develops and the distribution of the post yolk-sac stage therefore is highly variable. During the early juvenile stage, lateral migration behavior becomes strongly developed and the fish seek nearshore habitats. At that time, when they are too large to be easily entrained, they apparently remain farily sedentary until downstream fall migration begins.

Table 8.2-2 presents the migration preferences used in the real-time life-cycle model to simulate the downstream movement of the juveniles during 1974 and 1975. Migration preferences were calculated directly from beach seine data. The migration preferences represent the fractional distribution of the juvenile life stages among the segments in the real-time model. Procedures for computing the migration preferences and their application in the model are given by LMS (1975).

8.3 DISTRIBUTIONAL AND SURVIVAL PARAMETERS USED IN ENTRAINMENT ESTIMATES

As described in preceding sections, susceptibility of striped bass eggs and larvae to plant entrainment depends on their positions relative to the plant intake and their susceptibility to being transported by the current to the intake vicinity. Not all organisms in the river or even in the intake vicinity are at great risk to entrainment because of non-uniform distribution in the river, river morphology, and the fact that the plant may withdraw its cooling water from only a particular portion of the river. In addition, some striped bass larvae that have a more developed swimming ability because they are in a later stage may be able to avoid intake currents. Thus, the concentration of organisms entering the plant circulating water system may be related to their concentration in the river but may not be equal to that concentration. Also, upon being drawn by the intake current to the circulating water system, the entrained organisms are subject to mechanical, pressure, and thermal

Table 8.2-2 Fractional Distribution of Juvenile Striped Bass in Lower Hudson River 1974-75[*]

			1974		1975	
Segment	Kilometer	Miles	Juvenile I[**]	Juvenile II[†]	Juvenile I[**]	Juvenile II[†‡]
1	193.5-209.7	120-130	0.083	0.041	0.003	0.011
2	177.4-193.5	110-120	0.026	0.007	0.002	0.007
3	161.3-177.4	100-110	0.003	0.002	0.002	0.004
4	153.2-161.3	95-100	0.015	0.002	0.002	0.007
5	145.2-153.2	90-95	0.001	0.002	0.003	0.001
6	137.1-145.2	85-90	0.002	0.004	0.009	0.006
7	129.0-137.1	80-85	0.038	0.008	0.009	0.004
8	121.0-129.0	75-80	0.073	0.046	0.009	0.003
9	112.9-121.0	70-75	0.086	0.042	0.000	0.002
10	109.7-112.0	68-70	0.125	0.020	0.000	0.004
11	106.5-109.7	66-68	0.066	0.075	0.000	0.002
12	103.2-106.5	64-66	0.031	0.064	0.008	0.003
13	100 -103.2	62-64	0.022	0.153	0.008	0.006
14	96.8-100.0	60-62	0.005	0.025	0.015	0.011
15	93.5- 96.8	58-60	0.008	0.040	0.157	0.041
16	90.3- 93.5	56-58	0.065	0.014	0.028	0.015
17	85.5- 90.3	53-56	0.040	0.007	0.080	0.040
18	80.6- 85.5	50-53	0.022	0.002	0.018	0.010
19	75.8- 80.6	47-50	0.037	0.002	0.072	0.041
20	71.0- 75.8	44-47	0.004	0.003	0.000	0.000
21	67.7- 71.0	42-44	0.020	0.005	0.076	0.045
22	64.5- 67.7	40-42	0.015	0.003	0.152	0.136
23	61.3- 64.5	38-40	0.013	0.035	0.044	0.053
24	58.1- 61.3	36-38	0.040	0.011	0.017	0.029
25	54.8- 58.1	34-36	0.005	0.007	0.073	0.180
26	51.6- 54.8	32-34	0.119	0.215	0.065	0.029
27	48.4- 51.6	30-32	0.010	0.056	0.008	0.030
28	32.3- 48.4	20-30	0.011	0.058	0.007	0.062
29	16.2- 32.3	10-20	0.015	0.051	0.113	0.218

[*] Based on 1974 and 1975 beach-seine data from Texas Instruments Incorporated

[**] Entrainable juveniles (15-40 mm in length)

[†] Impingeable juveniles (40 mm in length)

[‡] Juvenile III migration preferences are the same as those for Juvenile II

stresses, but studies conducted at various plants (Lauer et al. 1974; EAI 1976a,b) show that a large portion of the entrained striped bass larvae can survive these stresses.

To account for variabilities in the environmental and biological factors that must be considered in Hudson River striped bass entrainment estimates, distributional and survival parameters are employed in the real-time life-cycle model. The model (Lawler et al., 1975f) predicts the average concentration of organisms in the upper and lower layers of the river (number of organisms per unit water volume) at any time (calendar date or days from commencement of spawning) and in any section along the river's longitudinal axis. The concentration of organisms of a particular stage entering the plant (C_p) can be related to the average upper- and lower-layer river concentrations of those organisms (C_{RU} and C_{RL}, respectively) as follows:

$$C_p = w_U \cdot f_{3U} \cdot f_{qU} \cdot C_{RU} + w_L \cdot f_{3L} \cdot f_{qL} \cdot C_{RL} \qquad (8.1)^*$$

where

w_U = ratio of the concentration of organisms at the plant, Cp, to the average concentration of these organisms in the upper layer of the river C_{RU} (Section 8.3.1)

w_L = ratio of the concentration of organisms at the plant, Cp, to the average concentration of these organisms in the lower layer of the river C_{RL} (Section 8.3.1)

f_{3U}, f_{3L} = for upper and lower layers respectively, ratio of concentration of live organisms at the plant intake to the uncorrected concentration of organisms at the plant, taking into consideration the near-field depletion of organisms (Section 8.3.3)

f_{qU}, f_{qL} = for upper and lower layers respectively, fractional withdrawal from the water column (Section 8.3.4)

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* The w ratios are equivalent to the product of the f_1 and f_2 factors described in J.P. Lawler's October 30, 1972, testimony (Lawler 1972).

The rate at which organisms enter the plant circulating water system per day (R_p) can be expressed as:

$$R_p = C_p \cdot Q_p \tag{8.2}$$

where Q_p is plant intake flow rate (volume of water per day).

Since some of the entrained organisms survive passage through the circulating water system, the remainder being returned to the river alive in the cooling water discharge, the rate of mortality due to entrainment may be expressed as:

$$R_c = C_p \cdot Q_p \cdot f_c \tag{8.3}$$

where

f_c = fraction of the entrained organisms that do not survive
R_c = number of organisms cropped per day

When Equations 8.1 and 8.2 are substituted into Equation 8.3, the result is:

$$R_c = \left(w_U \cdot f_{3U} \cdot f_{qU} \cdot C_{RU} + w_L \cdot f_{3L} \cdot f_{qL} \cdot C_{RL}\right) \cdot f_c \cdot Q_p \tag{8.4}$$

The various parameters in Equation 8.4 are evaluated in the following sections. Since each power plant on the Hudson River is unique and the various early life stages of the striped bass exhibit different biological and behavioral characteristics, these distributional/behavioral and survival parameters are evaluated individually for each plant, for each life stage, and for day and night.

8.3.1 RATIO OF CONCENTRATION OF ORGANISMS AT THE PLANT TO CROSS-SECTIONAL AVERAGE CONCENTRATION OF ORGANISMS IN RIVER (w). Samples collected at transects in the river and at plant intakes and discharges were used in the calculation of the w ratios for each plant. Samples from the river normally are collected from three depths at each of three to four longitudinal transects to attempt to determine the lateral variation of the concentration of organisms in front of the plant and over a 24-h period to account for diurnal differences in distribution. At the plant, samples from three depths at the intake and from one to three depths at the discharge generally are collected concurrent with river sampling so plant and river concentrations can be directly compared. Because of the heterogeneous distribution of organisms in the river and differences in sampling programs, site-specific physical and biological characteristics, and operations among plants on the Hudson, the following sections detail the calculations both at each plant and in the river.

The generalized equations for calculating the w ratios for each early life stage are as follows:

$$\text{Upper-Layer } w_U = \frac{\left[\sum_{i=1}^{m} (C_p)_i\right] / (m)}{\left[\sum_{i=1}^{n} (C_{RU})_i\right] / (n)} \qquad (8.5)$$

$$\text{Lower-layer } w_L = \frac{\left[\sum_{i=1}^{m} (C_p)_i\right] / (m)}{\left[\sum_{i=1}^{n} (C_{RL})_i\right] / (n)} \qquad (8.6)$$

where

m,n = number of weekly average plant and river concentrations respectively within organisms' period of abundance

$(C_p)_i$ = average plant concentration for i^{th} week
$(C_{RU})_i$ = average river upper-layer concentration for i^{th} week
$(C_{RL})_i$ = average river lower-layer concentration for i^{th} week

Normally, samples were collected once per week. However, in cases in which there was more than one sampling within the same week, the weekly mean concentrations were determined by averaging the mean concentrations of each sampling date within the week. The periods of abundance for each early life stage were determined from the ichthyoplankton surveys conducted during 1974 and 1975 with epibenthic sleds and Tucker trawls. The period between the first and last appearances of the striped bass ichthyoplankton in the river was defined as the period of abundance. Table 8.3-1 indicates the period of abundance used for calculating the w ratios. Note that both plant and river samples were not always collected during each sampling period.

During some weeks, only plant samples were taken; during other weeks, only river samples. Since abundances in the river and at the plant can change markedly from one week to the next, to include these unbalanced data sets could bias the calculated average abundance for the plant or the river; consequently, only balanced data sets (i.e., those with both plant and river data) were included when computing the w ratios at each plant.

8.3.1.1 Indian Point w Ratio. Tables 8.3-2 through 8.3-4 present the weekly average concentrations and the calculations of w ratios for eggs and yolk-sac and post yolk-sac larval stages respectively for Indian Point based on data collected during 1975. Similar calculations based on data collected during 1974 appear in Tables 8.3-5 through 8.3-7. Since 1974 and 1975 data were limited for juveniles, the w ratio was set equal to unity for the juvenile stage. Almost certainly, this was conservative. TI's 1974 and 1975 river data suggested that early juveniles moved to shallow areas of the river along the shoreline (Section 7.5).

Table 8.3-1 Period of Abundance of Striped Bass in Hudson River*

	Weeks, 1974			Weeks, 1975		
Life Stage	Start	End	No.	Start	End	No.
Egg	28 Apr-4 May	16-22 Jun	8	11-17 May	22-28 Jun	7
Yolk-sac larva	5-11 May	23-29 Jun	8	11-17 May	29 Jun-5 Jul	8
Post yolk-sac larva	12-18 May	21-27 Jul	11	18-24 May	20-26 Jul	10
Juvenile I	9-15 Jun	11-17 Aug	10	22-28 Jun	10-16 Aug	8

* Based on Texas Instruments river ichthyoplankton survey

Table 8.3-2 Mean Weekly Concentrations and w Ratios of Striped Bass Eggs, Indian Point, 1975*

	Day (0600-2059)			Night (2100-0559)		
Week of	Plant**	Upper River	Lower River	Plant	Upper River	Lower River
May 11-17	0.00	18.79	22.33	94.19	28.00	39.39
May 18-24	19.88	251.75	448.01	305.57	73.90	412.31
May 25-31	98.00	81.17	156.61	190.56	75.25	271.81
Jun 1-7	14.43	18.50	26.80	2.80	0.00	0.00
Jun 8-14	0.00	0.00	0.00	0.00	0.00	0.00
Jun 15-21	0.00	0.77	0.00	0.00	0.00	0.00
Jun 22-28	0.00	0.00	0.00	0.00	0.00	0.00
Mean	18.90	53.00	93.39	84.73	25.31	103.22
	w_U = 18.90/53.00 =		0.36	w_U = 84.73/ 25.31 =		3.35
	w_L = 18.90/93.39 =		0.20	w_L = 84.73/103.22 =		0.82

* Number of organisms $m^{-3} \times 10^3$

**Mean surface and mid-depth concentrations of river stations B,D, and G used; no plant samples taken during daytime.

Table 8.3-3 Mean Weekly Concentrations and w Ratios of Striped Bass Yolk-Sac Larvae, Indian Point, 1975*

	Day (0600-2059)			Night (2100-0559)		
Week of	Plant**	Upper River	Lower River	Plant	Upper River	Lower River
May 11-17	0.00	0.00	0.00	0.00	0.00	0.00
May 18-24	2.80	16.67	68.39	43.90	54.54	68.63
May 25-31	319.70	283.16	1441.04	43.40	1149.80	515.63
Jun 1-7	40.59	84.74	729.43	31.08	109.02	193.30
Jun 8-14	0.00	0.00	11.41	1.88	73.87	198.17
Jun 15-21	0.00	12.36	31.01	0.00	1.24	1.37
Jun 22-28	0.00	0.00	0.58	0.00	0.00	3.48
Jun 29-Jul 5	0.00	0.00	0.00	0.00	0.00	0.00
Mean	45.39	49.62	285.23	15.03	173.56	122.72
	w_U = 45.39/ 49.62 =		0.91	w_U = 15.03/173.56 =		0.09
	w_L = 45.39/285.23 =		0.16	w_L = 15.03/122.72 =		0.12

* Number of organisms m^{-3} x 10^3

**Mean surface and mid-depth concentrations of river stations B, D, and G used; no plant samples taken during daytime.

Table 8.3-4 Mean Weekly Concentrations and w Ratios of Striped Bass Post Yolk-Sac Larvae, Indian Point, 1975*

	Day (0600-2059)			Night (2100-0559)		
Week of	Plant**	Upper River	Lower River	Plant	Upper River	Lower River
May 18-24	0.00	0.00	0.00	2.36	0.00	0.00
May 25-31	454.05	610.54	1005.49	16.58	546.33	155.60
Jun 1-7	340.77	1020.71	1588.80	367.52	1631.16	1900.48
Jun 8-14	175.31	152.01	1494.40	264.54	2479.26	4038.98
Jun 15-21	76.00	57.28	139.41	194.45	28.41	43.98
Jun 22-28	0.00	6.25	2.00	23.60	7.01	7.81
Jun 29-Jul 5	12.27	13.52	79.41	8.85	0.00	9.39
Jul 6-12	0.00	0.00	2.92	0.00	0.00	0.00
Jul 13-19	0.00	0.00	0.00	1.25	0.00	0.00
Jul 20-26	0.00	0.00	0.00	NS†	0.00‡	0.00‡
Mean	105.84	186.03	431.24	97.68	521.36	684.02
	w_U = 105.84/186.03 =		0.57	w_U = 97.68/521.36 =		0.19
	w_L = 105.84/431.24 =		0.25	w_L = 97.68/684.02 =		0.14

* Number of organisms $m^{-3} \times 10^3$

** Mean surface and mid-depth concentrations of river stations B, D, and G used; no plant samples taken during daytime.

† NS- no samples

‡ Not included in the calculation of mean since plant data is not available

Table 8.3-5. Mean Weekly Concentrations and w Ratios of Striped Bass Eggs, Indian Point, 1974*

Week of	Day (0600-2059) Plant**	 Upper River	 Lower River	Night (2100-0559) Plant	 Upper River	 Lower River
Apr 28-May 5	NS***	NS***	NS***	NS***	NS***	NS***
May 5-11	0.00	1.71	2.45	NS***	2.77†	18.70†
May 12-18	96.16	107.69	265.78	NS***	0.61†	37.46†
May 19-25	203.42	196.09	1194.15	257.48†	0.00‡	NS ‡
May 26-Jun 1	11.28	55.12	52.92	42.49	3.06	4.49
Jun 2-8	9.25	6.35	8.11	28.00	5.24	44.08
Jun 9-15	1.68	1.72	2.56	2.40	1.77	0.00
Jun 16-22	0.00	0.00	0.00	0.00	0.00	0.00
Mean	45.97	52.67	218.00	18.22	2.52	12.14

w_U = 45.97/ 52.67 = 0.87 w_U = 18.22/ 2.52 = 7.17

w_L = 45.97/218.00 = 0.21 w_L = 18.22/12.14 = 1.50

* Number of organisms $m^{-3} \times 10^3$

** Mean surface and mid-depth concentrations of river stations B, D and G used; no plant samples were taken during daytime

*** NS - no samples

† Not included in the calculation of mean because neither plant nor river was samples

‡ Only one sample was taken at one of the seven stations. Data too limited to evaluate cross-sectional concentrations

Table 8.3-6 Mean Weekly Concentrations and w Ratios of Striped Bass Yolk-Sac Larvae, Indian Point, 1974*

	Day (0600-2059)			Night (2100-0559)		
Week of	Plant**	Upper River	Lower River	Plant	Upper River	Lower River
May 5-11	0.00	5.11	6.93	NS†	8.07‡	8.86‡
May 12-18	2.21	4.69	21.63	NS†	5.91‡	9.94‡
May 19-25	137.84	126.88	258.11	40.84	43.09	37.31
May 26-Jun 1	48.01	33.61	236.79	17.77	77.46	165.28
Jun 2-8	15.79	49.80	81.18	31.15	45.39	86.06
Jun 9-15	0.00	0.54	30.26	0.00	65.21	30.27
Jun 16-22	0.00	0.00	0.00	0.00	0.00	0.00
Jun 23-29	0.00	0.00	0.00	0.00	0.00	0.00
Mean	25.48	27.65	79.44	14.96	38.53	53.15

w_U = 25.48/27.65 =	0.92	w_U = 14.96/38.53 =	0.39
w_L = 25.48/79.44 =	0.32	w_L = 14.96/53.15 =	0.28

* Number of organisms $m^{-3} \times 10^3$

** Mean surface and mid-depth concentrations of river stations B, D and G used; no plant samples were taken during daytime

† NS - no samples

‡ Not included in the calculation mean since plant data is not available

Table 8.3-7 Mean Weekly Concentrations and w Ratios of Striped Bass Post Yolk-Sac Larvae, Indian Point, 1974*

	Day (0600-2059)			Night (2100-0559)		
Week of	Plant**	Upper River	Lower River	Plant	Upper River	Lower River
May 12-18	0.00	0.00	0.00	NS[†]	1.99[‡]	0.69[‡]
May 19-25	0.00	0.61	1.73	0.00	0.00	0.00
May 26-Jun 1	8.02	11.76	66.01	8.88	91.85	105.03
Jun 2-8	59.41	376.54	632.59	213.63	396.19	357.72
Jun 9-15	42.58	102.59	405.00	245.27	412.86	263.82
Jun 16-22	95.51	45.93	184.63	37.78	62.95	56.31
Jun 23-29	51.29	47.91	76.89	44.29	71.78	27.22
Jun 30-Jul 6	1.35	2.71	6.31	29.58	1.23	5.12
Jul 7-13	10.57	9.80	12.57	7.03	1.40	0.62
Jul 14-20	0.00	0.00	0.00	NS[†]	0.00[‡]	0.00[‡]
Jul 21-27	0.00	0.00	0.00	0.00	0.00	0.00
Mean	24.43	54.35	125.98	65.16	115.36	90.65
	w_U = 24.43/54.35 =		0.45	w_U = 65.16/115.36 =		0.56
	w_L = 24.43/125.98=		0.19	w_L = 65.16/ 90.65 =		0.72

* Number of organisms m^{-3} x 10^3

** Mean surface and mid-depth concentrations of river stations B, D and G used; no plant samples taken during daytime

[†] NS - no samples

[‡] Not included in the calculation of mean since plant data is not available

Data collected at river transects in deep water away from the shoreline during 1974 and 1975 confirmed this theory. Very few juveniles were collected during 1974: three from the Indian Point vicinity (RM 42; km 68) and nine each from the vicinities of Bowline (RM 37; km 60) and Roseton (RM 65; km 105); during 1975: only one at Indian Point, 20 from Bowline, and none from Roseton transects, indicating that the early juveniles either avoided the sampling gear or moved to shallow regions away from the channel. Sampling at plant intakes and discharges during 1974 and 1975 also produced few juveniles (during 1974: three from the Indian Point discharge and one each from the Bowline and Roseton intakes; during 1975: three from Indian Point, five by pump from Bowline, and none by net from Bowline and Roseton). These data suggest that early (>14-15 mm) striped bass juveniles may not be subject to plant entrainment because of their residency in shallow, protected areas of the estuary.

During 1974 and 1975, river samples were collected from three depths (surface, mid-depth, and bottom) at each of seven standard stations (A through G, Fig. 8.3-1), encompassing a stretch of approximately 4 river miles (6.5 kilometers) in front of the Indian Point plant. Stations A and B were north and stations F and G were south of Indian Point; stations C and D were directly in front of the Indian Point intake, and station E was near the discharge. Uniform weights were applied to the concentration at each station in determining the average upper- and lower-layer concentrations (C_{RU} and C_{RL} respectively) as shown below:

$$C_{RU} = \sum_{i=1}^{7} \left[(C_s + C_m)/2 \right]_i /7$$

$$C_{RL} = \sum_{i=1}^{7} \left[(C_m + C_b)/2 \right]_i /7$$

where C_s, C_m, and C_b were surface, mid-depth, and bottom concentrations at a given station.

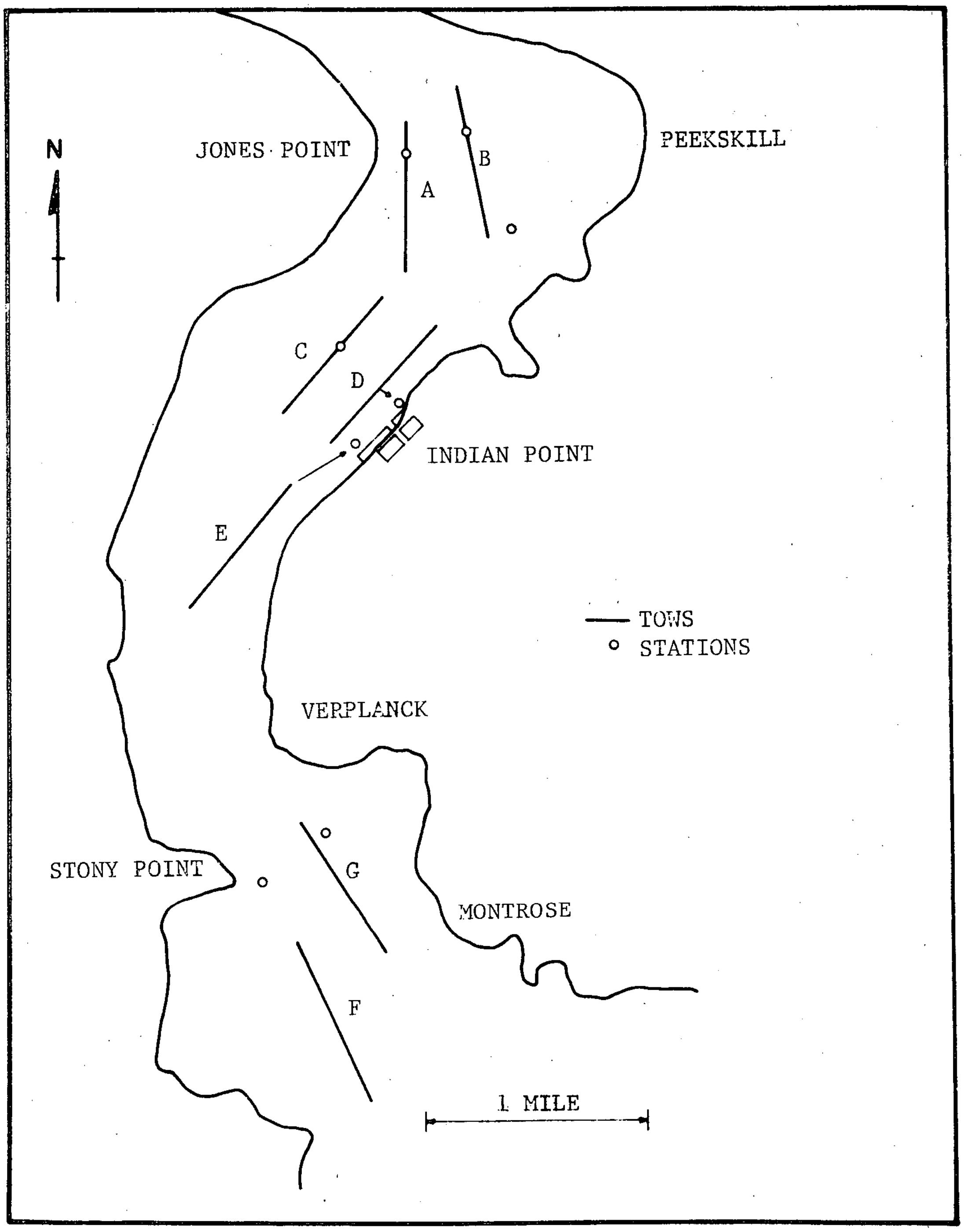

Figure 8.3-1 New York University 1974-75 Hudson River Sampling Stations

At the plant, samples were collected from two intake and tow discharge stations. Since the net towing speed in the river (approximately 1-3 ft sec^{-1} [0.30-0.91 m sec^{-1}]) fell between the average intake velocity (0.7-1.0 ft sec^{-1} [0.21-0.3 m sec^{-1}]) and the discharge velocity (2-4 ft sec^{-1} [0.61-1.2 m sec^{-1}]) the plant concentrations were determined by averaging the mean concentrations at intake and discharge as shown below:

$$C_p = (C_{in} + C_{ds})/2$$

where C_{in}, C_{ds}, and C_p were average intake, discharge, and plant concentrations respectively.

During 1975 when Unit 2 was in operation, intake samples were collected from stations II-2 and II-5 and from stations D-1, D-2, and DP for discharge samples (Fig. 8.3-2). Intake concentrations were determined from the simple arithmetic mean of the concentrations at II-2 and II-5. The only discharge concentrations averaged were those at D-1 and D-2 since the limited number of samples collected at station DP, which was the station near the diffuser ports, might have been contaminated with river organisms. During 1974 when both Units 1 and 2 were in operation, intake samples were collected from either stations I-1 and I-2 at Unit 1 or stations II-2 and II-5 at Unit 2 or one each at Units 1 and 2, depending on the plant operational mode. Average intake concentrations were determined by averaging concentrations at Unit 1 (average of I-1 and I-2) and Unit 2 (average of II-2 and II-5). Concentrations at D-1 and D-2 were averaged to obtain the discharge concentrations. Since no plant samples were collected during daytime in 1974 and 1975, the daytime average upper-layer concentrations at river stations B, D, and G (Fig. 8.3-1), the stations near the east shore, were substituted (Tables 8.3-2 through 8.3-7). This was equivalent to assuming that organisms in the plant withdrawal zone would be entrained. The selection of stations B, D, and G was justified by LaSalle Hydraulic Laboratory's model study (LaSalle-682 1976) in which a narrow zone of river water no more than 350 ft (107 m) from the east shore was found to be subject to plant withdrawal.

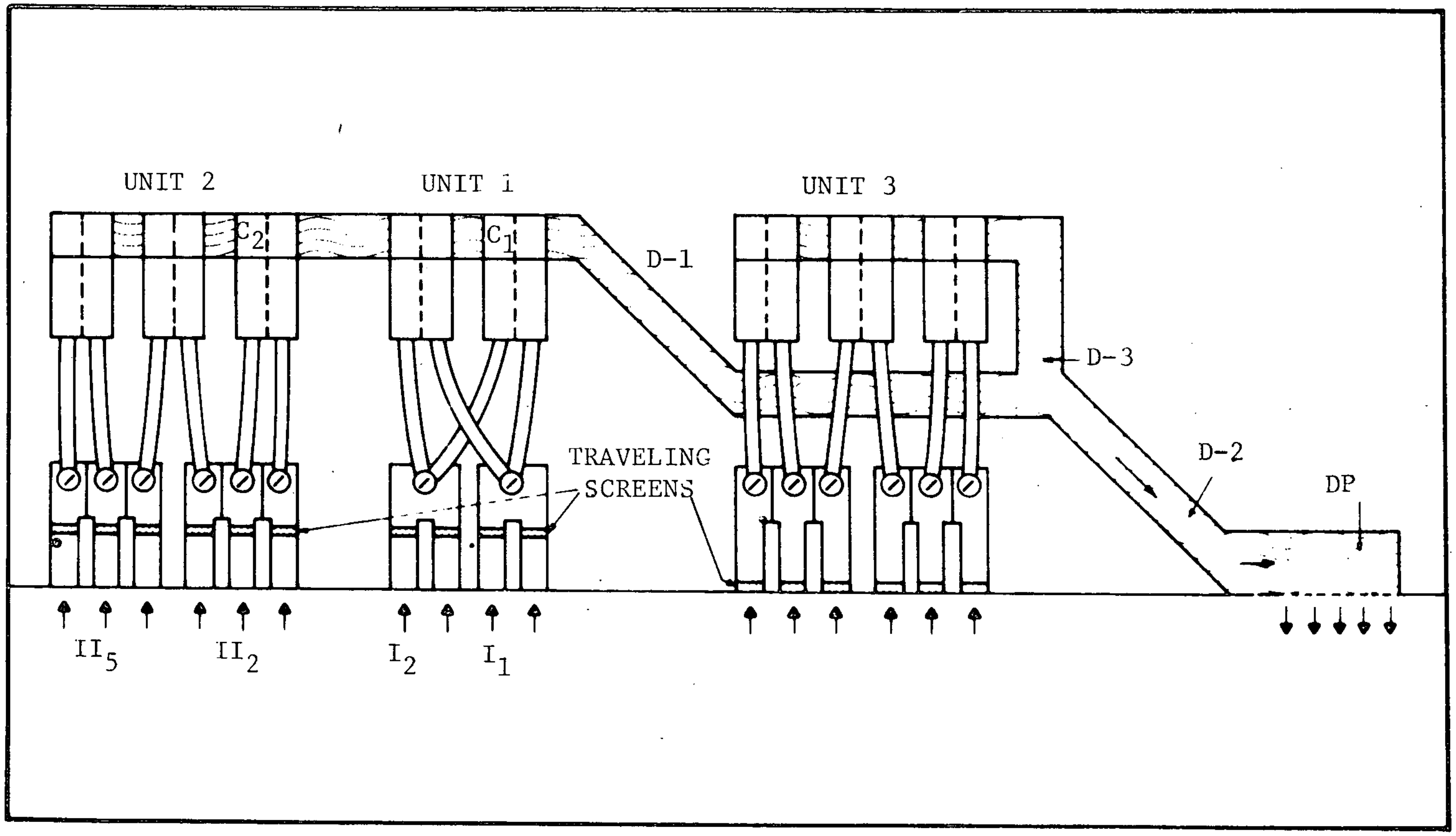

Figure 8.3-2 Indian Point Cooling-Water System Schematic Showing Locations of Sampling Stations

The w ratios (Equations 8.5 and 8.6) were calculated from the plant and river abundances averaged over the period of abundance for each life stage. Excluded from the analysis were data for which there was no comparable river or plant abundance within the same week. The patchy distribution of organisms in space and time would tend to bias comparisons of plant abundance in relation to river abundance if nonparellel data were included in the analysis.

8.3.1.2 Bowline w Ratio. In the Bowline region, river samples were collected from three longitudinal transects designated as Bowline West (BW), Bowline Channel (BC), and Bowline East (BE). Additional samples were collected from Bowline Pone (BP) from which the plant withdraws its cooling water.

During 1975, river samples were collected once per week on an alternate-week basis either from all three transects or from only the channel transect. When samples were collected from all three transects, the average river upper- and lower-layer concentrations for a given sampling date were calculated by:

$$C_{RU} = \sum_{i=1}^{3} [\ (C_s + C_m)/2\ ]_i/3$$

$$C_{RL} = \sum_{i=1}^{3} [\ (C_m + C_b)/2\ ]_i/3$$

where C_s, C_m, and C_b were surface, mid-depth, and bottom concentrations respectively for a given transect.

When only the channel transect was sampled, the average of surface and mid-depth concentrations and the average of mid-depth and bottom concentrations at the channel transect were presumed to represent the river upper- and lower-layer concentrations respectively. Pond samples, on the other hand, were collected weekly and only surface and mid-depth samples were taken because of bottom obstructions. Plant samples were collected in 1975 using plankton nets to take day and night samples at the intake and larval pumps to take night samples at both intake and discharge. The net samples taken at the intake also provided data at three depths and, during day and night, the same sampling stratification and frequency used at the river transects. The pump samples were taken only at night at a depth close to the bottom net sample. Plankton net sampling coincided with the river ichthyoplankton surveys. However no net collections were obtained until June 3, 1975, since Unit 1 was completely off line during the latter half of May. Nor was sampling at intake and discharge with the larval pump initiated until June 3, 1975.

Studies conducted by EAI (1976a) indicated that data obtained with the pump were superior to those with the nets for quantitative assessment of entrainment abundance because of the pumps' apparently greater sampling efficiency. Plant entrainment abundance could be estimated from either net samples or pump collections; to evaluate the withdrawal factor w, however, it was necessary to take data from the plant intakes and the river transects with gear of comparable efficiency. Since no samples were taken from the river with the larval pump, pump samples were not used to evaluate intake abundance in developing the withdrawal factor. As already mentioned, sampling at the Bowline plant intake was not initiated until June 3, 1975, when the period of abundance of striped bass eggs and yolk-sac larvae was nearly over; therefore, plant and river abundances of eggs and yolk-sac larvae could not be directly compared. Since the plant draws its cooling water from the pond, the egg and yolk-sac larval abundances calculated from the pond collections were used in place of the plant abundances (Tables 8.3-8 and 8.3-9). This was a conservative approach since it assumed that all organisms present in the pond would be entrained. For post yolk-sac larvae and the juvenile I stages (Tables 8.3-10 and 8.3-11), abundance calculated from net collections at the intake were compared with the river abundances. The calculation of the w ratios is indicated at the bottom of each table.

Table 8.3-8 Mean Weekly Concentrations and w Ratios of Striped Bass Eggs, Bowline Point, 1975*

	Day (0600-2059)				Night (2100-0559)			
Week of	Plant	Pond	Upper River	Lower River	Plant	Pond	Upper River	Lower River
May 11-17	NS†	0.0	0.0	0.0	NS†	0.0	0.0	0.0
May 18-24	NS†	0.0	52.0	182.5	NS†	0.0	5.2	132.8
May 25-31	NS†	0.0	0.0	0.0	NS†	1.5	12.0	70.5
Jun 1-7	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0
Jun 8-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jun 15-21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jun 22-28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean	-	0.0	7.43	26.19	-	0.21	2.46	29.04
	w_U = 0.0/ 7.43 =			0.00	w_U = 0.21/ 2.46 =			0.09
	w_L = 0.0/26.19 =			0.00	w_L = 0.21/29.04 =			0.01

*Number of organisms $m^{-3} x 10^3$

†NS - No sample

Table 8.3-9 Mean Weekly Concentrations and W Ratios of Striped Bass Yolk-Sac Larvae, Bowline Point, 1975*

	Day (0600-2059)				Night (2100-0559)			
Week of	Plant	Pond	Upper River	Lower River	Plant	Pond	Upper River	Lower River
May 11-17	NS	0.0	0.0	0.0	NS	0.0	0.0	2.5
May 18-24	NS	0.0	9.7	43.5	NS	4.0	33.5	10.2
May 25-31	NS	28.0	44.0	174.2	NS	37.0	330.0	258.7
Jun 1-7	2.2	1.5	4.3	19.1	3.7	3.0	102.2	14.1
Jun 8-14	0.0	2.0	37.3	37.3	0.0	7.0	0.0	0.0
Jun 15-21	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0
Jun 22-28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
Jun 29-Jul 5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean	-	3.94	11.91	34.38	-	6.38	58.21	35.94
	w_U = 3.94/11.91 =			0.33	w_U = 6.38/58.21 =			0.11
	w_L = 3.94/34.38 =			0.11	w_L = 6.38/35.94 =			0.18

*Number of organisms $m^{-3} \times 10^3$

Table 8.3-10 Mean Weekly Concentrations and w Rations of Striped Bass Post Yolk-Sac Larvae, Bowline Point, 1975*

	Day (0600-2059)			Night (2100-0559)		
Week Of	Plant	Upper River	Lower River	Plant	Upper River	Lower River
May 18-24	NS †	0.0 **	0.0 **	NS †	0.0 **	0.0 **
May 25-31	NS †	0.0 **	9.3 **	NS †	46.5 **	0.3 **
Jun 1-7	5.4	59.3	489.0	5.5	350.8	280.6
Jun 8-14	80.0	102.7	333.2	60.8	91.0	235.5
Jun 15-21	11.3	18.0	45.7	66.9	25.1	48.8
Jun 22-28	0.0	0.0	0.0	6.6	2.5	2.5
Jun 29-Jul 5	0.0	0.0	0.8	0.0	0.0	0.0
Jul 6-12	0.0	0.0	0.0	0.0	0.0	0.0
Jul 13-19	0.0	2.0	0.0	0.0	0.0	0.0
Jul 20-26	0.0	0.0	0.0	0.0	0.0	0.0
Mean	12.09	22.75	108.59	17.48	58.68	70.93

$w_U = 12.09/22.75 =$ 0.53 $w_U = 17.48/58.68 =$ 0.30

$w_L = 12.09/108.59 =$ 0.11 $w_L = 17.48/70.93 =$ 0.25

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* Number of organism $m^{-3} \times 10^3$

** Not included in the calculation of mean since plant data is not available

† NS - No sample

Table 8.3-11 Mean Weekly Concentrations and w Ratios of Striped Bass Juvenile I Stage, Bowline Point, 1975 *

	Day (0600-2059)			Night (2100-0559)		
Week Of	Plant	Upper River	Lower River	Plant	Upper River	Lower River
Jun 22-28	0.0	0.0	0.0	0.0	0.0	0.0
Jun 29-Jul 5	0.0	0.0	0.0	0.0	0.0	4.3
Jul 6-12	0.0	0.0	0.0	0.0	0.0	0.0
Jul 13-19	0.0	0.0	0.0	0.0	0.0	0.0
Jul 20-26	0.0	0.0	2.0	0.0	0.0	2.0
Jul 27-Aug 2	0.0	0.0	0.0	0.0	0.0	0.8
Aug 3-9	0.0	0.0	0.0	0.0	2.0	2.0
Aug 10-16	0.0	0.0	0.0	0.0	0.0	0.0
Mean	0.0	0.0	0.25	0.00	0.25	1.14

w_U = 0.00/0.00 = 0.00 w_U = 0.00/0.25 = 0.00

w_L = 0.00/0.25 = 0.00 w_L = 0.00/1.14 = 0.00

*Number of organisms $m^{-3}x10^3$

Net sampling during the 1975 entrainment sampling season yielded no juveniles at the Bowline intake. Also, despite the pumps' high sampling efficiency, a total of only five juveniles were collected. This indicates that few entrainable striped bass juveniles were present in the Bowline region, suggesting that a w ratio of nearly 0 for juveniles (Table 8.3-11) reflected the condition at Bowline during 1975.

During 1974, both plant and river samples were collected. While the plant intake samples were collected once per week during the period of striped bass larval abundance, river samples from all three transects were collected once every 2 wk; however, plant abundance data collected during weeks when no river samples were taken were excluded from the calculation of w ratios in order to avoid biasing estimates of mean plant abundances relative to mean river abundances. The mean plant and river abundances as well as the w ratios for eggs, yolk-sac larvae, and post yolk-sac larvae for 1974 are shown in Tables 8.3-12 through 8.3-14.

Striped bass juvenile collections during 1974 were sporadic. The limited number from either plant or river stations did not permit meaningful evaluation of w ratios; therefore, the w ratio was set equal to unity for the juvenile stage. This was probably a conservative value.

As noted in Table 8.3-12, the eggs collected during 1974 were not identified to species; consequently, all eggs were used in the calculations, which was a conservative approach since striped bass eggs may have accounted for only a small percentage of the total and since the Bowline region has been observed to be on the fringe of the striped bass spawning grounds in the Hudson River. Furthermore, the tendency of striped bass eggs to sink to the bottom in quiet water would limit the likelihood of their being transported into Bowline Pond and subsequently drawn into the plant.

8.3.1.3 Roseton w Ratio. Calculations for striped bass eggs, yolk-sac larvae, and the juvenile I stage for Roseton, based on the data collected

Table 8.3-12 Mean Weekly Concentrations and w Ratios of Striped Bass Eggs, Bowline Point, 1974*

Week Of	Day (0600-2059) Plant**	Day (0600-2059) Upper River	Day (0600-2059) Lower River	Night (2100-0559) Plant**	Night (2100-0559) Upper River	Night (2100-0559) Lower River
Apr 28-May 4	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
May 5-11	NS‡	0.00†	0.00†	NS‡	0.00†	0.00†
May 12-18	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
May 19-25	0.59	204.86	128.56	NS‡	35.20†	21.50†
May 26-Jun 1	1.09†	NS‡	NS‡	0.00†	NS‡	NS‡
Jun 2-8	0.34	0.00	9.10	0.00	16.83	0.00
Jun 9-15	1.32†	NS‡	NS‡	0.00†	NS‡	NS‡
Jun 16-22	0.00	1.67	3.00	0.00	29.00	0.00
Mean	0.31	68.84	46.89	0.00	22.92	0.00
	w_U = 0.31/68.84 =		0.00	w_U = 0.00/22.92 =		0.00
	w_L = 0.31/46.89 =		0.00	w_L = 0.00/ 0.00 =		0.00

*Number of organisms $m^{-3} \times 10^3$.

**Intake data

†Not included in the calculation of mean

‡NS - No sample

Table 8.3-13 Mean Weekly Concentrations and w Ratios of Striped Bass Yolk-Sac Larvae, Bowline Point, 1974*

	Day (0600-2059)			Night (2100-0559)		
Week of	Plant**	Upper River	Lower River	Plant**	Upper River	Lower River
May 5-11	0.00	0.00	0.00	0.00	0.00	0.00
May 12-18	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
May 19-25	0.88	31.73	33.26	NS‡	50.43†	30.06†
May 26-Jun 1	0.84†	NS‡	NS‡	1.32†	NS‡	NS‡
Jun 2-8	3.10	27.08	76.76	6.39	145.25	156.10
Jun 9-15	2.54†	NS‡	NS‡	1.68†	NS‡	NS‡
Jun 16-22	1.05	5.99	23.46	2.01	11.94	11.84
Jun 23-29	8.96	60.07	10.28	9.19†	NS‡	NS‡
Mean	2.80	24.97	28.75	2.80	52.40	55.98

Day		Night	
w_U = 2.80/24.97 =	0.11	w_U = 2.80/52.40 =	0.05
w_L = 2.80/28.75 =	0.10	w_L = 2.80/55.98 =	0.05

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*Number of organisms $m^{-3} \times 10^{3}$

**Intake data only; limited discharge sampling started on 5 June when yolk-sac abundance was nearly over.

†Not included in the calculation of mean.

‡NS - no sample

Table 8.3-14 Mean Weekly Concentrations and w Ratios of Striped Bass Post Yolk-Sac Larvae, Bowline Point, 1974*

Week of	Day (0600-2059)			Night (2100-0559)		
	Plant**	Upper River	Lower River	Plant**	Upper River	Lower River
May 12-18	0.00 †	NS‡	NS‡	0.00 †	NS‡	NS‡
May 19-25	0.00	0.00	0.00	NS‡	0.00†	0.00†
May 26-Jun 1	0.00	0.00	0.00	0.00 †	NS‡	NS‡
Jun 2-8	0.41	8.47	22.15	1.00	43.63	44.64
Jun 9-15	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Jun 16-22	0.35	5.19	36.93	2.89	21.62	20.23
Jun 23-29	5.41	29.19	15.65	14.32	NS‡	NS‡
Jun 30-Jul 6	8.73	1.14	6.05	3.80	5.40	5.63
Jul 7-13	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Jul 14-20	0.00	0.00	0.00	0.00	0.00	0.00
Jul 21-27	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Mean	2.13	6.28	11.54	1.92	17.66	17.63

w_U = 2.13/ 6.28 = 0.34 w_U = 1.92/17.66 = 0.11

w_L = 2.13/11.54 = 0.18 w_L = 1.92/17.63 = 0.11

* Number of organisms $m^{-3} \times 10^3$

** Intake data only

† Not included in the calculation of mean

‡ NS - no sample

during 1974 and 1975, appear in Tables 8.3-15 through 8.3-22. During both years, river samples were collected in the Roseton vicinity along three longitudinal transects between RM 65 and 66 designated Roseton/Danskammer West (RDW), Roseton/Danskammer Channel (RDC), and Roseton/Danskammer East (RDE).

The 1975 river samples normally were taken from all three transects once each week during May and June and once each month thereafter. The plant samples were taken at the intake nearly twice each week during May and June and once each week during July and August. Calculations of mean abundances in the river in upper and lower layers followed the same procedures used at Bowline. For plant abundances, weekly mean abundances were determined by averaging the mean abundances for each sampling date. River samplings were normally scheduled to coincide with a plant sampling although the plant was sampled nearly twice as frequently. To compare plant abundances with river abundances, weekly mean abundances for plant and river upper and lower layers were calculated. However, beginning in early July, there were some weeks when plant samples were not matched with coincident river samples; therefore, the plant abundances for these weeks were not included in the analysis in order to avoid biasing estimates of mean seasonal abundance for either plant or river and thereby the calculation of w ratios (Tables 8.3-16 through 8.3-18). Since no juveniles were caught at the plant during 1975, the w ratios were 0.

During 1974, all three river transects were samples once every 2 wk until August, when the sampling frequency changed to once per month. Samples were collected at the Roseton intake once each week, and river samples normally coincided with plant collections. Consistent with the procedures just described, the analysis of the w ratios excluded sampling dates when both river and plant samples were not taken (Tables 8.3-19 through 8.3-22).

Table 8.3-15 Mean Weekly Concentrations and w Ratios of Striped Bass Eggs, Roseton, 1975*

	Day (0600-2059)			Night (2100-0559)		
Week of	Plant**	Upper River	Lower River	Plant**	Upper River	Lower River
May 11-17	0.0	0.0	0.0	0.0	0.0	0.0
May 18-24	16.9	0.0	29.3	0.0	0.0	4.0
May 25-31	1.5	1.0	0.0	0.0	0.0	0.0
Jun 1-7	0.0	0.0	0.0	0.0	0.0	0.0
Jun 8-14	0.0	0.0	0.0	0.0	0.0	0.0
Jun 15-21	0.0	0.0	0.0	0.0	0.0	0.0
Jun 22-28	0.0	0.0	0.0	0.0	0.0	0.0
Mean	2.62	0.14	4.19	0.00	0.00	0.57
	w_U = 2.62/ 0.14 =		18.71	w_U =	0.00/ 0.00	0.00
	w_L = 2.62/ 4.19 =		0.63	w_L =	0.00/ 0.57	0.00

* Number of organisms $m^{-3} \times 10^3$

** Intake data

Table 8.3-16 Mean Weekly Concentrations and w Ratios of Striped Bass Yolk-Sac Larvae, Roseton, 1975*

	Day (0600-2059)			Night (2100-0559)		
Week of	Plant**	Upper River	Lower River	Plant**	Upper River	Lower River
May 11-17	1.33	0.00	0.00	17.33	0.00	5.30
May 18-24	6.61	3.70	67.80	12.17	32.40	17.30
May 25-31	3.83	20.20	53.70	0.00	144.10	219.40
Jun 1-7	55.23	1.18	25.03	106.83	11.51	19.13
Jun 8-14	0.00	0.00	0.00	0.00	0.00	0.00
Jun 15-21	0.00	0.00	0.00	0.00	0.00	0.00
Jun 22-28	0.00	0.00	0.00	0.00	0.00	0.00
Jun 29-Jul 5	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Mean	9.57	3.58	20.93	19.48	26.86	37.30

w_U = 9.57/3.58 = 2.67

w_L = 9.57/3.58 = 0.46

w_U = 19.48/26.86 = 0.73

w_L = 19.48/37.30 = 0.52

* Number of organisms $m^{-3} \times 10^3$

** Intake data

† Not included in calculation of mean

‡ NS- no sample

Table 8.3-17 Mean Weekly Concentrations and w Ratios of Striped Bass Post Yolk-Sac Larvae, Roseton, 1975*

	Day (0600-2059)			Night (2100-0559)		
Week of	Plant**	Upper River	Lower River	Plant**	Upper River	Lower River
May 18-24	0.00	7.60	0.00	0.00	1.55	9.90
May 25-31	1.17	6.00	28.70	2.33	4.20	31.40
Jun 1-7	280.46	41.65	163.73	228.02	652.49	434.87
Jun 8-14	188.11	38.50	197.80	285.50	325.00	693.00
Jun 15-21	4.00	0.70	4.20	0.00	0.70	7.70
Jun 22-28	0.00	2.00	9.20	0.00	14.10	3.50
Jun 29-Jul 5	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Jul 6-12	0.00†	NS‡	NS‡	2.00†	NS‡	NS‡
Jul 13-19	1.67	0.00	0.00	0.00	1.80	1.50
Jul 20-26	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Mean	67.92	13.78	57.66	73.69	142.83	168.84

w_U = 67.92/13.78 = 4.93 w_U = 73.69/142.83 = 0.52

w_L = 67.92/57.66 = 1.18 w_L = 73.69/168.84 = 0.44

* Number of organisms m^{-3} x 10^{3}
** Intake data
† Not included in calculation of mean
‡ NS-no sample

Table 8.3-18 Mean Weekly Concentrations and w Ratios of Striped Bass Juvenile I Stage, Roseton, 1975*

	Day (0600-2059)			Night (2100-0559)		
Week of	Plant**	Upper River	Lower River	Plant**	Upper River	Lower River
Jun 22-28	0.00	0.00	0.00	0.00	0.00	0.00
Jun 29-Jul 5	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Jul 6-12	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Jul 13-19	0.00	0.00	0.00	0.00	0.00	0.00
Jul 20-26	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Jul 27-Aug 2	0.00	0.00	0.00	0.00	0.00	0.00
Aug 3-9	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Aug 10-16	0.00	0.00	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00	0.00	0.00
	w_U = 0.00/0.00		0.00	w_U = 0.00/0.00 =		0.00
	w_L = 0.00/0.00 =		0.00	w_L = 0.00/0.00 =		0.00

* Number of organisms $m^{-3} \times 10^3$

**Intake data

† Not included in calculation of mean

‡ NS-no sample

Table 8.3-19 Mean Weekly Concentrations and w Ratios of Striped Bass Eggs, Roseton, 1974*

	Day (0600-2059)			Night (2100-0559)		
Week of	Plant**	Upper River	Lower River	Plant**	Upper River	Lower River
Apr 28-May 4	NS‡	NS‡	NS‡	NS‡	NS‡	NS‡
May 5-11	0.00	0.00	0.00	39.22	40.83	81.44
May 12-18	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
May 19-25	0.00	14.60	0.13	0.00	3.76	0.00
May 26-Jun 1	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Jun 2-8	0.00	1.87	1.95	0.00	0.00	0.00
Jun 9-15	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Jun 16-22	0.00	0.00	0.00	0.00	0.00	0.00
Mean	0.00	4.12	0.52	9.81	11.15	20.36
	w_U = 0.00/4.12 =		0.00	w_U = 9.81/11.15 =		0.88
	w_L = 0.00/0.52 =		0.00	w_L = 9.81/20.36 =		0.48

* Number of organisms $m^{-3} \times 10^{3}$

** Intake data only; outliers excluded

† Not included in calculation of mean

‡ NS-no sample

Table 8.3-20 Mean Weekly Concentrations and w Ratios of Striped Bass Yolk-Sac Larvae, Roseton, 1974*

	Day (0600-2059)			Night (2100-0559)		
Week of	Plant**	Upper River	Lower River	Plant**	Upper River	Lower River
May 5-11	0.00	0.32	0.59	0.00	1.12	0.78
May 12-18	7.98†	NS‡	NS‡	20.83†	NS‡	NS‡
May 19-25	0.00	5.63	4.28	0.00	5.32	6.10
May 26-Jun 1	16.95†	NS‡	NS‡	5.01†	NS‡	NS‡
Jun 2-8	9.03	40.80	42.81	73.69	66.14	128.93
Jun 9-15	172.58†	NS‡	NS‡	0.00†	NS‡	NS‡
Jun 16-22	0.00	67.00	62.90	0.00	51.59	53.94
Jun 23-29	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Mean	2.26	28.44	27.65	18.42	31.05	47.44
	w_U = 2.26/28.44 =		0.08	w_U = 18.42/31.05 =		0.59
	w_L = 2.26/27.65 =		0.08	w_L = 18.42/47.44 =		0.39

* Number of organisms $m^{-3} \times 10^3$
** Intake data only; outliers excluded
† Not included in calculation of mean
‡ NS-no sample

Table 8.3-21 Mean Weekly Concentrations and w Ratis of Striped Bass Post Yolk-Sac Larvae, Roseton, 1974*

Week of	Day (0600-2059)			Night (2100-0559)		
	Plant**	Upper River	Lower River	**Plant	Upper River	Lower River
May 12-18	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
May 19-25	0.00	0.00	0.00	0.00	0.00	0.00
May 26-Jun 1	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Jun 2-8	0.00	2.01	1.95	0.00	33.06	26.52
Jun 9-15	29.76†	NS‡	NS‡	0.00†	NS‡	NS‡
Jun 16-22	0.00	14.26	39.77	0.00	114.99	137.04
Jun 23-29	0.00†	NS‡	NS‡	11.57†	NS‡	NS‡
Jun 30-Jul 6	0.00	0.97	3.44	15.29	3.21	2.91
Jul 7-13	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Jul 14-20	0.00	0.00	0.45	9.92	1.42	1.18
Jul 21-27	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Mean	0.00	3.45	9.12	5.04	30.54	33.53
	w_U = 0.00/3.45	=	0.00	w_U = 5.04/30.54 =		0.17
	w_L = 0.00/9.12	=	0.00	w_L = 5.04/33.53 =		0.15

* Number of organisms $m^{-3} \times 10^3$

**Intake data only; outliers excluded

† Not included in the calculation of mean

‡ NS - No sample

Table 8.3-22 Mean Weekly Concentrations and w Ratios of Striped Bass Juvenile I Stage, Roseton, 1974*

	Day (0600-2059)			Night (2100-0559)		
Week of	Plant	Upper River	Lower River	Plant	Upper River	Lower River
Jun 9-15	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Jun 16-22	0.00	0.00	0.00	0.00	1.91	2.03
Jun 23-29	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Jun 30-Jul 6	0.00	0.00	0.00	2.46	0.17	1.01
Jul 7-13	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Jul 14-20	0.00	0.00	0.00	0.00	0.08	0.31
Jul 21-27	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Jul 28-Aug 3	0.00	0.00	0.00	0.00	0.00	0.00
Aug 4-10	0.00†	NS‡	NS‡	0.00†	NS‡	NS‡
Aug 11-17	NS‡	NS‡	NS‡	NS‡	NS‡	NS‡
Mean	0.00	0.00	0.00	0.62	0.54	0.84
	w_U = 0.00/0.00 =		0.00	w_U = 0.62/0.54 =		1.15
	w_L = 0.00/0.00 =		0.00	w_L = 0.62/0.84 =		0.74

* Number of organisms $m^{-3} \times 10^3$

† Not included in calculation of mean

‡ NS-no sample

The volume of water strained through the sampling nets was estimated with TSK flowmeters, but there was some malfunctioning of the flowmeters at the intake. Thus, samples for which meter readings were obviously erroneous (either lower or higher than the expected flow velocity) were considered as outlying samples and were excluded from calculations of plant abundances.

8.3.2 PLANT ENTRAINMENT MORTALITY (f_c).

Mortality of live striped bass ichthyoplankton entrained through a plant's cooling water system may occur in two ways: instantaneous death during transit through the cooling-water system (initial mortality) and injury or weakening, manifested by an increase in death rate after initial survival of entrainment (latent mortality).

The estimation of these mortalities was based on observations of organisms collected at the intakes and discharges of the plants during plant operations. The entrainment - induced mortality can be derived from the following probability terms:

$P(A)$ = probability of surviving entrainment
$P(B)$ = probability of surviving collecting and handling
$P(A \cap B)$ = probability of surviving entrainment, and collecting and handling
$P(B|A)$ = probability of surviving collecting and handling given survival of entrainment

Entrainment-induced mortality f_c^* is:

$$f_c^* = 1 - P(A) \tag{8.7}$$

This quantity cannot be estimated directly. Thus, the following quantity is used as an estimate of f_c^*:

$$f_c = 1 - \frac{P(A \cap B)}{P(B)} \tag{8.8}$$

The quantity $P(A \cap B)$ can be estimated as the proportion of organisms surviving in the sample taken at the discharge. $P(B)$ can be estimated as the proportion of organisms surviving in the intake sample.

If collecting and handling survival is independent of entrainment survival, then:

$$P(A \cap B) = P(A) \cdot P(B) \qquad (8.9)$$

and Equation 8.8 becomes equivalent to Equation 8.7, i.e., $f_c = f_c^*$.

Under general conditions, f_c is a conservative measure of entrainment mortality when:

$$f_c \geqq f_c^*$$

That is,

$$1 - \frac{P(A \cap B)}{P(B)} \geqq [1 - P(A)] \qquad (8.10)$$

Equation 8.10 reduces to:

$$\frac{P(A) \cdot P(B|A)}{P(B)} \leqq P(A) \qquad (8.11)$$

$$P(B|A) \leqq P(B)$$

In other words, f_c is a conservative measure if entrained organisms are no more likely to survive collecting and handling than are nonentrained organisms.

During observation for latent effects, both intake and discharge samples were treated similarly so that there would be no differences in collecting and handling mortality, thus any differences in latent mortality between the intake and discharge samples were assumed to be the latent effect of entrainment. Combining initial and latent effects, the overall proportions of survival for both intake and discharge samples could be estimated by the product of initial and latent survival proportions, i.e.,

$$f_c = 1 - (I_d \cdot L_d / I_i \cdot L_i) \qquad (8.12)$$

where

I_d, L_d = initial and latent survival proportions respectively for discharge sample

I_i, L_i = initial and latent survival proportions respectively for intake sample

During 1974, New York University carried out entrainment viability studies at Indian Point (NYU 1976b) by collecting organisms with plankton nets fitted with velocity-reducing cones. In 1975 Ecological Analysts, Inc., conducted similar studies (EAI 1976a) at Bowline and Roseton using a larval table developed and designed by LMS. The results of the NYU and EAI studies were used to compute f_c for the various early life stages of striped bass. Statistical analysis of the data collected from these studies indicated that null hypothesis stating there are no differences in latent mortalities between the organisms collected at the intake and at the discharge could not be rejected at the 5% significance level. Thus, Equation (8.12) can be reduced to:

$$f_c = 1 - (I_d / I_i) \qquad (8.13)$$

Based on Equation 8.13 and the data shown in Table 8.3-23, f_c factors were calculated for the various life stages at Indian Point, Bowline, and Roseton and are presented in Table 8.3-24.

Table 8.3-23 Numbers of Striped Bass Collected During Entrainment Survival Studies

Plant	Life Stage*	Intake Live	Intake Stun	Intake Dead	Intake Total	Discharge Live	Discharge Stun	Discharge Dead	Discharge Total
Indian Point**	E	498	-	470	968	59	‡	168	227
	Y	15	54	127	196	0	2	37	39
	L	141	243	270	654	25	40	338	403
	J	25	0	0	25	6	10	3	19
Bowline†	E	0	‡	0	0	0	-	0	0
	Y	2	0	0	2	0	0	0	0
	L	70	44	27	141	55	27	29	111
	J	0	0	0	0	NAǂ	NA	NA	3
Roseton†	E	0	‡	2	2	0	‡	0	0
	Y	3	1	1	5	3	0	13	16
	L	49	33	18	100	56	50	66	172
	J	4	0	3	7	2	1	0	3

* E = egg; Y = yolk-sac larvae; L = post yolk-sac larvae; J = juveniles.

** Collected by New York University during 1974. Intake consists of stations I-1, I-2, and II-2; discharge consists of stations D-1 and D-2.

† Collected by Ecological Analysts, Inc., during 1975.

‡ Not applicable

ǂ NA - not available

Table 8.3-24 f_c for Selected Life Stages of Striped Bass

Life Stage	Indian Point*	Bowline†	Roseton†
Eggs	0.49	0.49**	0.49**
Yolk-sac larvae	0.85	0.77***	0.77
Post yolk-sac larvae	0.51	0.09	0.25
Juvenile I	0.16	0.16**	0.16**

* Based on New York University 1974 study at Indian Point.

† Based on Ecological Analysts Inc. 1975 study, unless otherwise specified.

** Indian Point value assumed to apply because data for Bowline and Roseton were limited.

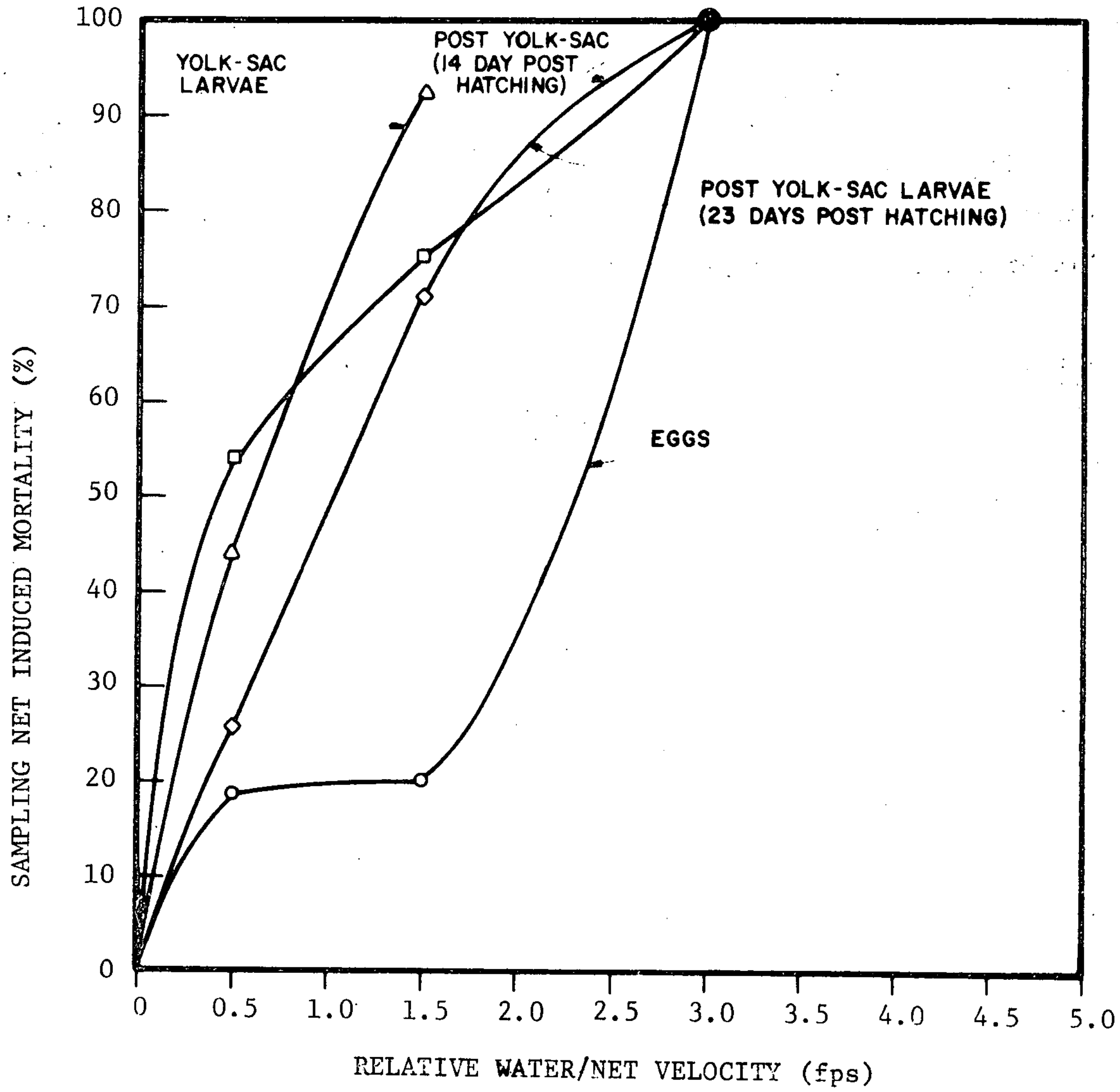
*** Roseton value assumed to apply because of limited data.

In calculating the initial survival proportions, the organisms classified as "stunned" were considered to be live. This approach is consistent with United States Nuclear Regulatory Commission staff statements (NRC 1975:V-88). Although stunned organisms had a significantly higher death rate than did nonstunned organisms, their higher mortality rate could not be identified as being attributable to the effect of entrainment since no significant difference could be detected between the death rates of the stunned organisms collected at the intake and those collected at the discharge. Furthermore, except for the juvenile stage at Indian Point, the stunned organisms accounted for a higher percentage of the total collected at the intake than at the discharge.

Since plankton nets were used at Indian Point during 1974 to collect organisms for viability studies, velocity differences between the intake and discharge influenced the sampling mortality at the two stations. NYU's 1975 flume studies (NYU 1976b) exposed striped bass ichthyoplankton to nets at known velocities for predetermined periods of time, and demonstrated (Fig. 8.3-3) that water velocity and life stage strongly affected initial survival. Velocity studies with electromagnetic flowmeters (NYU personal communication) at the intake and discharge of Indian Point Unit 2 in December 1975 indicated that average velocities in the intake and discharge were approximately 0.67 and 1.45 ft sec^{-1} (0.20 and 0.44 m sec^{-1}) respectively during the 1974 entrainment period when the viability samples were collected. Although the sampling nets were fitted with velocity-reduction cones, the NYU flume studies indicated that these devices were not effective in reducing velocities in the nets; hence, in attempting to develop a quantitative correction for the effects of differential velocities in the intake and discharge, the average velocities (0.67 and 1.45 ft sec^{-1} [0.20 and 0.44 m sec^{-1}]) were used.

As shown in Figure 8.3-3, egg mortality due to the sampling nets did not change markedly between 0.67 and 1.45 ft sec^{-1} (0.20 and 0.44 m sec^{-1}).

Figure 8.3-3 Immediate Plankton Net Sampling Mortality of Striped Bass Ichthyoplankton at Various Water Velocities (NYU 1976b)



Consequently, f_c for the egg stage was not corrected for possible differential sampling mortality. The f_c computed for the yolk-sac larval stage (0.85) under the assumption of equivalent sampling mortality at the intake and discharge was close to the f_c for the yolk-sac stage (0.77) determined for Roseton by EAI using the larval tables. Although the results of the flume study suggested that there was considerable difference between sampling mortality associated with nets in the intake and discharge at Indian Point, the f_c factor was not modified to account for differential sampling mortality. This was probably a conservative approach. Future studies with the larval table may provide more complete data indicating higher survivals at Bowline and Roseton.

The f_c for the post yolk-sac larval stage at Indian Point computed from the 1974 data without any correction for differential sampling mortality was 0.73. The larval table results for the post yolk-sac larvae stage at Bowline and Roseton indicated an f_c of 0.09 and 0.25 respectively. The flume study suggested that differential sampling mortality due to the velocity difference between the intake and discharge may have accounted in part for the considerably higher uncorrected value at Indian Point. When results from the flume study for post yolk-sac larva at 14 days post hatching and at 23 days post hatching were averaged, the sampling mortality was 46% at 0.67 ft sec^{-1} (0.20 m sec^{-1}) and 72% at 1.45 ft sec^{-1} (0.44 m sec^{-1}). Using these values, the corrected value for the post yolk-sac f_c at Indian Point was 0.48. The equation used to obtain the corrected f_c is:

$$f_c = 1 - [I_d\ (1 - M_i)/I_i\ (1 - M_d)] \qquad (8.14)$$

where M_i and M_d were net-induced mortalities for intake and discharge samples respectively. In the model runs presented in Section 12 and in the calculation of composite f factors presented in Section 8.3.5, an f_c value of 0.51 based on preliminary analysis of the data from the flume study was used. In view of the 0.48 f_c value resulting from the more detailed analysis presented above, the 0.51 value used in the model runs is conservative.

At Bowline, sample sizes adequate for evaluating and interpreting entrainment mortality were obtained only for the post yolk-sac larval stage. Also, sample sizes for egg and juvenile stages at Roseton, which has nearly the same pumping capacity and operating conditions as Bowline, were inadequate. Thus, f_c for the egg and juvenile stages at Indian Point were assumed for Bowline and Roseton. For the yolk-sac larval stage, the f_c value determined at Bowline was assumed to be equal to the value at Roseton.

8.3.3 NEARFIELD DEPLETION AND RECIRCULATION FACTOR (f_3). Recirculation of plant cooling water may protect some organisms from entrainment since it results in re-entrainment of a water mass containing organisms already killed by the plant in the place of a water mass containing a fresh supply of live organisms. For the case of total organism mortality on the first pass through the circulating cooling-water system, it unquestionably reduces entrainment impact. When mortality is <100% on the first pass, recirculation increases the probability that a given organism will be exposed to potentially destructive stresses.

When the plant withdraws its cooling water from the river, the organisms depleted from the zone near the intake may not be immediately replenished by the population nearby. In addition, because of the physical geometry near the plant and the tidal action, part of the cooling-water discharge can be recirculated back into the intake. The f_3 factor is introduced here to represent both the long-term population drawdown effects and recirculation.

Assuming steady-state conditions with no buildup or accumulation of organisms within the circulating water system, LMS developed an equation that determined the f_3 factor at specified levels of recirculation and entrainment mortality (Section 8.3.2). The equation is expressed as follows:

$$f_3 = (1 - R)/[1 - R (1 - f_c)]$$

where

R = recirculation ratio, i.e., fraction of water entering plant that is recirculated

f_c = entrainment mortality factor

Using entrainment mortality factors obtained in Section 8.3.2, the recirculation values obtained in the LaSalle hydraulic model studies in the Indian Point area (LaSalle-682 1976), and the LMS mathematical model studies of the Roseton area (LMS 1975f), f_3 factors were calculated for various life stages at Indian Point and Roseton. The results are shown below:

	Indian Point		Roseton	
	f_c	f_3(R=7%)	f_c	f_3(R=22%)
Eggs	0.49	0.96	0.49	0.88
Yolk-sac larvae	0.85	0.94	0.77	0.82
Post yolk-sac larvae	0.51	0.96	0.25	0.93
Juvenile I stage	0.16	0.99	0.16	0.96

Studies by Ecological Analysts, Inc (1976) in the Bowline plant area indicated that an average of about 13% of the discharge would be recirculated. However, due to the preliminary nature of the data, they were not used to calculate the f_3 factor for Bowline; instead, the conservative value of unity was used.

8.3.4 FRACTIONAL WATER-COLUMN WITHDRAWAL (f_q). In the real-time model, the fraction of intake water from the upper layer (f_{qU}) and the lower layer (f_{qL}) of the water column must be specified.

Hydraulic model studies of the Indian Point area by LaSalle Hydraulic Laboratory (LaSalle-682 1976) indicated that slightly more water was drawn from the upper layer than from the lower layer; a similar hydraulic model study for the proposed Cornwall pumped-storage facility (LaSalle-667 1976) produced similar results. The results of the LaSalle studies indicated that values of 0.57 and 0.43 for f_{qU} and f_{qL}, respectively should be used for Indian Point.

Hydraulic model studies to determine f_q have not been performed for the Bowline and Roseton plants. Based on preliminary mathematical studies of intake velocities at the Roseton plant, the values of f_{qU} and f_{qL} determined for Indian Point were used for Roseton. The cooling water for the Bowline plant is withdrawn from a pond directly in front of the plant intake. The existing inlet to Bowline Pond is approximately 200 ft (61 m) wide and has a substantial ridge that shoals up to about 10 ft (3 m) at mean low water. While these dimensions may restrict the flow of river water into and out of the pond significant velocities near the river bottom as a result of plant withdrawl can be expected. Consequently, the Indian Point values for f_{qU} and f_{qL} were assumed for Bowline also.

8.3.5 SUMMARY OF DISTRIBUTIONAL AND SURVIVAL PARAMETERS. Tables 8.3-25 and 8.3-26 summarize the various distributional and survival factors for Indian Point based on the data collected during 1975 and 1974. The values in column "$w.f_3.f_c.f_q$" are inputs to the real-time model for plant-impact prediction runs (Section 12.2). Similar summaries for Bowline and Roseton are shown in Tables 8.3-27 through 8.3-30.

The composite f factors presented in these summary tables are calculated by appropriate weighting of the day/night values (15/24 for day and 9/24 for night) and applying the f_{qU} and f_{qL} factors to combine the values for the upper and lower layers. The composite f factors are presented here to permit comparison with the f factors presented in previous studies (JPL 1972; Con Ed 1975c).

Table 8.3-25 Summary of Distributional and Survival Parameters for Striped Bass, Indian Point Vicinity, 1975

Life Stage	Layer	Time	w	f_3*	f_c**	f_q***	$w.f_3.f_c.f_q$	Composite f
Eggs	Upper	Day	0.36†	0.96	0.49	0.57	0.10	0.49
		Night	3.35	0.96	0.49	0.57	0.90	
	Lower	Day	0.20†	0.96	0.49	0.43	0.04	
		Night	0.82	0.96	0.49	0.43	0.17	
Yolk-sac Larvae	Upper	Day	0.91†	0.94	0.85	0.57	0.41	0.32
		Night	0.09	0.94	0.85	0.57	0.04	
	Lower	Day	0.16†	0.94	0.85	0.43	0.05	
		Night	0.12	0.94	0.85	0.43	0.04	
Post Yolk-sac Larvae	Upper	Day	0.57†	0.96	0.51	0.57	0.16	0.16
		Night	0.19	0.96	0.51	0.57	0.05	
	Lower	Day	0.25†	0.96	0.51	0.43	0.05	
		Night	0.14	0.96	0.51	0.43	0.03	
Juvenile I	Upper	Day	1.00‡	0.99	0.16	0.57	0.09	0.16
		Night	1.00‡	0.99	0.16	0.57	0.09	
	Lower	Day	1.00‡	0.99	0.16	0.43	0.07	
		Night	1.00‡	0.99	0.16	0.43	0.07	

$$\text{Composite } f = 0.625\,(w_U \cdot f_{3U} \cdot f_c \cdot f_{qU} + w_L \cdot f_{3L} \cdot f_c \cdot f_{qL}) \quad \text{Day}$$

$$+\ 0.375\,(w_U \cdot f_{3U} \cdot f_c \cdot f_{qU} + w_L \cdot f_{3L} \cdot f_c \cdot f_{qL}) \quad \text{Night}$$

* Based on tidally averaged recirculation of 7%.

**Based on NYU's 1974 study at Indian Point.

***Evaluated from LaSalle Hydraulic Laboratory's study.

† Based on assumption that plant concentration equals near-field concentration.

‡ Assumed because of limited data.

Table 8.3-26 Summary of Distributional and Survival Parameters for Striped bass, Indian Point Vicinity, 1974

Life Stage	Layer	Time	w	f_3*	f_c**	f_q***	$w.f_3.f_c.f_q$	Composite f
Eggs	Upper	Day	0.87†	0.96	0.49	0.57	0.23	1.00
		Night	7.17	0.96	0.49	0.57	1.92	
	Lower	Day	0.21†	0.96	0.49	0.43	0.04	
		Night	1.50	0.96	0.49	0.43	0.30	
Yolk-sac Larvae	Upper	Day	0.92†	0.94	0.85	0.57	0.42	0.44
		Night	0.39	0.94	0.85	0.57	0.18	
	Lower	Day	0.32†	0.94	0.85	0.43	0.11	
		Night	0.28	0.94	0.85	0.43	0.10	
Post Yolk-sac Larvae	Upper	Day	0.45†	0.96	0.51	0.57	0.13	0.22
		Night	0.56	0.96	0.51	0.57	0.16	
	Lower	Day	0.19†	0.96	0.51	0.43	0.04	
		Night	0.72	0.96	0.51	0.43	0.15	
Juvenile I	Upper	Day	1.00‡	0.99	0.16	0.57	0.09	0.16
		Night	1.00‡	0.99	0.16	0.57	0.09	
	Lower	Day	1.00‡	0.99	0.16	0.43	0.07	
		Night	1.00‡	0.99	0.16	0.43	0.07	

$$\text{Composite } f = 0.625\,(w_U \cdot f_{3U} \cdot f_c \cdot f_{qU} + w_L \cdot f_{3L} \cdot f_c \cdot f_{qL}) \quad \text{Day}$$

$$+\ 0.375\,(w_U \cdot f_{3U} \cdot f_c \cdot f_{qU} + w_L \cdot f_{3L} \cdot f_c \cdot f_{qL}) \quad \text{Night}$$

* Based on tidally averaged recirculation of 7%.

** Based on NYU's 1974 study at Indian Point.

*** Evaluated from LaSalle Hydraulic Laboratory's study.

† Based on assumption that plant concentration equals near-field concentration.

‡ Assumed because of limited data.

Table 8.3-27 Summary of Distributional and Survival Parameters for Striped Bass, Bowline Vicinity, 1975

Life Stage	Layer	Time	w	f_3^*	f_c	f_q^{**}	$w.f_3.f_c.f_q$	Composite f
Eggs	Upper	Day	0.00	1.00	0.49[†]	0.57	0.00	0.01
		Night	0.09	1.00	0.49[†]	0.57	0.03	
	Lower	Day	0.00	1.00	0.49[†]	0.43	0.00	
		Night	0.01	1.00	0.49[†]	0.43	0.00	
Yolk-sac Larvae	Upper	Day	0.33	1.00	0.77[‡]	0.57	0.14	0.15
		Night	0.11	1.00	0.77[‡]	0.57	0.05	
	Lower	Day	0.11	1.00	0.77[‡]	0.43	0.04	
		Night	0.18	1.00	0.77[‡]	0.43	0.06	
Post Yolk-sac Larvae	Upper	Day	0.53	1.00	0.09[⸸]	0.57	0.03	0.03
		Night	0.30	1.00	0.09[⸸]	0.57	0.02	
	Lower	Day	0.11	1.00	0.09[⸸]	0.43	0.00	
		Night	0.25	1.00	0.09[⸸]	0.43	0.01	
Juvenile I	Upper	Day	0.00	1.00	0.16[†]	0.57	0.00	0.00
		Night	0.00	1.00	0.16[†]	0.57	0.00	
	Lower	Day	0.00	1.00	0.16[†]	0.43	0.00	
		Night	0.00	1.00	0.16[†]	0.43	0.00	

$$\text{Composite } f = 0.625\,(w_U \cdot f_{3U} \cdot f_c \cdot f_{qU} + w_L \cdot f_{3L} \cdot f_c \cdot f_{qL})\text{ Day}$$
$$+\,0.375\,(w_U \cdot f_{3U} \cdot f_c \cdot f_{qU} + w_L \cdot f_{3L} \cdot f_c \cdot f_{qL})\text{ Night}$$

* 1.0 assumed for lack of data
** Assumed values
† Based on NYU's 1974 study at Indian Point
‡ Based on EAI's 1975 study at Roseton
⸸ Based on EAI's 1975 study at Bowline

Table 8.3-28 Summary of Distributional and Survival Parameters for Striped Bass, Bowline Vicinity, 1974

Life Stage	Layer	Time	w	f_3 **	f_c	f_q ***	$w \cdot f_3 \cdot f_c \cdot f_q$	Composite f
Eggs	Upper	Day	0.00*	1.00	0.49†	0.57	0.00	0.00
		Night	0.00*	1.00	0.49†	0.57	0.00	
	Lower	Day	0.00*	1.00	0.49†	0.43	0.00	
		Night	0.00*	1.00	0.49†	0.43	0.00	
Yolk-sac Larvae	Upper	Day	0.11	1.00	0.77‡	0.57	0.05	0.07
		Night	0.05	1.00	0.77‡	0.57	0.02	
	Lower	Day	0.10	1.00	0.77‡	0.43	0.03	
		Night	0.05	1.00	0.77‡	0.43	0.02	
Post Yolk-sac Larvae	Upper	Day	0.34	1.00	0.09ǂ	0.57	0.02	0.02
		Night	0.11	1.00	0.09ǂ	0.57	0.01	
	Lower	Day	0.18	1.00	0.09ǂ	0.43	0.01	
		Night	0.11	1.00	0.09ǂ	0.43	0.00	
Juvenile I	Upper	Day	1.00§	1.00	0.16†	0.57	0.09	0.16
		Night	1.00§	1.00	0.16†	0.57	0.09	
	Lower	Day	1.00§	1.00	0.16†	0.43	0.07	
		Night	1.00§	1.00	0.16†	0.43	0.07	

$$\text{Composite } f = 0.625\,(w_U \cdot f_{3U} \cdot f_c \cdot f_{qU} + w_L \cdot f_{3L} \cdot f_c \cdot f_{qL})\ \text{Day}$$
$$+\ 0.375\,(w_U \cdot f_{3U} \cdot f_c \cdot f_{qU} + w_L \cdot f_{3L} \cdot f_c \cdot f_{qL})\ \text{Night}$$

* Eggs of all species were used
** 1.0 assumed for lack of data
*** Assumed values
† Based on NYU's 1974 study at Indian Point
‡ Based on EAI's 1975 study at Roseton
ǂ Based on EAI's 1975 study at Bowline
§ Assumed because of limited data

Table 8.3-29 Summary of Distributional and Survival Parameters for Striped Bass, Roseton Vicinity, 1975

Life Stage	Layer	Time	w	f_3 *	f_c	f_q **	$w.f_3.f_c.f_q$	Composite f
Eggs	Upper	Day	18.71	0.88	0.49 †	0.57	4.60	2.92
		Night	0.00	0.88	0.49 †	0.57	0.00	
	Lower	Day	0.63	0.88	0.49 †	0.43	0.12	
		Night	0.00	0.88	0.49 †	0.43	0.00	
Yolk-Sac Larvae	Upper	Day	2.67	0.82	0.77 ‡	0.57	0.96	0.83
		Night	0.73	0.82	0.77 ‡	0.57	0.26	
	Lower	Day	0.46	0.82	0.77 ‡	0.43	0.12	
		Night	0.52	0.82	0.77 ‡	0.43	0.14	
Post Yolk-Sac Larvae	Upper	Day	4.93	0.93	0.25 ‡	0.57	0.65	0.52
		Night	0.52	0.93	0.25 ‡	0.57	0.07	
	Lower	Day	1.18	0.93	0.25 ‡	0.43	0.12	
		Night	0.44	0.93	0.25 ‡	0.43	0.04	
Juvenile I	Upper	Day	0.00	0.96	0.16 †	0.57	0.00	0.00
		Night	0.00	0.96	0.16 †	0.57	0.00	
	Lower	Day	0.00	0.96	0.16 †	0.43	0.00	
		Night	0.00	0.96	0.16 †	0.43	0.00	

$$\text{Composite } f = 0.625\,(w_U \cdot f_{3U} \cdot f_c \cdot f_{qU} + w_L \cdot f_{3L} \cdot f_c \cdot f_{qL})\ \text{Day}$$
$$+\ 0.375\,(w_U \cdot f_{3U} \cdot f_c \cdot f_{qU} + w_L \cdot f_{3L} \cdot f_c \cdot f_{qL})\ \text{Night}$$

* Based on a tidally averaged recirculation of 22%
** Assumed values
† Based on NYU's 1974 study at Indian Point
‡ Based on EAI's 1975 study at Roseton

Table 8.3-30 Summary of Distributional and Survival Parameters for Striped Bass, Roseton Vicinity, 1974

Life Stage	Layer	Time	w	f_3 *	f_c	f_q **	$w.f_3.f_c.f_q$	Composite f
Eggs	Upper	Day	0.00	0.88	0.49 †	0.57	0.00	0.12
		Night	0.88	0.88	0.49 †	0.57	0.22	
	Lower	Day	0.00	0.88	0.49 †	0.43	0.00	
		Night	0.48	0.88	0.49 †	0.43	0.09	
Yolk-Sac Larvae	Upper	Day	0.08	0.82	0.77 ‡	0.57	0.03	0.15
		Night	0.59	0.82	0.77 ‡	0.57	0.21	
	Lower	Day	0.08	0.82	0.77 ‡	0.43	0.02	
		Night	0.39	0.82	0.77 ‡	0.43	0.11	
Post Yolk-Sac Larvae	Upper	Day	0.00	0.93	0.25 ‡	0.57	0.00	0.01
		Night	0.17	0.93	0.25 ‡	0.57	0.02	
	Lower	Day	0.00	0.93	0.25 ‡	0.43	0.00	
		Night	0.15	0.93	0.25 ‡	0.43	0.01	
Juvenile I	Upper	Day	0.00	0.96	0.16 †	0.57	0.00	0.06
		Night	1.15	0.96	0.16 †	0.57	0.10	
	Lower	Day	0.00	0.96	0.16 †	0.43	0.00	
		Night	0.74	0.96	0.16 †	0.43	0.05	

$$\text{Composite } f = 0.625\,(w_U \cdot f_{3U} \cdot f_c \cdot f_{qU} + w_L \cdot f_{3L} \cdot f_c \cdot f_{qL})\ \text{Day}$$

$$+\ 0.375\,(w_U \cdot f_{3U} \cdot f_c \cdot f_{qU} + w_L \cdot f_{3L} \cdot f_c \cdot f_{qL})\ \text{Night}$$

* Based on a tidally averaged recirculation of 22%

** Assumed values

† Based on NYU's 1974 study at Indian Point

‡ Based on EAI's 1975 study at Roseton

8.4 ENTRAINMENT AT INDIAN POINT UNIT 2

8.4.1 COMPUTATION OF NUMBERS ENTRAINED. Striped bass ichthyoplankton entrainment rates and cumulative entrainment were estimated using ichthyoplankton concentrations measured by New York University at Unit 2 intake stations II-2 and II-5 (Fig. 8.3-1). The computational methods applied to entrainment estimates were the same as those used for Roseton (Section 8.7).

Entrainment samplings at Indian Point during 1974 and 1975, from which entrainment estimates were made, were conducted during nighttime; no samples were collected during daytime. To estimate the daytime entrainment rates, striped bass ichthyoplankton concentrations obtained by averaging daytime concentrations at the surface and mid-depth of near field river stations B, D, and G (Fig. 8.3-1) were used.

8.4.2 RESULTS. Striped bass eggs were found at the Indian Point Unit 2 intake during 1974 from the week of May 7 through the week of June 13 (Table 8.4-1). Maximum entrainment rates coincided with peak egg abundance (May 21-22) at the Unit 2 intake. Entrainment rates appeared to be higher at night than during the day. In 1974, an estimated 6,500,000 striped bass eggs were entrained between May 7 and June 18.

Striped bass larvae exhibited an interesting pattern of diurnal entrainment rates at Unit 2 during 1974. During May when yolk-sac larvae were more abundant, entrainment rates were higher during the day than at night (Table 8.4-2). As post yolk-sac larvae started to become more abundant in late May-early June, the diurnal pattern reversed; i.e., more larvae were entrained at night than during the day. This higher nighttime entraninment rate lasted until mid-June when early juveniles began to show up at Unit 2 intake. As noted in Section 7, striped bass larvae tend to concentrate near the bottom during the day at which time they may not be as susceptible to plant withdrawal as they are at night when they

Table 8.4-1 Striped Bass Eggs in Entrainment Collections, Indian Point Unit 2, 1974

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
740507	D	0	0	0
	N	1657	5	1657
740514	D	75041	364	534445
	N	0	0	6173
740521	D	498887	771	2179493
	N	356343	917	1007372
740523	D	364253	563	2543745
	N	497132	1280	1504503
740528	D	33046	43	3174701
	N	98982	213	2490212
740530	D	31374	41	3206074
	N	109982	237	2600193
740604	D	22930	35	3313905
	N	48517	124	2892614
740611	D	4907	6	3399073
	N	17067	37	3096224
740613	D	0	0	3399073
	N	5500	12	3101723
740618	D	0	0	3399073
	N	0	0	3105549
740625	D	0	0	3399073
	N	0	0	3105549
740628	D	0	0	3399073
	N	0	0	3105549
740702	D	0	0	3399073
	N	0	0	3105549
740709	D	0	0	3399073
	N	0	0	3105549
740716	D	0	0	3399073
	N	0	0	3105549
740723	D	0	0	3399073
	N	0	0	3105549
740819	D	0	0	3399073
	N	0	0	3105549

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

Table 8.4-2 Striped Bass Larvae in Entrainment Collections, Indian Point Unit 2, 1974

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
740507	D	0	0	0
	N	12116	39	12116
740514	D	1725	8	12288
	N	6021	49	88024
740521	D	337175	521	965227
	N	46193	119	237337
740523	D	285159	440	1250386
	N	130880	337	368217
740528	D	182646	236	2106826
	N	75416	163	741845
740530	D	0	0	2106826
	N	120979	261	862824
740604	D	185711	285	2605682
	N	276546	707	1783986
740611	D	124730	161	3592961
	N	346630	747	3817290
740613	D	0	0	3592961
	N	351939	758	4169229
740618	D	279779	362	4156127
	N	82485	178	4580188
740625	D	114607	194	5064491
	N	33601	95	4847377
740628	D	0	0	5064491
	N	21580	48	4868957
740702	D	299300	387	5644818
	N	24044	52	4936732
740709	D	30949	40	6431441
	N	13748	30	5038423
740716	D	0	0	6503156
	N	5757	15	5090047
740723	D	0	0	6503156
	N	0	0	5104935
740819	D	0	0	6503156
	N	0	0	5104935

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

are more uniformly dispersed throughout the water column. Thus, the higher daytime entrainment rates may have been due to the substitution of the river near field concentrations for intake concentrations. In 1974, an estimate 11,600,000 striped bass yolk-sac larvae, post yolk-sac larvae and early juveniles were entrained at Indian Point Unit 2 between May 7 and July 23.

During 1975, striped bass eggs were found at the Indian Point Unit 2 intake for a shorter period than during 1974 but were more abundant: approximately 7,200,000 were estimated to have been entrained. Maximum egg entrainment rates occurred on May 20-22 (Table 8.4-3). As in 1974 the entrainment rates (expressed in terms of number of eggs per million gallons) tended to be greater at night than during the day.

Probably due to the shorter period of egg abundance in 1975, the period of larval abundance at the Unit 2 intake also was shorter than in 1974; 9 wk in 1975 compared with 11 wk in 1974. Nevertheless, the higher larval abundances in 1975 resulted in an estimate of approximately 31,600,000 striped bass larvae entrained during 1975 (Table 8.4-4). This is nearly four times as much as the 1974 entrainment estimate. The diurnal pattern of larval entrainment rates in 1975 resembles that of 1974. Larval entrainment peaked June 3, 1975, a date when striped bass post yolk-sac larvae appeared to be most abundant in the river (Section 8.3).

8.4.3 LIMITATIONS OF ESTIMATES. The accuracy of the abundance estimates (No. $m^{-3} \times 10^{3}$) upon which the entrainment estimates depended may have been influenced by the velocity of water flow at the Indian Point Unit 2 intake. No current flowmeters were attached to the sampling nets during the 1974 and 1975 entrainment samplings, so the volume of water strained was estimated from calculated average intake velocities based on plant flow rates. During sampling, the mouths of the 0.5-m sampling nets were fitted with velocity reduction cones. The effects of these cones on the sampling efficiency of the nets is not known.

Table 8.4-3 Striped Bass Eggs in Entrainment Collections, Indian Point, Unit 2, 1975

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
750506	D	0	0	0
	N	0	0	0
750513	D	0	0	0
	N	137651	357	551370
750520	D	48639	75	169676
	N	413816	1068	2339014
750522	D	103498	160	273174
	N	489694	1261	2828708
750527	D	242014	371	1031696
	N	390625	999	4537262
750603	D	42189	55	1671453
	N	6051	13	5397750
750610	D	0	0	1776088
	N	0	0	5412755
750617	D	0	0	1776088
	N	0	0	5412755
750624	D	0	0	1776088
	N	0	0	5412755
750701	D	0	0	1776088
	N	0	0	5412755
750708	D	0	0	1776088
	N	0	0	5412755
750715	D	0	0	1776088
	N	0	0	5412755
750819	D	0	0	1776088
	N	0	0	5412755

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

Table 8.4-4 Striped Bass Larvae in Entrainment Collections, Indian Point Unit 2, 1975

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
750506	D	0	0	0
	N	0	0	0
750513	D	0	0	0
	N	3961	10	15864
750520	D	6857	11	23921
	N	56558	146	223066
750522	D	547086	845	571008
	N	163653	421	386719
750527	D	1910792	2931	6154482
	N	147664	377	1000374
750603	D	1115061	1445	13374857
	N	764809	1651	3440959
750610	D	513540	664	17935280
	N	429992	927	6840703
750617	D	223741	288	19941040
	N	446286	958	9406355
750624	D	13733	18	20549328
	N	29351	63	10626606
750701	D	36141	46	20709392
	N	14624	31	10750536
750708	D	0	0	20791968
	N	10731	23	10819382
750715	D	0	0	20791968
	N	0	0	10846169
750819	D	0	0	20791968
	N	0	0	10846169

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

River nearfield concentrations were used as estimates of striped bass ichthyoplankton entering the plant during the daytime. These nearfield concentrations were obtained from samples collected with nets 1 m in diameter equiped with current flowmeters. The nets were towed at a speed falling within the accuracy limits of the flowmeter (approximately 2-3 ft sec^{-1} [0.61-0.91 m sec^{-1}]). It should be noted that not all of the striped bass ichthyoplankton present in the nearfield were entrained. Therefore, it was a conservative approach to use nearfield concentrations as estimates of numbers of striped bass ichthyoplankton entering the plant.

8.5 ENTRAINMENT AT INDIAN POINT UNIT 3. Since Indian Point Unit 3 was not operational until February 1976 when limited operation of the circulating water pumps began (the actual electrical generation started in May 1976), no striped bass ichthyoplankton were entrained either during 1974 or 1975. To complete the information necessary for assessing the potential entrainment impact of all three units at Indian point, this section discusses probable entrainment at Unit 3 in relation to entrainment measurements at Units 1 and 2 during 1974-75.

Factors that determine striped bass entrainment at any generating unit include the abundance of the organisms in the intake vicinity and the pumping rates. Other physical and biological factors such as river morphometry in the plant vicinity, recirculation of the discharge flow, and the physical and biological characteristics of the striped bass ichthyoplankton also play an important role in entrainment. Since the design and pumping rates of Unit 3 are identical to those of Unit 2 and the intakes of the two units are only about 700 ft (213 m) apart, striped bass entrainment at Unit 3 can be expected to be about the same as that at Unit 2 when both units are being operated at the same levels of cooling water withdrawal. There are no data that would indicate aggregation of striped bass ichthyoplankton at Unit 2 or Unit 3 intakes. However, data collected at Unit 1 and 2 intakes (Table 8.5-1) and the patchy distribution of organisms in the river suggest that at any given time there may be a difference in entrainment at Units 2 and 3.

Table 8.5-1 Summary of Striped Bass Abundance, Indian Point, 1974

I.	Abundance[†] and 95% Confidence Intervals					
	Unit 1 Intake		Unit 2 Intake		Discharge Canal	
Collections	I-1	I-2	II-2	II-5	D-1	D-2
Eggs 21 May-4 June	113±37 n=168	105±44 n=114	210±71 n=131	NS	131±38 n=71	83±28 n=132
Yolk-sac larvae 21 May-4 June	29±9 n=168	37±11 n=114	48±17 n=131	NS	26±15 n=71	17±11 n=132
Larvae 28 May-9 Jul	46±12 n=270	47±15 n=180	74±16 n=150	19±56 n=216	163±19 n=216	60±19 n=210
Juveniles[‡]	0	0	0	0	0	0

II. Differences Among Locations in Night Collections

Life Stage	I vs II	I vs D	II vs D
Eggs	II>I	none	II>D
Yolk-sac larvae	II>I	I>D	II>D
Larvae	II>I	D>I	D>II
Juveniles	----	----	----

*NYU 1976c

[†] Mean numbers collected per $m^3 \times 10^3$

[‡] Only one juvenile caught during sampling period (June 28 in discharge-canal bottom sample)

NS = No sample
n = Number of samples
I = Unit 1 intake
II = Unit 2 intake
D = Discharge canal

Another factor that might cause a difference in entrainment impact between Units 2 and 3 would be the extent to which the discharge flow is recirculated back to the intakes. LaSalle Hydraulic Laboratory's hydraulic model study for Indian Point (LaSalle-682 1976) indicated that an average of about 7% of the discharge water was recirculated back to the intake. However, data to indicate the amount of recirculation to Units 2 and 3 separately are not available.

In summary, a variety of biotic and abiotic factors interact in the entrainment processes at Indian Point. Given the physical similarity and the close proximity between Units 2 and 3, it seems likely that total striped bass ichthyoplankton entrainment over the entire entrainment period at Unit 3 would not differ substantially from that at Unit 2.

8.6 ENTRAINMENT AT INDIAN POINT UNIT 1

8.6.1 COMPUTATION OF NUMBERS ENTRAINED. Striped bass ichthyoplankton entrainment rates and cumulative entrainment at the Unit 1 intake were estimated using concentrations of ichthyoplankton measured by New York University. The same methods applied to entrainment estimates at Roseton (Section 8.7) were used. Entrainment samplings at Indian Point during 1974 and 1975, from which entrainment estimates are made, were conducted only during nighttime; to estimate day entrainment rates, day concentrations of striped bass ichthyoplankton at the surface and the mid-depth of nearfield river stations B, D and G (Fig. 8.3-2) were averaged.

8.6.2 RESULTS. Sampling conducted at Unit 1 intake stations I-1 and I-2 (Fig. 8.3-2) during 1974 collected striped bass eggs between May 7 and June 13. Abundance peaked during the week of May 21. Except for the May 14 survey date, nighttime concentrations of eggs at the plant were consistently higher than daytime nearfield collections (Table 8.6-1). Approximately 2,600,000 striped bass eggs were estimated to have been entrained between May 7 and June 18.

Table 8.6-1 Striped Bass Eggs in Entrainment Collections, Indian Point Unit 1, 1974

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
740507	D	0	0	0
	N	218	5	218
740514	D	42581	364	178072
	N	0	0	1314
740521	D	208216	771	981027
	N	149614	923	466794
740523	D	152025	563	1133052
	N	148609	917	615403
740528	D	11547	43	1389954
	N	14939	92	875662
740530	D	10963	41	1400916
	N	40219	248	915881
740604	D	9504	35	1440331
	N	20110	124	1023871
740611	D	1714	6	1470088
	N	7597	47	1100731
740613	D	0	0	1470088
	N	4022	25	1104753
740618	D	0	0	1470088
	N	0	0	1110815
740625	D	0	0	1470088
	N	0	0	1110815
740628	D	0	0	1470088
	N	0	0	1110815
740702	D	0	0	1470088
	N	0	0	1110815
740709	D	0	0	1470088
	N	0	0	1110815
740716	D	0	0	1470088
	N	0	0	1110815
740723	D	0	0	1470088
	N	0	0	1110815
740819	D	0	0	1470088
	N	0	0	1110815

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

Striped bass larvae were present at the Unit 1 intake from May 7 through July 16, 1974 (Table 8.6-2). Maximum entrainment rates occurred on May 21 and June 4; on May 21, the average larval concentration during the day was higher than during the night (137.84 vs 35.95 larvae $m^{-3} \times 10^3$). The diurnal pattern reversed on June 4 (75.20 vs 244.78 larvae $m^{-3} \times 10^3$). There was no consistent diurnal pattern of larval entrainment. Approximately 4,100,000 striped bass larvae were estimated to have been entrained between May 7 and July 23, 1974.

Since Unit 1 was off line during most of the entrainment sampling season during 1975, no entrainment samples were collected at the Unit 1 intake. Unit 1 entrainment was estimated using concentrations of striped bass ichthyoplankton measured at the Unit 2 intake. Due to low flow rates, only about 700,000 striped bass eggs were estimated to have been entrained at Unit 1 between May 6 and June 10, 1975 (Table 8.6-3). Maximum entrainment rates occurred on May 22 and May 27. The entrainment rate of striped bass eggs was higher at night than during the day.

As in 1974, larval entrainment at Unit 1 during 1975 exhibited no consistent diurnal pattern (Table 8.6-4). During the maximum entrainment period between May 27 and June 3, larval entrainment rates were higher during the day than at night; during the remainder of the survey, nighttime rates were generally higher than daytime rates. Nearly 3,300,000 striped bass larvae were estimated to have been entrained between May 6 and July 15, 1975.

Studies by New York University at Indian Point during 1974 (NYU 1976c) indicated that the abundances of striped bass eggs, yolk-sac larvae, and post yolk-sac larvae were significantly higher at the Unit 2 intake than at Unit 1 (Table 8.5-1). Thus the total number of striped bass eggs and larvae entrained during 1975 may be overestimated in Tables 8.6-3 and 8.6-4.

Table 8.6-2 Striped Bass Larvae in Entrainment Collections, Indian Point Unit 1, 1974

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
740507	D	0	0	0
	N	1593	39	1593
740514	D	979	8	4094
	N	3417	49	23898
740521	D	141092	522	446628
	N	26545	164	118933
740523	D	119014	440	565642
	N	21517	133	140451
740528	D	63820	236	903714
	N	7757	48	192118
740530	D	0	0	903714
	N	22120	136	214238
740604	D	76974	285	1094720
	N	114624	707	530620
740611	D	43583	161	1439692
	N	98983	610	1163617
740613	D	0	0	1439692
	N	94569	583	1258186
740618	D	98249	362	1685308
	N	2695	17	1407483
740625	D	51451	194	2082483
	N	15084	95	1461157
740628	D	0	0	2082483
	N	7236	48	1468393
740702	D	105103	387	2275334
	N	8443	52	1490729
740709	D	792	40	2534769
	N	352	30	1518811
740716	D	0	0	2555112
	N	2414	15	1535991
740723	D	0	0	2555112
	N	0	0	1542023
740819	D	0	0	2555112
	N	0	0	1542023

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

Table 8.6-3 Striped Bass Eggs in Entrainment Collections, Indian Point Unit 1, 1975

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
750506	D	0	0	0
	N	0	0	0
750513	D	0	0	0
	N	28104	357	113681
750520	D	6088	75	30807
	N	51799	1068	446046
750522	D	647	160	31454
	N	3061	1261	449107
750527	D	1502	371	36180
	N	2425	999	459759
750603	D	2792	55	119448
	N	400	13	567423
750610	D	0	0	129159
	N	0	0	568815
750617	D	0	0	129159
	N	0	0	568815
750624	D	0	0	129159
	N	0	0	568815
750701	D	0	0	129159
	N	0	0	568815
750708	D	0	0	129159
	N	0	0	568815
750715	D	0	0	129159
	N	0	0	568815
750819	D	0	0	129159
	N	0	0	568815

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

Table 8.6-4 Striped Bass Larvae in Entrainment Collections, Indian Point Unit 1, 1975

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
750506	D	0	0	0
	N	0	0	0
750513	D	0	0	0
	N	809	10	3271
750520	D	858	11	4343
	N	7080	146	41116
750522	D	3419	845	7763
	N	1023	421	42139
750527	D	11860	2931	42542
	N	917	377	45964
750603	D	73783	1445	1036956
	N	50607	1651	415261
750610	D	62461	664	1543824
	N	52299	927	800807
750617	D	21270	288	1874476
	N	42427	958	1210642
750624	D	1696	18	1954649
	N	3627	63	1371587
750701	D	188	46	1957004
	N	76	31	1374574
750708	D	0	0	1960077
	N	56	23	1376165
750715	D	0	0	1960077
	N	0	0	1377524
750819	D	0	0	1960077
	N	0	0	1377524

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

8.6.3 LIMITATIONS OF ESTIMATES. The accuracy of abundance estimates upon which entrainment estimates depended may have been influenced by the velocity of water flow at the Indian Point Unit 1 intake. During the 1974 and 1975 entrainment samplings at the Indian Point intake, no current flowmeters were attached to the sampling nets, so the volume of water strained was estimated from calculated average intake velocities based on plant flow rates. Since the mouths of the 0.5-m sampling nets were fitted with velocity reduction cones, the intake velocity was multiplied by the area of the opening of the cone to obtain the volume strained by the net.

River nearfield concentrations were used as estimates of striped bass ichthyoplankton entering the plant during the day. These nearfield concentrations were obtained from samples collected with 1-m nets equipped with current flowmeters. The nets were towed at a speed (approximately 2-3 ft sec^{-1} [0.61-0.91 m sec^{-1}]) falling within the accuracy limits of the flowmeter.

8.7 ENTRAINMENT AT ROSETON

8.7.1 COMPUTATION OF NUMBERS ENTRAINED. The number of striped bass ichthyoplankton entrained at Roseton (RM 65; km 105) was determined from measurements of concentrations of ichthyoplankton entering the plant and from records of the volume of water withdrawn by the plant during the period of ichthyoplankton abundance. The concentrations of striped bass ichthyoplankton withdrawn by the Roseton plant were determined from field studies using 0.5-m nets on fixed sampling racks at the intake of the cooling system. Field studies provided estimates of day and night concentrations of ichthyoplankton entrained by the Roseton plant on the sampling dates.

To estimate the total number of striped bass ichthyoplankton entrained, the day and night concentrations on dates in-between the sampling days were approximated by linear interpolation. These estimates of ichthyoplankton concentrations for each life stage and for each day and night period were multiplied by the total volume of water passing through the plant during the period of ichthyoplankton abundance. The calculations were performed separately for day and night periods to account for diurnal migration patterns of striped bass larvae.

8.7.2 RESULTS. During 1974, the first year of operations at Roseton, striped bass eggs were found only during the May 9 night survey, and total numbers entrained were therefore small - approximately 20,000 (Table 8.7-1). Striped bass larvae were present intermittently from May 14 through July 16; on June 4 and 13, maximum entrainment rates were recorded. In general, entrainment rates were greater at night than during the day. Approximately 500,000 larvae were estimated to have been entrained during the period of striped bass larval occurrence, most being entrained between June 4 and 13 (Table 8.7-2).

During 1975, striped bass eggs were found on only one survey date, May 22, and the total number entrained was small - approximately 150,000 (Table 8.7-3). Striped bass larvae were present from May 15 through June 19 and on July 17. Maximum entrainment rates occurred on June 4 and 9. In May, entrainment rates were greater at night than during the day; in June and July, the dirunal entrainment pattern was usually the opposite. Approximately 12,000,000 striped bass larvae were estimated to have been entrained during 1975, most occurring between May 29 and June 9 (Table 8.7-4).

8.7.3 LIMITATIONS OF ESTIMATES. The entrainment estimates were dependent on the accuracy and precision of abundance estimates at the intake. At Roseton, abundance estimates were most affected by the velocity of water flow at the intake and by periodically high concentrations

Table 8.7-1 Striped Bass Eggs in Entrainment Collections, Roseton, 1974

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
5/9/74	D	0	0	0
	N	17575	148	17575
5/14/74	D	0	0	0
	N	0	0	22905
5/21/74	D	0	0	0
	N	0	0	22905
5/30/74	D	0	0	0
	N	0	0	22905
6/4/74	D	0	0	0
	N	0	0	22905
6/13/74	D	0	0	0
	N	0	0	22905
6/19/74	D	0	0	0
	N	0	0	22905
6/25/74	D	0	0	0
	N	0	0	22905
7/2/74	D	0	0	0
	N	0	0	22905
7/9/74	D	0	0	0
	N	0	0	22905
7/16/74	D	0	0	0
	N	0	0	22905

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

Table 8.7-2 Striped Bass Larvae in Entrainment Collection, Roseton, 1974

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
5/9/74	D	0	0	0
	N	0	0	0
5/14/74	D	8657	30	9109
	N	13559	79	14267
5/21/74	D	0	0	12374
	N	0	0	19380
5/30/74	D	7142	64	40734
	N	1267	19	24410
6/4/74	D	9683	34	54285
	N	47357	279	74597
6/13/74	D	211606	766	283168
	N	0	0	96697
6/19/74	D	0	0	353123
	N	0	0	96697
6/25/74	D	0	0	353123
	N	7380	44	105007
7/2/74	D	0	0	353123
	N	10712	67	121290
7/9/74	D	0	0	353123
	N	0	0	125885
7/16/74	D	0	0	353123
	N	6473	39	132928

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

Table 8.7-3 Striped Bass Eggs in Entrainment Collections, Roseton, 1975

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
5/8/75	D	0	0	0
	N	0	0	0
5/15/75	D	0	0	0
	N	0	0	0
5/22/75	D	21023	42	84093
	N	0	0	0
5/29/75	D	0	0	147163
	N	0	0	0
6/4/75	D	0	0	147163
	N	0	0	0
6/9/75	D	0	0	147163
	N	0	0	0
6/19/75	D	0	0	147163
	N	0	0	0
6/23/75	D	0	0	147163
	N	0	0	0
6/26/75	D	0	0	147163
	N	0	0	0
7/1/75	D	0	0	147163
	N	0	0	0

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

Table 8.7-4 Striped Bass Larvae in Entrainment Collections, Roseton, 1975

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
5/8/75	D	0	0	0
	N	0	0	0
5/15/75	D	2548	5	8838
	N	19876	66	68950
5/22/75	D	10831	21	59804
	N	27903	92	240192
5/29/75	D	4459	9	110132
	N	5352	18	345309
6/4/75	D	871432	1731	3146058
	N	114709	380	756424
6/9/75	D	459491	1221	6246534
	N	346612	1536	2085902
6/19/75	D	6308	15	8340869
	N	0	0	3641651
6/23/75	D	0	0	8351794
	N	0	0	3641651
6/26/75	D	0	0	8351794
	N	0	0	3641651
7/17/75	D	2791	6	8384298
	N	0	0	3641651

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

of detritus and planktonic invertebrates. Velocity studies conducted in late 1974 showed that mean intake velocity was 0.65 ft sec^{-1} (0.20 m sec^{-1}) (Baslow and McGroddy personal communications). At the lower end of the velocity range at the Roseton intake, the TSK meters that determined the flow through the sampling nets were marginally effective, providing spurious values 20% of the time. Such values were eliminated from all analyses (LMS 1975d).

Living and nonliving particulates clogging the sampling nets may reduce velocities in the nets to a range in which the flowmeters are not accurate. Clogging was suspected during spring 1974, and its presence was verified in 1975 through comparison of inner and outer flowmeter readings (LMS 1976).

8.8 ENTRAINMENT AT BOWLINE PLANT

8.8.1 COMPUTATION OF NUMBERS ENTRAINED. Estimates of striped bass ichthyoplankton entrainment rates and cumulative entrainment were computed using the same methods applied at Roseton (RM 65; km 105) (Section 8.7).

8.8.2 RESULTS. During 1974, striped bass larvae were found in the May22-July 2 collections from the Bowline Point (RM 37; km 60) intake. Striped bass eggs were not enumerated, and larval abundances represent yolk-sac and post yolk-sac larvae and early juveniles combined. Maximum entrainment rates were recorded on June 26 and July 2, and more larvae were entrained at night than during the day. The total for striped bass larvae entrained during 1974 was estimated to be 700,000,000 (Table 8.8-1).

No striped bass eggs were found in entrainment collections at Bowline Point during 1975; yolk-sac and post yolk-sac larvae and early juveniles combined were present during the June 3-24 surveys, with maximum entrainment rates recorded on June 10 and 17. As during 1974, numbers entrained per million gallons tended to be greater at night than during the day. An estimated total of approximately 2,300,000 striped bass larvae were entrained during 1975, the majority during the second half of June (Table 8.8-2).

Table 8.8-1 Striped Bass Larvae in Entrainment Collections, Bowline Point, 1974

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
5/15/74	D	0	0	0
	N	0	0	0
5/22/74	D	0	0	1029
	N	0	0	1
5/30/74	D	0	0	1029
	N	0	0	1
6/ 6/74	D	6928	14	12640
	N	8280	28	13809
6/12/74	D	4360	10	39379
	N	1730	6	35557
6/19/74	D	3014	5	64588
	N	6330	19	64506
6/26/74	D	31564	55	184603
	N	30372	89	189895
7/ 2/74	D	16522	41	335709
	N	4335	18	284299
7/10/74	D	0	0	416457
	N	0	0	305487
7/17/74	D	0	0	416457
	N	0	0	305487
7/24/74	D	0	0	416457
	N	0	0	305487
8/ 1/74	D	0	0	416457
	N	0	0	305487
8/14/74	D	0	0	416457
	N	0	0	305487

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

Table 8.8-2 Striped Bass Larvae in Entrainment Collections, Bowline Point, 1975

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
5/6/75	D	0	0	0
	N	0	0	0
6/3/75	D	12303	29	100294
	N	8981	35	73210
6/10/75	D	140073	303	701359
	N	63834	220	357676
6/17/75	D	19814	43	1200833
	N	70392	254	830744
6/24/75	D	0	0	1260273
	N	6935	25	1069661
7/1/75	D	0	0	1260273
	N	0	0	1091035

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

8.8.3 LIMITATIONS OF ESTIMATES. The accuracy and precision of abundance estimates at the intake upon which entrainment estimates depended were most influenced by the velocity of water flow at Bowline Point. Velocity studies conducted during late 1974 (Baslow and McGroddy personal communication) showed the average velocity at Bowline intake to be 0.5 ft sec^{-1} (0.15 m sec^{-1}) and velocities at the intake sampling site to be slightly lower. At such velocities, the TSK flowmeters were marginally effective. Thus, during 1974 and 1975, volume sampled was based on results of velocity studies and plant flow data; net filtration efficiency correction factors were also included in the computation of abundance (LMS 1975c, EA 1976c).

8.9 ENTRAINMENT AT LOVETT

8.9.1 COMPUTATION OF NUMBERS ENTRAINED. Estimates of striped bass ichthyoplankton entrainment rates and cumulative entrainment were computed using the same methods applied at Roseton (Section 8.7).

8.9.2 RESULTS. Striped bass were not enumerated in intake collections during 1974. Yolk-sac and post yolk-sac larvae and early juveniles combined were present during the May 21-July 9 river surveys at Lovett, peaking on June 25, the date of maximum entrainment rates. Entrainment rates were generally higher at night than during the day. Approximately 2,100,000 striped bass larvae were estimated to have been entrained at Lovett during 1974, most of these between June 18 and July 1 (Table 8.9-1).

During 1975, striped bass eggs were found in the May 13-27 and June 10 collections at the Lovett intake. Maximum entrainment rates were observed on May 13 and 20. On three of the four survey dates when striped bass eggs were present, entrainment rates were higher at night than during the day. Approximately 2,100,000 striped bass eggs were estimated to have been entrained at Lovett during 1975, mostly during the mid-May period of maximum abundance (Table 8.9-2).

Table 8.9-1 Striped Bass Larvae in Entrainment Collections, Lovett, 1974

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
5/14/74	D	0	0	0
	N	0	0	0
5/21/74	D	1501	7	5991
	N	0	0	0
5/28/74	D	4710	23	30005
	N	7876	65	32197
6/ 4/74	D	13127	65	93836
	N	14360	118	109845
6/11/74	D	4407	18	153664
	N	45735	308	323371
6/18/74	D	82072	365	437729
	N	8734	65	457970
6/25/74	D	38983	193	843776
	N	82107	676	822143
7/ 1/74	D	6839	30	963091
	N	8187	61	1053297
7/ 9/74	D	382	2	988854
	N	502	3	1084320
7/16/74	D	0	0	989844
	N	0	0	1085621
7/23/74	D	0	0	989844
	N	0	0	1085621
7/30/74	D	0	0	989844
	N	0	0	1085621
8/ 8/74	D	0	0	989844
	N	0	0	1085621

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

Table 8.9-2 Striped Bass Eggs in Entrainment Collections, Lovett, 1975

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
5/6/75	D	0	0	0
	N	0	0	0
5/13/75	D	43316	340	147002
	N	104659	1370	355184
5/20/75	D	118299	468	659084
	N	31616	208	797039
5/27/75	D	17533	87	1012313
	N	28432	235	989174
6/3/75	D	0	0	1064913
	N	0	0	1074470
6/10/75	D	0	0	1064913
	N	1301	11	1079672
6/17/75	D	0	0	1064913
	N	0	0	1083286
6/25/75	D	0	0	1064913
	N	0	0	1083286
7/1/75	D	0	0	1064913
	N	0	0	1063286
7/8/75	D	0	0	1064913
	N	0	0	1063286
7/16/75	D	0	0	1064913
	N	0	0	1083286

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

During 1975, striped bass larvae were found at the Lovett intake from May 13 through July 1 and on July 16. Maximum entrainment rates were recorded for June 10. On most survey dates, entrainment rates were higher at night than during the day. Approximately 6,900,000 striped bass larvae were estimated to have been entrained at Lovett during 1975, most during June 3-17. (Table 8.9-3).

8.9.3 LIMITATIONS OF ESTIMATES. The accuracy and precision of abundance estimates upon which entrainment estimates depended were influenced by the velocity of water flow at the Lovett intake. Results of intensive velocity studies conducted late in 1974 (Baslow and McGroddy personal communication) were used in conjunction with plant flow data and correction factors for net filtration efficiency (LMS 1975c; EA 1976b) to estimate the volume of water sampled and the 1974 and 1975 abundances.

8.10 ENTRAINMENT AT DANSKAMMER

8.10.1 COMPUTATION OF NUMBERS ENTRAINED. Estimates of striped bass ichthyoplankton entrainment rates and cumulative entrainment were computed using the same methods applied at Roseton (Section 8.7).

8.10.2 RESULTS. During 1974, striped bass eggs were found in the May 7-June 4 entrainment collections at Danskammer. Maximum entrainment rates were recorded on May 20. There was no consistent diurnal pattern in numbers of eggs entrained per million gallons. Total entrainment of striped bass eggs was estimated to be approximately 800,000 at Danskammer during 1974 (Table 8.10-1).

Striped bass larvae were found in 1974 Danskammer intake samples collected on May 7 and from May 21-July 16. Several peaks in entrainment rates were recorded, and maximum rates were observed on June 11. The diurnal distribution of entrainment rates varies over time, but there was a

Table 8.9-3 Striped Bass Larvae in Entrainment Collections, Lovett, 1975

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
5/6/75	D	0	0	0
	N	0	0	0
5/13/75	D	4780	38	16222
	N	1226	16	4162
5/20/75	D	0	0	31884
	N	3396	22	18805
5/27/75	D	13653	68	88076
	N	19076	157	105386
6/3/75	D	3242	16	142001
	N	63404	523	416231
6/10/75	D	314521	1558	1409809
	N	451320	3726	2411721
6/17/75	D	49118	243	2452050
	N	69235	572	3903009
6/25/75	D	7485	30	2647657
	N	7202	48	4165795
7/1/75	D	0	0	2662819
	N	4367	36	4195667
7/8/75	D	0	0	2662819
	N	0	0	4206095
7/16/75	D	3564	18	2678481
	N	0	0	4206095

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

Table 8.10-1 Striped Bass Eggs in Entrainment Collections, Danskammer, 1974

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
5/7/74	D	0	0	0
	N	300	2.725	300
5/14/74	D	0	0	0
	N	0	0	1232
5/21/74	D	16435	75	64589
	N	245	2	2196
5/30/74	D	41522	204	355946
	N	26976	221	149597
6/4/74	D	15901	87	501040
	N	0	0	209685
6/11/74	D	0	0	542937
	N	0	0	209685
6/18/74	D	0	0	542937
	N	0	0	209685
6/25/74	D	0	0	542938
	N	0	0	209685
7/2/74	D	0	0	542937
	N	0	0	209685
7/9/74	D	0	0	542937
	N	0	0	209685
7/16/74	D	0	0	542937
	N	0	0	208685

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

tendency toward greater values during the day than at night. Approximately 2,900,000 striped bass larvae were estimated to have been entrained at Danskammer during 1974, the majority occurring between May 30 and June 11 (Table 8.10-2).

During 1975, striped bass eggs were collected at Danskammer on only one entrainment survey date, May 22, at night. Estimated totals entrained were therefore small - approximately 100,000 (Table 8.10-3).

Striped bass larvae were found in Danskammer intake samples from May 15 through June 23. Maximum entrainment rates were recorded during the June 9 survey, with a second smaller peak having been recorded earlier, (June 4). Contrary to the 1974 findings, entrainment rates tended to be greater at night than during the day. Approximately 2,900,000 striped bass larvae were estimated to have been entrained during 1975 (Table 8.10-4).

8.10.3 LIMITATIONS OF ESTIMATES. As was the case at Roseton, the accuracy of entrainment estimates at Danskammer could have been influenced by the velocity of water flow at the intake and by periodically high concentrations of detritus and planktonic invertebrates. Velocity studies conducted during late 1974 indicated that mean intake channel velocity was 1.06 ft sec^{-1} (0.34 m s^{-1}); velocity at the entrainment sampling location was approximately 0.8 ft sec^{-1} (0.24 m s^{-1}). At these velocities, the TSK flowmeters that determined flow through the sampling nets were on the borderline of effectiveness; however, flowmeter accuracy and precision was generally within acceptable limits.

Periodically high concentrations of living and nonliving particulates may clog the sampling nets. Net clogging at Danskammer intake was suspected during spring 1974 and was documented in 1975 through use of inner and outer flowmeters (LMS 1976). Therefore, accuracy of abundance estimates was influenced by clogging during the period of striped bass egg and larval occurrence.

Table 8.10-2 Striped Bass Larvae in Entrainment Collections, Danskammer, 1974

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
5/7/74	D	4264	23	4246
	N	313	3	313
5/14/74	D	0	0	17418
	N	0	0	1283
5/21/74	D	17369	79	85681
	N	491	4	3212
5/30/74	D	24750	122	289758
	N	10461	86	61961
6/4/74	D	58240	317	537555
	N	49159	446	247890
6/11/74	D	43921	279	857279
	N	51178	542	571160
6/18/74	D	26743	146	1102287
	N	26671	242	839000
6/25/74	D	78293	387	1403050
	N	11052	91	967189
7/2/74	D	3199	14	1721693
	N	7492	53	1023507
7/9/74	D	10067	45	1768439
	N	3654	27	1058859
7/16/74	D	0	0	1801146
	N	1141	8	1075253

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

Table 8.10-3 Striped Bass Eggs in Entrainment Collections, Danskammer, 1975

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
5/ 8/75	D	0	0	0
	N	0	0	0
5/15/75	D	0	0	0
	N	0	0	0
5/22/75	D	0	0	0
	N	16853	188	65825
5/29/75	D	0	0	0
	N	0	0	113470
6/ 4/75	D	0	0	0
	N	0	0	113470
6/ 9/75	D	0	0	0
	N	0	0	113470
6/19/75	D	0	0	0
	N	0	0	113470
6/23/75	D	0	0	0
	N	0	0	113470
6/26/75	D	0	0	0
	N	0	0	113470
7/17/75	D	0	0	0
	N	0	0	113470

D = Day (0600-2059 Hrs)
N = Night (2100-0559 Hrs)

Table 8.10-4 Striped Bass Larvae in Entrainment Collections, Danskammer, 1975

Date	Time	Total Entrained	Total Number Entrained/MG	Cumulative Entrainment
5/ 8/75	D	0	0	0.0
	N	0	0	0.0
5/15/75	D	19643	13	81321
	N	0	0	0
5/22/75	D	0	0	140016
	N	2488	28	9719
5/29/75	D	2782	13	148415
	N	6677	50	36913
6/ 4/75	D	30372	134	263492
	N	23725	174	138348
6/ 9/75	D	177829	1126	1113135
	N	5622	59	213177
6/19/75	D	4066	20	2484754
	N	7929	65.611	311061
6/23/75	D	0	0	2493673
	N	8335	67	354267
6/26/75	D	0	0	2493673
	N	0	0	368186
7/17/75	D	0	0	2493673
	N	0	0	368186

D = (0600-2059 Hrs)
N = (2100-0559 Hrs)

8.11 COMPARISONS OF EMPIRICAL AND MODEL-GENERATED ENTRAINMENT ESTIMATES

Ichthyoplankton data collected at the intakes and discharges of power plants along the Hudson during 1974 and 1975 were analyzed in preceding sections with three objectives in mind. First, the data were used in Section 8.3 to calculate w and f factors that relate concentrations in the power plants' cooling systems to estimates of abundance in the river in front of the plants. Second, data related to entrainment survival were analyzed to estimate the proportion of entrained organisms that will be killed due to passage through the plants. In subsequent sections, data collected at the plants are being used to estimate the number of striped bass ichthyoplankton entrained by these plants during 1974 and 1975. In this section, these estimates of entrainment are compared with estimates derived from modeling studies using the w and f factors.

The most important application of entrainment data is in modeling studies (Sections 11 and 12), which provide estimates of the impact of power plant operations on the striped bass population. If a model is to be applicable in a predictive mode (i.e., under different plant operating conditions and for different standing crops), the procedure used to estimate entrainment impact must be expressed in terms of the concentration of organisms in the river. In the real-time life-cycle model applied in Section 12, river ichthyoplankton concentrations are multiplied by plant flow and the product $w.f_3.f_c.f_q$ in order to estimate the number of organisms killed by entrainment.

An empirical procedure for estimating the number of organisms entrained is presented in Sections 8.4 through 8.10. The entrainment estimates presented in these sections were derived from the product of the ichthyoplankton concentrations measured at the plant intake and/or discharge stations and the prevailing plant flow rates. Since sampling was performed about once per week, linear interpolation was used to estimate concentrations of ichthyoplankton passing through the plant on days between sampling dates. This procedure provided estimates of number of striped bass ichthyoplankton entrained at power plants during 1974 and

1975. These estimates are inflated since they do not reflect the fact that a proportion of the entrained organisms may have survived passage through the plant. Also, they are not useful in predicting impact under different biological or plant conditions but can be used to verify model predictions of entrainment under the 1974 and 1975 conditions.

Table 8.11-1 shows estimates of the number of striped bass ichthyoplankton killed by entrainment at the Indian Point, Roseton, and Bowline Point generating stations during 1974 and 1975 as calculated by the real-time model and by empirical procedure used in Sections 8.4 through 8.10. Results were not available from the model for Indian Point Unit 1 and the Danskammer and Lovett plants since they are considered background plants (Section 10.6.2); and no entrainment estimates for Indian Point Unit 3 were presented since that unit was not in operation during 1974 and 1975.

To permit a meaningful comparison with the model results, the numbers from the direct calculation were multiplied by entrainment mortality factors (f_c) for each life stage. For the larval stage, the most important in the evaluation of entrainment impact, results from the two methods (Table 8.11-1) agreed very well for the Bowline plant in 1974; for all other cases, the estimates of larval entrainment from the model were considerably higher than those calculated directly from field data. Estimates of entrainment of eggs at Bowline and Roseton during 1974 were small when calculated by either method. In 1975 the model produced estimates of egg entrainment that were several orders of magnitude greater than those derived from direct calculations.

In general, the results presented in Table 8.11-1 indicate that application of the w and f factors presented in Section 8.3.5 in the real-time model produced overestimates of the number of organisms entrained.

Table 8.11-1 Comparisons of Entrainment Estimates, Indian Point, Roseton, and Bowline Point, 1974-75

Plant	1974				1975			
	Model Calculation		Direct Calculation		Model Calculation		Direct Calculation	
	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae
Indian Point Unit 2	25.58 x 10^6	18.57 x 10^6	3.19 x 10^6	5.92 x 10^6	26.27 x 10^6	28.92 x 10^6	3.52 x 10^6	16.14 x 10^6
Roseton Unit 1, 2	4.84 x 10^6	0.51 x 10^6	0.01 x 10^6	0.19 x 10^6	46.10 x 10^6	8.19 x 10^6	0.07 x 10^6	4.68 x 10^6
Bowline Units 1,2	0.00	0.32 x 10^6	0.00	0.24 x 10^6	1.37 x 10^6	1.67 x 10^6	0.00	0.78 x 10^6

Entrainment estimates presented in Sections 8.4, 8.7 and 8.8 multiplied by 0.49 for eggs at Indian Point, Roseton, and Bowline and by 0.51, 0.39, and 0.34 for larvae at Indian Point, Roseton, and Bowline respectively to account for proportion that may be killed as a result of entrainment. Numbers of larvae are combination of yolk-sac larvae, post yolk-sac larvae, and juveniles, so factors of 0.51, 0.39, and 0.34 represent the average of the entrainment mortality factors for these three life stages at Indian Point, Roseton, and Bowline, respectively.

Preliminary analysis of data indicated no striped bass eggs at Bowline intake or discharge.

The plant concentration was set equal to the concentration in Bowline Pond in the model.

It should be noted that the computational procedure for the withdrawal ratio detailed in Section 8.3 (Equations 8.5 and 8.6) effectively ignored those samples in which no organisms were captured in either the intake or the river; in fact the procedure was designed to cause samples representing the periods of peak abundance to carry the most weight in determination of the w ratio. Examination of the data indicates that a single day's sampling may determine the value of the average w ratio. This point was most evident in the calculation of the w ratio for the egg stage at Roseton during 1975 (Table 8.3-15). The w ratio of 18.7 for the upper layer was determined from eggs collected at the Roseton intake on two sampling days. The comparisons of model results with direct calcuations of numbers entrained indicates that application of the weighted w ratio over the entire period of abundance for a given life stage results in an overestimate of entrainment in the model.

In the projection of long-range estimates of impact presented in Section 12.2, the w and f factors calculated from a single year's data were applied repeatedly over the entire projection period. A statistical analysis of the data used to calculate the f factors and withdrawal ratios could be used to establish standard deviations about the mean-value w and f factors used in the present study; this would provide a measure of the statistical uncertainty associated with the w and f factors and establish a basis for a simulation of random fluctuations in the w and f factors. However, due to the conservative approach used in the calculation and application of the w and f factors in the present study, it is doubtful that the statistical analysis will justify higher estimates of entrainment impact.

An important consideration in developing an estimate of the plant withdrawal ratios is that the efficiency of sampling gear used in the plant intakes and discharges be comparable with the gear used in the river sampling or that any known differences in gear efficiencies be quantifiable. In the present study, no correction was made for possible differences in gear efficiencies. It appears that one important factor influencing gear efficiencies is the approach those experienced in river sampling, whereas velocities in the discharge canals are usually equal to or greater than the 2 to 3 ft s^{-1} velocities in the river. Evaluation of intake and discharge data collected at Indian Point suggests that the influence of approach velocity on sampling efficiency may vary with life stage of the entrained organisms.

SECTION 9

STRIPED BASS IMPINGEMENT

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SECTION 9

STRIPED BASS IMPINGEMENT

9.1 INTRODUCTION

Impingement of fish on cooling-water intake screens has been described in Section 2.3.2.4. In the present section, estimates of the total numbers of striped bass impinged at Indian Point, Bowline, Roseton, Lovett, Danskammer, and the Albany Steam Station are made on the basis of sample counts taken at each plant. Numbers of fish impinged are used along with estimates of population size from Section 7.9 to estimate impingement impact for Hudson River striped bass in Sections 11 and 12.

Impingement samples were collected at least biweekly from 1973 to 1975 at the Roseton (RM 65.4; km 105), Bowline Point (RM 37.5; km 60), Lovett (RM 41; km 66), and Danskammer Point (RM 66; km 106) Generating Stations. There was only 1 mo (March 1974 at Lovett) during which no samples were obtained (Table 9.1-1). Sampling on each date was generally over a continuous 24-h interval. Impingement samples were collected daily from operating units at Indian Point from June 1972 to the present date, and procedures are detailed in Section 9.2.1.

Fish were collected at the other four plants in a net, screen, or screen basket positioned to strain the entire flow from the traveling screen washings. The mesh of the collecting nets or screens was always equal to or smaller in size than the plant screen mesh, thereby preventing the escape of impinged fish through the collection gear. Occasionally, collection equipment failed or nets or screens became clogged with debris and overflowed, with consequent loss of specimens. However, these problems were infrequent and few fish were lost. After being collected, fish were brought to the laboratory for processing. The total flow through the plant during each sampling interval was obtained from the plant operators in order to relate the number collected to the volume of water pumped. The rate of impingement was expressed as number of fish impinged per million cubic metres pumped. The monthly impingement rate, computed by averaging the weekly average impingement rates within each month, was multiplied by total monthly flow in millions of cubic metres to estimate total monthly impingement. Total monthly flow was derived from average daily flow for the month, multiplied by number of days in the month.

Table 9.1-1 Frequency of Impingement Sampling at Selected Hudson River Generating Stations other than Indian Point, 1973-75

	Frequency of Sampling		
Power Plant	1973	1974	1975
Roseton RM 65.4; km 105	Biweekly	Biweekly, Jan-Apr; weekly, May-Dec	Weekly, Jan-Dec
Bowline Point RM 37.5; km 60	2-3 samples per mo except Jan (5) and Mar (1)	Jan (3); Feb (1); Mar (3); Apr (2); weekly, May-Dec	Weekly, Jan-Dec (1 extra sample in Jan)
Lovett RM 41; km 66	Biweekly except Jan (5); Feb (4), Apr (3)	Jan (2); Feb (2); Mar (0, plant down); Apr (2); weekly, May-Dec	Weekly, Jan-Dec unless unit not operating
Danskammer RM 66; km 106	Biweekly	Biweekly, Jan-Apr; weekly, May-Dec	Weekly, Jan-Dec (1 extra sample in Jan)

Normally, sampling dates were evenly spaced throughout each month; there were a few occasions, however, when simultaneous samples or samples within a few days of each other were collected. To prevent such cases from weighting the average rate for the month in favor of a short time interval, samples occurring within a week of each other were averaged together before being averaged with the other weekly rates for that month.

Estimates of total monthly impingement did not include adjustments for known but unquantified losses, nor were they adjusted for factors that could inflate estimates. Even when traveling screens were inoperative, they continued to impinge fish if the circulating water pump continued to operate, but these fish could not be collected from the inoperative screens. When a traveling screen was inoperative during a sampling interval, the total number collected was less than the total number impinged, thereby causing the total monthly and annual impingement to be underestimated.

At all plants under consideration, impinged fish were returned to the Hudson River when impingement was not being sampled. Individuals killed as a result of the impingement process may have been reimpinged on the intake screens and accumulated between sampling intervals. If the impingement sample contained the accumulated reimpinged fish, the estimate of total impingement was inflated. Generally, the traveling screens were washed and the collected fish retained prior to initiation of a 24-h sampling interval, thereby removing all accumulated fish from potential recirculation. In a few instances, however, traveling screens were operated continuously or were not washed prior to the sampling period.

Impact assessment to date has assumed 100% mortality of impinged fishes. However, visual observations of fish collected from the traveling screens, as well as preliminary survival experiments, indicate that fish can survive the impingement process and that survival rate is species-specific and probably influenced by environmental conditions, particularly ambient water temperature and salinity. An assumption of 100% mortality for impinged fishes is a maximum estimate of the impingement losses in a population.

Adjustments for inoperative traveling screens, recirculation, and survival have not been made because there are no reliable quantitative estimate of these factors for each plant. These factors may be offsetting to some extent.

9.2 IMPINGEMENT ESTIMATES

9.2.1 INDIAN POINT UNIT 2. Estimates of absolute numbers of striped bass killed by impingement at Indian Point Unit 2 were based on daily collections of fish impinged on the intake screens.

Each cooling-water circulator at Unit 2 is served by an intake forebay with a fixed screen at the entrance and a vertical traveling screen about 10 m behind the fixed screen to prevent fish and debris from entering the circulator (detailed intake descriptions are provided in Section 2.). The screens were normally washed once each day. The collection methods used have been detailed in two annual reports of impingement collection (TI 1974b:II, 1975f:II).

Fishes collected during each screen wash were identified and enumerated. The numbers of striped bass impinged will vary with several environmental, biological, and plant operational variables, including seasonal changes in abundance and distribution of fish and volume of water pumped and salt front movement (Section 13.4). Consequently, striped bass numbers impinged were reported by season delineated by 3-mo intervals beginning January 1, along with volume of water circulated during each time interval (Table 9.2-1). Only during 1973 did striped bass exceed 2% of the total collection; at that time, striped bass composed 5% of the spring season total.

This is a replacement table.

Table 9.2-1 Numbers by Season of Striped Bass Collected and Volume of Water Circulated at Indian Point Unit 2

Numbers Collected and Circulated Vol (10^6 m^3)

	Winter		Spring		Summer		Fall	
Year	No. Collected	Vol. Circul.	No. Collected	Vol. Circul.	No. Collected	Vol. Circul.	No. Collected	Vol. Circul.
1972			4	22.656	45	50.842	20	12.385
1973	784	63.874	468	90.847	263	193.876	228	80.317
1974	1065	51.624	1517	264.296	1328	342.673	658	203.334
1975	778	124.193	534	327.904	2824	329.131	778	280.266

Table 9.2-1 Numbers by Season of Striped Bass Collected and Volume of Water Circulated at Indian Point Unit 2

	Numbers Collected/Circulated Vol (10^6 m^3)							
	Winter		Spring		Summer		Fall	
Year	No. Collected	Vol. Circul.	No. Collected	Vol. Circul.	No. Collected	Vol. Circul.	No. Collected	Vol. Circul.
1972			4	22.687	44	37.229	20	13.091
1973	768	63.799	448	94.687	272	241.721	228	96.385
1974	1065	55.692	1517	264.299	1328	342.727	658	203.021
1975	778	123.753	534	312.887	2824	329.658	778	275.371

Numbers of fish collected from intake screen washes were not an accurate estimate of the actual numbers of striped bass killed by impingement at Indian Point Unit 2(TI 1975f:II-5). Collection efficiency can be affected by the fixed-screen wash procedure, tidal stage at time of the wash, air-bubbler operation, debris load on the screens, and species composition. Marked dead fish were used during 1974 and 1975 to estimate the proportion of impinged fish collected. Collection efficiency tests produced data with a collection mean of 15.38% and a range of 2.0-45.33% (Table 9.2-2). Details of the methods and analyses have already been given by Texas Instruments (TI 1975f:II-5). The limited number of data points and the non-normal nature of the data prevented a definitive statistical analysis of the variance. Therefore, the best available estimate of a scaling factor to adjust impingement collection counts was a multiplier of 6.5* calculated from the mean of the collection values. This estimate was based on tests conducted during air-bubbler operation, because that device generally was used whenever the circulators operated at Unit 2. The validity of this test procedure for collection of consistent data under a variety of plant and environmental conditions was indicated by the data collected at Unit 3 (Section 9.2.2).

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*The multiplier is based on the mean collection efficiency of 0.1538 shown in Table 9.2-2.

Table 9.2-2 Summary of Impingement Collection Efficiency Tests at Indian Point Unit 2 from Which Scaling Factor Was Calculated to Estimate Absolute Numbers of Striped Bass Killed by Impingement

Date	No. Released	% Recovery
Nov 1974	~~400~~ 200	8.00
Nov 1974	~~400~~ 200	16.00
Dec 1974	~~400~~ 200	8.00
Dec 1974	~~400~~ 200	16.50
Jun 1975	150	10.00
Jun 1975	150	8.00
Jun 1975	150	20.00
Jun 1975	150	10.00
Sep 1975	150	45.33
Sep 1975	150	24.67
Oct 1975	150	2.00
Oct 1975	150	16.00
Mean		15.38

Table 9.2-3 Best Estimates of Absolute Numbers of Striped Bass Killed by Impingement at Indian Point Unit 2*.

Year	Winter	Spring	Summer	Fall	Total
1972		26	286	130	442
1973	4,992	2,912	1,768	1,482	11,154
1974	6,923	9,861	8,632	4,277	29,693
1975	5,057	3,471	18,356	5,057	31,941

* Corrected by factor of 6.5 to account for loss of fish during collection process. Assumes 100% mortality of all impinged fishes

This is a replacement Table.

Table 9.2-3 Best Estimates of Absolute Numbers of Striped Bass Killed by Impingement at Indian Point Unit 2*.

Year	Winter	Spring	Summer	Fall	Total
1972		26	293	130	449
1973	5,096	3,042	1,710	1,482	11,330
1974	6,923	9,861	8,632	4,277	29,693
1975	5,057	3,471	18,356	5,057	31,941

*Corrected by factor of 6.5 to account for loss of fish during collection process. Assumes 100% mortality of all impinged fishes

This is a replacement table.

Table 9.2-4 Numbers by Season in 1974 of Striped Bass Collected and Volume of Water Circulated at Indian Point Unit 3*

Season	No. Collected	Vol. of Water Circulated (10^6 m^3)
Winter	1	0.147
Spring	131	22,584
Summer	33	13.911
Fall	41	4.706

Estimates of absolute kill (Table 9.2-3) assumed 100% mortality although some impinged fish not collected may have survived. Several studies have examined survival of impinged fish (TI 1975f:IV-6, LMS 1976b:VIII-5, EA 1976c:3-1), however differences in collection methods and intake structures plus highly variable results precluded basing a survival correction on those data. Because some fish do survive impingement, the estimate of absolute kill reported here probably overestimates actual numbers killed.

9.2.2 INDIAN POINT UNIT 3. Estimates of absolute numbers of striped bass killed by impingement at Indian Point Unit 3 were based on limited operation of the unit during 1974; Unit 3 did not operate during 1975. Unlike Indian Point Unit 2, Unit 3 has only a vertical traveling screen located at the intake for each circulator (Section 2).

Collections were made from two intake screens at 4-h intervals for a 1-wk period each month. All fish collected during those washes were identified and enumerated as described by Texas Instruments (1975f:II). Numbers of striped bass identified from collections were recorded by season, along with volume of water pumped (Table 9.2-4). Unit 3 operated at approximately 5% of maximum pumping capacity during spring 1974 and at <5% flow during all other seasons of that year.

Collection-efficiency tests conducted with marked dead fish at Indian Point Unit 3 during the first half of 1976 yielded a mean collection efficiency of approximately 80%. The data (Table 9.2-5) indicated a large difference in efficiency between Indian Point Units 2 (Section 9.2-1) and 3; the higher efficiency at the latter may have been due to the wash method that included only traveling screens, thus eliminating loss of fish during backwash of fixed screens at Unit 2. Estimates of absolute numbers of striped bass killed at Unit 3 (Table 9.2-6), which were determined using a scaling factor of 1.25 ~~1.2~~ times the actual collection, may have overestimated absolute kill since the survival rate of lost fish had not been determined and was assumed to be zero.

Table 9.2-4 Numbers by Season in 1974 of Striped Bass Collected and Volume of Water Circulated at Indian Point Unit 3*

Season	No. Collected	Vol. of Water Circulated (10^6 m^3)
Spring	110	21.945
Summer	33	13.608
Fall	41	4.833

*Unit was not operated during winter.

Table 9.2-5 Summary of Impingement Collection Efficiency Tests at Indian Point Unit 3 from which Scaling Factor was Calculated to Estimate Absolute Numbers of Striped Bass Killed by Impingement

Date	No. Released	% Recovery
JUNE ~~May~~ 1976	50	82.0
JUNE ~~May~~ 1976	50	80.0
Jun 1976	50	86.0
Jun 1976	100	81.0
Jul 1976	100	75.0
Jul 1976	100	76.0
Aug 1976	100	79.0
Mean		79.9

Table 9.2-6 Best Estimates of Absolute Numbers of Striped Bass Killed by Impingement at Indian Point Unit 3*

Season	No. Killed
Spring	~~132~~ 164
Summer	~~40~~ 41
Fall	~~49~~ 51

*Corrected by factor of ~~1.2~~ 1.25 to account for loss of fish. Assumes 100% mortality.

This is a replacement Table.

Table 9.2-7 Numbers by Season of Striped Bass Collected and Volume of Water Circulated at Indian Point Unit 1

	No. Collected and Water Volume Circulated (10^6 m^3)							
	Winter		Spring		Summer		Fall	
Year	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.
1972			6	20.279	895	127.304	645	104.668
1973	0	2.193	17	29.745	0	5,183	39	*
1974	278	60.608	440	97.860	287	143.874	570	88.444
1975	938	45.221	108	40.737	17	10.910	Unit Inoperative	

*No flow recorded

9.2.3 INDIAN POINT UNIT 1. Estimates of absolute numbers of striped bass killed by impingement at Indian Point Unit 1 have been determined since June 15 1972, when Texas Instruments began monitoring impingement collections; those estimates contributed to the background mortality attributed to pre-1970 power plant operation. Circulator operation was limited during 1973 and the first half of 1975 and was completely absent subsequent to August 29, 1975; however, when circulators were operated, the associated intake screens were generally washed at least once a day and all fish collected from each screen were identified and enumerated (TI 1974b:II, 1975f:II). Similar to Unit 2, Unit 1 has a vertical traveling screen located behind a fixed screen.

Impingement counts can be affected by several environmental, biological, and plant operational variables including seasonal changes in abundance and distribution of fish, as well as volume of water pumped; therefore, Table 9.2-7 summarizes the numbers of striped bass by season and volume of water pumped.

Table 9.2-7 Numbers by Season of Striped Bass Collected and Volume of Water Circulated at Indian Point Unit 1

	No. Collected and Water Volume Circulated (10^6 m^3)							
	Winter		Spring		Summer		Fall	
Year	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.
1972			8	12.536	886	111.995	634	77.629
1973	0	1.232	17	22.295	0	3.867	39	*
1974	278	61.202	440	97.636	287	143.879	313	88.523
1975	938	48.335	108	40.741	17	10.910	Unit Inoperative	

*No flow recorded.

9.2.4 ROSETON GENERATING STATION. Estimates of total numbers of striped bass impinged at the Roseton Generating Station from 1974 through 1975 appear in Table 9.2-8. Since this plant was in only limited operation during 1973, total monthly and annual impingement estimates for that year are not presented.

Table 9.2-8 Estimated Total Annual Impingement of Striped Bass at Roseton Generating Stations, 1974-75*

	1974			1975		
Month	No./MCM[†]	MCM/Mo	No./Mo	No./MCM	MCM/Mo	No./Mo
Jan	0.53	3.14	2	2.64	71.75	189
Feb	NS[‡]	0.69	-	0.00	75.76	0
Mar	0.00	9.27	0	0.00	70.82	0
Apr	0.26	31.37	8	0.00	68.52	0
May	1.58	16.40	26	0.00	88.49	0
Jun	1.58	23.14	37	0.00	82.25	0
Jul	0.79	24.35	19	5.28	93.34	492
Aug	1.06	57.55	61	5.28	74.22	391
Sep	1.06	49.12	52	2.64	65.94	174
Oct	1.58	24.25	38	5.28	75.75	399
Nov	3.70	64.88	240	2.64	66.37	175
Dec	0.53	70.68	37	0.00	39.97	0
Total			520			1,820

* Limited operation precludes 1973 estimates.

[†] MCM - Million cubic metres

[‡] NS - No samples

9.2.5 BOWLINE POINT GENERATING STATION. Estimates of total numbers of striped bass impinged at the Bowline Point Generating Station from 1973 through 1975 appear in Table 9.2-9. From January 1973 through May 1974, only Unit 1 at this plant was in operation; from June 1974 to December 1975, however, both Units 1 and 2 were in operation.

9.2.6 LOVETT GENERATING STATION. Estimates of total numbers of striped bass impinged at the Lovett Generating Station from 1973 through 1975 appear in Table 9.2-10.

9.2.7 DANSKAMMER GENERATING STATION. Estimates of total numbers of striped bass impinged at the Danskammer Point Generating Station from 1973 through 1975 appear in Table 9.2-11.

9.2.8 ALBANY STEAM STATION. Impingement at the Albany Steam Station was sampled from April 1974 through March 1976. From the beginning of the survey through March 1975, a sample was taken for 24h (consecutive) every Monday and Friday; from April 1975 through March 1976, sampling was biweekly, with alternating 12- and 24-h samples.

The traveling screen wash sluices at the Albany Steam Station empty into drains that return impinged fish to the river a short distance downstream of the plant intake. Because this section of the Hudson River is tidal, fish killed in the impingement process could be carried by river currents to the intakes and become reimpinged. Fish were collected with a screen placed across the discharge of the sluices that carried the traveling screen wash water; the collecting screen mesh was the same size as the plant screen mesh. No samples were lost due to collecting screen failure or overflow during the 2 yr of impingement sampling at the Albany Steam Station; however, there were inoperative traveling screens that impinged fish that could not be collected.

Table 9.2-9 Estimated Total Annual Impingement of Striped Bass at Bowline Point Generating Station, 1973–75

	1973			1974			1975		
Month	No./MCM*	MCM/Mo	No./Mo	No./MCM	MCM/Mo	No./Mo	No./MCM	MCM/Mo	No./Mo
Jan	28.78	57.5	1,655	130.68	53.5	6,991	266.64	92.96	24,787
Feb	45.94	45.7	2,101	259.25	38.6	9,996	66.00	75.70	4,996
Mar	19.27	15.5	299	189.55	53.4	10,118	161.04	81.41	13,109
Apr	44.88	51.7	2,321	552.29	61.7	34,092	380.16	84.11	31,974
May	8.45	62.5	528	19.80	31.8	629	2.64	54.62	144
Jun	0.00	41.4	0	0.79	77.0	61	0.00	81.57	0
Jul	7.39	50.4	373	2.11	101.0	213	2.64	93.88	247
Aug	3.96	60.0	238	1.32	108.5	143	0.00	105.66	0
Sep	1.06	60.1	63	2.64	118.0	311	0.00	102.85	0
Oct	1.32	64.9	86	19.54	126.2	2,465	0.00	55.84	0
Nov	4.22	52.7	222	22.44	87.3	1,958	0.00	51.71	0
Dec	24.02	48.4	1,164	139.92	106.7	14,927	87.12	88.27	7,690
Total			9,050			81,904			82,947

* MCM - Million cubic metres

Table 9.2-10 Estimated Total Annual Impingement of Striped Bass at Lovett Generating Station, 1973–75

	1973			1974			1975		
Month	No./MCM*	MCM/Mo	No./Mo	No./MCM	MCM/Mo	No./Mo	No./MCM	MCM/Mo	No./Mo
Jan	2.90	50.0	145	75.77	43.8	3,318	39.60	42.56	1,685
Feb	9.24	43.9	406	59.93	31.8	1,907	23.76	35.62	846
Mar	1.32	49.7	66	NS†	29.9	NA‡	26.40	25.19	664
Apr	16.10	43.6	703	53.59	36.1	1,934	42.24	21.73	918
May	0.26	41.0	11	5.02	38.3	192	0.00	30.06	0
Jun	2.38	45.5	108	7.66	37.4	286	2.64	35.93	94
Jul	1.06	49.9	53	1.85	20.5	38	2.64	36.88	97
Aug	10.56	51.5	544	4.22	40.5	171	7.92	38.39	304
Sep	2.38	43.7	104	3.17	37.5	119	5.28	26.41	139
Oct	2.11	35.1	74	11.62	26.9	312	2.64	32.16	84
Nov	12.67	42.5	539	10.03	38.8	390	15.84	30.77	487
Dec	23.76	44.4	1,055	12.67	38.7	491	13.20	30.98	408
Total			3,808			9,158			5,726

* MCM- Million cubic metres
‡ NA - Not applicable
† NS - No samples

Table 9.2-11 Estimated Total Annual Impingement of Striped Bass at Danskammer Point Generating Station, 1973–75

	1973			1974			1975				
							No./MCM UNITS		MCM/Mo UNITS		
Month	No./MCM*	MCM/Mo	No./Mo	No./MCM	MCM/Mo	No./Mo	1&2	3&4	1&2	3&4	No./Mo
Jan	0.00	30.95	0	4.75	30.75	146	7.92	0.00	7.47	24.21	59
Feb	1.32	23.97	32	0.79	28.76	23	2.64	0.00	6.74	15.34	17
Mar	0.00	29.59	0	0.00	30.59	0	0.00	0.00	7.13	6.96	0
Apr	0.26	34.16	9	7.39	29.21	216	5.28	0.00	7.49	7.75	39
May	2.38	43.52	103	8.18	39.39	322	0.00	0.00	12.27	15.84	0
Jun	8.71	47.38	413	19.27	33.90	653	18.48	7.92	11.13	35.04	482
Jul	33.26	52.82	1,757	40.66	46.19	1,878	10.56	2.64	12.08	32.51	213
Aug	15.84	53.28	844	25.87	49.70	1,286	7.92	5.28	10.27	38.88	286
Sep	35.64	50.45	1,798	16.10	43.31	697	0.00	7.92	8.06	37.51	297
Oct	233.11	39.84	9,288	8.71	48.94	426	10.56	15.84	10.50	31.72	613
Nov	71.54	39.58	2,832	6.34	42.55	270	18.48	10.56	5.04	34.51	457
Dec	34.85	29.12	1,015	12.12	42.55	517	0.00	13.20	3.56	23.98	316
Total			18,091			6,434					2,779

* MCM - Million cubic metres

Since the traveling screens were not washed prior to the start of an impingement sampling interval, accumulated reimpinged fish could have been included in the impingement sample. If substantial numbers of reimpinged fish had occurred in the samples, the computed impingement rates would have overestimated the total number impinged.

The survival rate of impinged fish at Albany has not been quantified; so an assumption of 100% mortality would cause an overestimate of the total number of fish killed (assuming that the estimate accounts for other sources or error).

The number of fish impinged per million cubic metres on each sampling date was computed from the total number collected and the total flow during the sampling interval (Table 9.2-12). From April 1974 through March 1975, the mean monthly impingement rate was the mean of the impingement rate for each sampling interval in that month. From April 1975 through March 1976, the mean monthly impingement rate was computed by averaging the two diurnal samples per month to obtain a mean day rate and then averaging the day rate with the night rate to obtain a mean monthly impingement rate.

Table 9.2-12 Estimated Total Annual Impingement of Striped at Albany Steam Electric Generating Station, April 1974-December 1975*

Month	1974**			1975***		
	No./MCM†	MCM/Mo	No./Mo	No./MCM	MCM/Mo	No./Mo
Jan				0.00	58.54	0
Feb				0.00	42.02	0
Mar				0.00	42.78	0
Apr	0.00	56.41	0	0.00	47.26	0
May	13.20	57.45	758	2.64	41.07	108
Jun	116.16	57.60	6,691	29.04	47.30	1,374
Jul	81.84	59.34	4,856	36.96	39.18	1,448
Aug	66.00	59.51	3,928	39.60	49.06	1,943
Sep	42.24	55.49	2,344	29.04	50.75	1,474
Oct	15.84	56.76	899	5.28	45.25	239
Nov	2.64	57.55	152	0.00	42.00	0
Dec	0.00	59.44	0	0.00	47.70	0
Total			19,628			6,586

* Mean monthly impingement rate of 0.01 deleted.

** From April 1974 to March 1975, total flow in million cubic metres per month is computed from mean total flows on days of impingement sampling.

*** From April 1975 to March 1975, total flow in million cubic metres per month is computed from mean total flows on all operating days in each month.

† MCM - Million cubic metres

9.3 SUMMARY OF IMPINGEMENT DATA AND BEST ESTIMATE OF NUMBERS AND WEIGHT OF ABSOLUTE KILL

9.3.1 NUMBERS. To estimate the absolute numbers of striped bass killed by impingement by season for 1973, 1974, and 1975 (Tables 9.3-1, 9.3-2, and 9.3-3), numbers impinged (Section 9.2) were summarized by 3-mo periods for each plant, for all plants combined, and for the post-1970 units (Bowline, Roseton, and Indian Point Units 2 and 3). Impingement estimates for the Albany Steam Station are not included in this summary. To assess the impact of power plant operation on the Hudson River striped bass population, these numbers must be viewed in light of existing population size, total mortality rate, and the ability of the striped bass population to compensate for density-independent changes in mortality (Sections 11 and 12).

The number of striped bass impinged at any plant during a season is a function of the spatiotemporal distribution and abundance of fish, coupled with each unit's magnitude of operation. In 1973, striped bass impingement was highest in the fall at the upriver plant (Danskammer); in 1974 and 1975, however, impingement was highest during the winter at the downriver plant (Bowline). This pattern suggested a major shift in the distribution of juvenile striped bass between years. The high impingement at Bowline was indicative of its location on the nursery and overwintering areas of Croton-Haverstraw Bay. The increase in impingement for all plants combined from 1973 to the levels of the 1974 and 1975 paralleled increased operation of the post-1970 units between 1973 and 1974 (Table 9.3-4).

If absolute kill is to be estimated, the number of striped bass impinged must be adjusted to account for the ability of juveniles to survive the impingement process. As noted earlier, 100% impingement mortality was assumed for this discussion; this provided an upperbound estimate of impingement kill, as preliminary studies showed that large numbers of impinged fish often survive.

This is a replacement Table.

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Table 9.3-1 Estimates of Absolute Numbers of Striped Bass Killed by Impingement at Each Plant, All Plants Combined, and Post-1970 Units during 3-Mo Intervals, 1973

Plant	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Annual
Bowline	4,055	2,849	674	1,472	9,050
Lovett	617	822	701	1,668	3,808
Indian Point Unit 1	0	17	0	39	56
Indian Point Unit 2	5,096	3,042	1,710	1,482	11,330
Indian Point Unit 3	*	*	*	*	*
Indian Point-all units combined	5,096	3,059	1,710	1,521	11,386
Roseton	*	*	*	*	*
Danskammer	32	525	4,399	13,135	18,091
Post-1970 units	9,151	5,891	2,384	2,954	20,380
All plants combined	9,800	7,255	7,484	17,796	42,335

*Not operating

Table 9.3-1 Estimates of Absolute Numbers of Striped Bass Killed by Impingement at Each Plant, All Plants Combined, and Post-1970 Units during 3-Mo Intervals, 1973

Plant	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Annual
Bowline	4,055	2,849	674	1,472	9,050
Lovett	617	822	701	1,668	3,808
Indian Point Unit 1	0	17	0	39	56
Indian Point Unit 2	4,992	2,912	1,768	1,482	11,154
Indian Point Unit 3	*	*	*	*	*
Indian Point-all units combined	4,992	2,929	1,768	1,521	11,210
Roseton	*	*	*	*	*
Danskammer	32	525	4,399	13,135	18,091
Post-1970 units	9,047	5,761	2,442	2,954	20,260
All plants combined	9,696	7,125	7,542	17,796	42,159

*Not operating

Table 9.3-2 Estimates of Absolute Numbers of Striped Bass Killed by Impingement at Each Plant, All Plants Combined, and Post-1970 Units during 3-Mo Intervals, 1974

Plant	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Annual
Bowline	27,105	34,782	667	19,350	81,904
Lovett	5,225	2,412	328	1,193	9,158
Indian Point Unit 1	278	440	287	~~313~~ 570	~~1,318~~ 1,575
Indian Point Unit 2	6,923	9,861	8,632	4,277	29,693
Indian Point Unit 3	~~*~~ 1	~~132~~ 164	~~40~~ 41	~~49~~ 51	~~221~~ 257
Indian Point-all units combined	~~7,201~~ 7,202	~~10,433~~ 10,465	~~8,959~~ 8,960	~~4,639~~ 4,898	~~31,232~~ 31,525
Roseton	2	71	132	315	520
Danskammer	169	1,191	3,861	1,213	6,434
Post-1970 units	~~34,030~~ 34,031	~~44,846~~ 44,878	~~9,471~~ 9,472	~~23,991~~ 23,993	~~112,338~~ 112,374
All plants combined	~~39,702~~ 39,703	~~48,889~~ 48,921	~~13,947~~ 13,948	~~26,710~~ 26,969	~~129,248~~ 129,541

delete — *Not operating

Table 9.3-3 Estimates of Absolute Numbers of Striped Bass Killed by Impingement at Each Plant, All Plants Combined, and Post-1970 Units during 3-Mo Intervals, 1975†

Plant	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Annual
Bowline	42,892	32,118	247	7,690	82,947
Lovett	3,195	1,012	540	979	5,726
Indian Point Unit 1	938	108	17	*	1,063
Indian Point Unit 2	5,057	3,471	18,356	5,057	31,941
Indian Point Unit 3	*	*	*	*	*
Indian Point -all units combined	5,995	3,579	18,373	5,057	33,004
Roseton	189	0	1,057	574	1,820
Danskammer	76	521	796	1,386	2,779
Post-1970 units	48,138	35,589	19,660	13,321	116,708
All plants combined	52,347	37,230	21,013	15,686	126,276

†Assumes 100% mortality.
*Not operating.

~~Table 9.3-4 Pumping Rates of Post-1970 Units and All Plants Combined during 1973, 1974, and 1975~~

	~~1973~~	~~1974~~	~~1975~~
~~Post-1970 units~~	~~1,107.4*~~	~~2,245.1~~	~~2,883.5~~
~~All plants combined~~	~~2,150.4~~	~~3,522.3~~	~~3,776.1~~

~~*Indian Point Unit 1 flow not recorded for Oct-Dec 1973.~~

This is a replacement table.

Table 9.3-4 Pumping Rates of Post-1970 Units and All Plants Combined during 1973, 1974, and 1975

	Volume ($10^6 m^3$) per Year		
	1973	1974	1975
Post-1970 units	1,039.7	2,241.8	2,903.3
All plants combined	2,092.3*	3,518.6	3,792.8

*Indian Point Unit 1 flow not recorded for Oct-Dec 1973.

While the results are extremely variable, recent investigations of white perch impingement survival at Bowline (EA 1976c) suggest that impingement survival is related to both conductivity and temperature (Fig. 9.3-1), Impingement survival is highest during periods of high conductivity and low temperature, conditions often existing during mid-winter periods of salt front intrusion when impingement is sometimes extremely high. Thus, during these periods, impingement survival should also be high.

9.3.2 WEIGHT. Estimates of the weight of the striped bass killed by impingement were calculated for each plant, the post-1970 units, and all plants combined (Tables 9.3-5, 9.3-6, and 9.3-7). To estimate the total weight of striped bass impinged, estimates of the seasonal average weight per fish impinged at Indian Point were multiplied by the estimated numbers impinged. These estimates must be viewed in light of the existing biomass of striped bass in the estuary, as well as the potential for compensatory changes in mortality rates (Section 10.4). The weight of striped bass killed by impingement is a function of the number of striped bass killed by impingement and the average weight per fish. For this estimation, the same seasonal average weight per fish has been used for each plant. Thus, differences between plants of the weight of striped bass impinged parallel the differences in numbers of striped bass impinged.

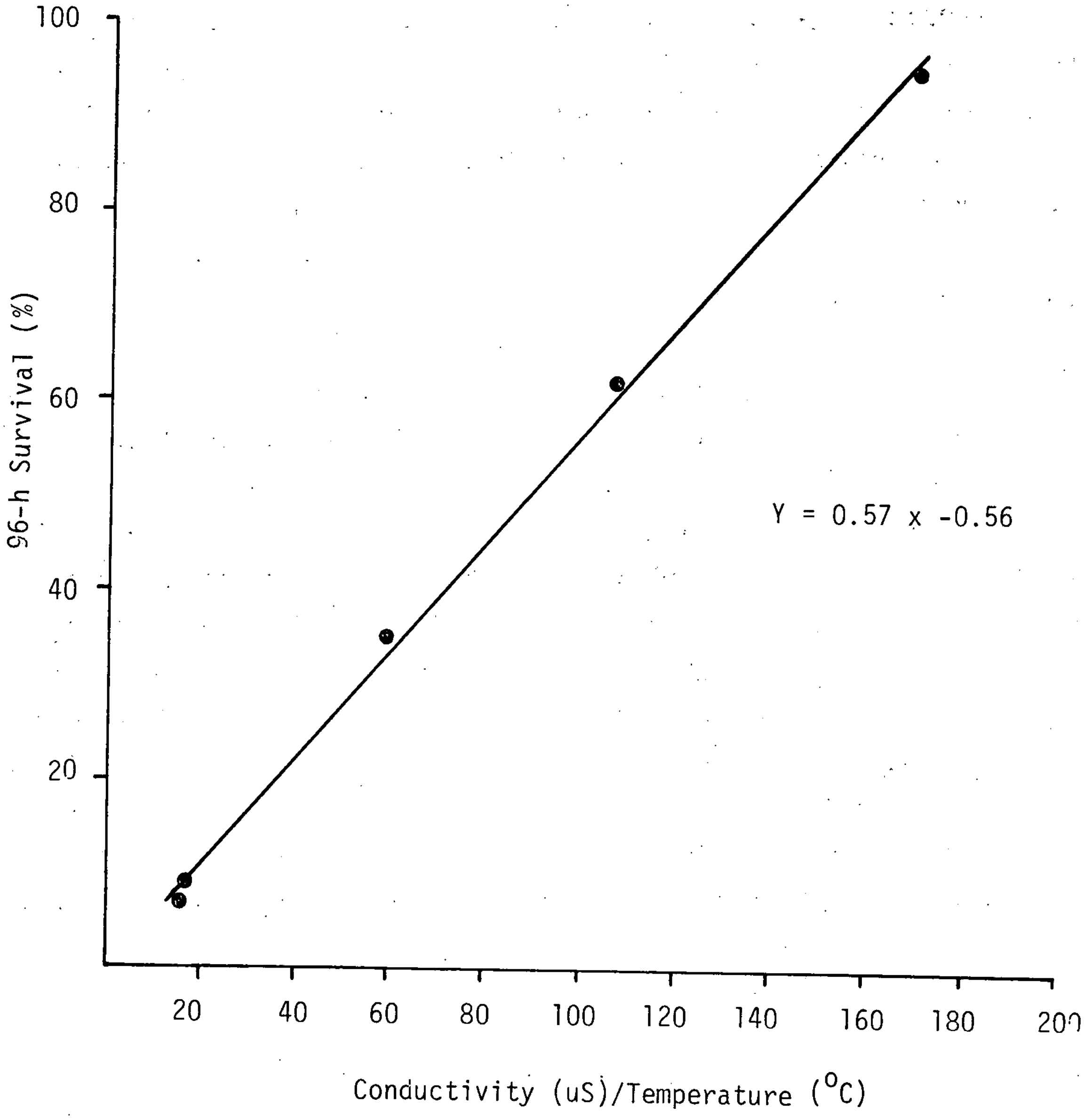

Figure 9.3-1 Relationship between Long-Term Survival of Impinged White Perch and Salinity-Temperature Interaction Term (Adapted from EAI 1976c:Table 7.3.2)

This is a replacement Table.

Table 9.3-5 Estimates of Absolute Weight (Pounds) of Striped Bass Killed by Impingement at Each Plant, All Plants Combined, and Post-1970 Units during 3-Mo Intervals, 1973

Plant	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Annual
Bowline	48.7	51.3	13.5	25.0	138.5
Lovett	7.4	14.8	14.0	28.4	64.6
Indian Point Unit 1	0.0	0.3	0.0	0.7	1.0
Indian Point Unit 2	61.2	54.8	34.2	25.2	175.4
Indian Point Unit 3	*	*	*	*	*
Indian Point all units combined	61.2	55.1	34.2	25.9	176.4
Roseton	*	*	*	*	*
Danskammer	0.4	9.5	88.0	223.3	321.2
Post-1970 units	109.8	106.0	47.7	50.2	313.7
All plants combined	117.6	130.6	149.7	302.5	700.4

*Not operating

Table 9.3-5 Estimates of Absolute Weight (Pounds) of Striped Bass Killed by Impingement at Each Plant, All Plants Combined, and Post-1970 Units during 3-Mo Intervals, 1973

Plant	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Annual
Bowline	56.8	51.3	12.8	25.0	145.9
Lovett	8.6	14.8	13.3	28.4	65.1
Indian Point Unit 1	0.0	0.3	0.0	0.7	1.0
Indian Point Unit 2	69.9	57.1	33.6	31.8	192.4
Indian Point Unit 3	*	*	*	*	*
Indian Point all units combined	69.9	57.4	33.6	72.5	193.4
Roseton	*	*	*	*	*
Danskammer	0.5	9.5	83.6	223.3	316.9
Post-1970 units	126.7	108.4	46.4	56.8	338.3
All plants combined	135.8	133,0	143.3	309.2	721.3

* Not operating

Table 9.3-6 Estimates of Absolute Weight (Pounds) of Striped Bass Killed by Impingement at Each Plant, All Plants Combined, and Post-1970 Units during 3-Mo Intervals, 1974

Plant	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Annual
Bowline	460.8	660.9	30.7	~~774.0~~ 716.0	~~1,926.4~~ 1,868.4
Lovett	88.8	45.8	15.1	~~47.7~~ 44.1	~~197.4~~ 193.8
Indian Point Unit 1	4.7	8.4	13.2	~~12.5~~ 21.1	~~38.8~~ 47.4
Indian Point Unit 2	117.7	187.4	397.1	~~171.1~~ 158.2	~~873.3~~ 860.4
Indian Point Unit 3	<0.1 X	~~2.5~~ 3.1	~~1.8~~ 1.9	~~2.0~~ 1.9	~~6.3~~ 6.9
Indian Point, all units combined	122.4	~~198.3~~ 198.9	~~412.1~~ 412.2	~~185.6~~ 181.2	~~918.4~~ 914.7
Roseton	<0.1	1.3	6.1	~~12.6~~ 11.7	~~20.1~~ 19.1
Danskammer	2.9	22.6	177.6	~~48.5~~ 44.9	~~251.6~~ 248.0
Post-1970 units	578.5 ~~578.6~~	~~852.1~~ 852.7	435.7	~~959.7~~ 887.7	~~2,826.1~~ 2,754.6
All plants combined	675.0	~~928.9~~ 929.5	641.6	~~1,068.4~~ 997.9	~~3,313.9~~ 3,244.0

Delete

* Not operating

Table 9.3-7 Estimates of Absolute Weight (Pounds) of Striped Bass Killed by Impingement at Each Plant, All Plants Combined, and Post-1970 Units during 3-Mo Intervals, 1975

Plant	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Annual
Bowline	986.5	674.5	2.2	207.6	1,870.8
Lovett	73.5	21.3	4.9	26.4	126.1
Indian Point Unit 1	21.6	2.3	0.2	*	24.1
Indian Point Unit 2	116.3	72.9	165.2	136.5	490.9
Indian Point Unit 3	*	*	*	*	*
Indian Point, all units combined	137.9	75.2	165.4	136.5	515.0
Roseton	4.3	0.0	9.5	15.5	29.3
Danskammer	1.7	10.9	7.2	37.4	57.2
Post-1970 units	~~1,107.1~~ 1,107.2	747.4	176.9	~~359.6~~ 359.7	2,391.0
All plants combined	~~1,203.9~~ 1,204.0	~~781.9~~ 781.8	~~189.2~~ 189.1	~~423.4~~ 423.5	2,598.4

* Not operating

SECTION 10

COMPENSATION IN STRIPED BASS POPULATIONS

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SECTION 10

COMPENSATION IN STRIPED BASS POPULATIONS

10.1 HISTORICAL DEVELOPMENT OF GENERAL CONCEPT

10.1.1 DEFINITION. The term "compensation" refers to the tendency of populations of living organisms to experience (a) an increase in death rate or decrease in birth rate as they grow in density, thus establishing some ultimate upper limit, and (b) a decrease in death rate or increase in birth rate as population density declines, thus leading to stabilization before extinction, or even to an eventual return to higher numbers.

The concept arises directly from recognition that living organisms depend on resources such as food and space, which are available in limited amounts. When density of organisms is low, competition for resources is slight; when density is high, competition becomes intense to the disadvantage of survival or reproduction. It is also possible that large populations will attract greater attention from predators either because the latter congregate in the vicinity of a food source or reproduce more rapidly when prey is abundant or become conditioned to seek the more abundant prey. Cannibalism also may contribute importantly to compensation in some species because the large numbers of parents from which initially large broods arise also constitute a large pool of predators. The number of physical and biological forces that may play a role in compensation is very large, and the possible modes of operation are numerous and complex. As Cushing (1975:237) describes it, "Any description of the phenomenon reveals the stability and leaves the possible mechanisms indistinct." This is not to say that no mechanisms of compensation can be identified; many indeed have been identified, and a number of examples will be cited in the following sections. However, of the number of mechanisms operating simultaneously (often with a high degree of interaction) and sequentially through the various life-history stages--with intensity of operation at each stage determined in part by the population density established in the preceding stage--only a few may be statistically verifiable during a single period of observation. Undoubtedly too, the operation of one mechanism under certain environmental conditions may preempt the operation of other potentially effective mechanisms.

Thus, a common state of affairs is to observe the stability in a population generated by compensation and even be able to estimate the compensatory capacity while not being able to explain all or even very many of the mechanisms involved. This latter limitation has not prevented scientists from developing highly successful management programs grounded on the reality of compensation, as will be shown.

Because compensation involves changes in birth rates or death rates in response to changes in population density, the biological processes involved are often termed "density dependent". Thus, a density-dependent increase in mortality rate might be expected to result from a substantial increase in population density. Strictly speaking, only processes that reduce population growth at high densities and increase growth at low densities--"direct density-dependent processes"*-are compensatory. Nevertheless, the term "density dependence" is often used synonymously with "compensation."

10.1.2 DEVELOPMENT OF CONCEPT. The concept of compensation is very important in assessing the impact of power plant operation on fish populations because compensation represents the capacity of a fish population to offset, in whole or in part, reductions in numbers caused

---

*Mortality may also take an <u>inverse</u> density-dependent form; i.e., the mortality rate decreases with an increase in population density. This could happen where very abundant prey "saturate" the capacity of a predator to capture them, thereby causing a smaller fraction of the prey to be caught when they are more abundant. Other types of "protection in numbers" would bring about the same result. Inverse density-dependent mortality is not synonymous with compensation.

by entrainment and impingement kills. However, not only the extent but even the reality of compensation in Hudson River striped bass has been contested by the NRC staff. In the staff's Indian Point 3 review, the position taken was that the fishery operates in a compensatory manner but that no natural compensatory processes have been demonstrated and hence none should be accounted in assessing power plant impact (USNRC 1975b). This position represents a slight retrenchment from the one taken in relation to Summit Power Station Units 1 and 2 in July 1974: "Examination of relevant information concerning striped bass populations has led the staff to conclude that density-dependent regulatory processes as described above are not operative in East Coast striped bass larval and juvenile populations, because the breeding stock is not sufficient to saturate the nursery areas to population levels at which such processes would be operative" (USAEC 1974). An opposite position is taken in this report. It is maintained, as a general proposition, that some natural compensatory capacity must be recognized as a logical necessity; that general observation of natural populations, a wide range of specific scientific studies, and the prevailing concepts of the field of fishery management all support this view; and that the operation of compensation in the Hudson River striped bass population can be empirically demonstrated and quantified.

Resistance during the course of the Indian Point proceedings notwithstanding, the concept of compensation has been long and widely accepted. In 1798 Thomas Malthus published his famous *Essay On The Principle Of Population* (Malthus, 1798) in which he maintained that, when unchecked, a population increases in a geometrical ratio; that the increase is always up to the limits of the means of subsistence; and that further increase is prevented by war, famine, pestilence, etc. He termed the processed involved in regulation of population size the "struggle for existence". His observations, based on human populations, clearly encompassed the compensatory concept that population growth declines as population size increases. The ideas presented by Malthus were not entirely new; for example, Machiavelli had realized 275 yr earlier that human populations in some areas might increase beyond the limits of subsistence and be checked by want and disease. In 1835, Quetelet, a Belgian statistician, concluded that a population's resistance to growth increases in proportion to the square of the rate of population growth (Quetelet 1835). In 1838, Verhulst, a student of Quetelet, published a short essay developing an equation describing the course of population increases in proportion to population density; his equation generated the S-shaped population growth curve so familiar today, the logistic curve. Nearly 100 yr later, this formulation of population growth was rediscovered by Pearl and Reed (1920) and was soon shown to describe the performance of such diverse organisms as yeast, protozoa, fruit flies, and man. Pearl recognized the importance of density-dependent mortality and reproduction stating, "In general there can be no question that this whole matter of influence of density of population, in all senses, upon biological phenomena, deserves a great deal more investigation than it has had. All indications are that it is one of the most significant elements in the biological, as distinguished from the physical, environment of organisms" (Pearl 1930:145).

In the last four decades, the concept of compensation has been debated, refined, and amplified. A well-balanced review is presented by Krebs (1972:269-288). Major contributions to our understanding have come from studies of insects, fishes, birds, and ~~memals~~ mammals,. Despite the long history of the concept and its simple, almost intuitive basis, its explicit formulation and modern emphasis are usually attributed to the Australian entomologist Nicholson (1933). His inspiration was later referred to by another notable population ecologist (Haldane 1953) as "a blinding glimpse of the obvious."

Thus, the emergence of the concept of compensation can be traced over the past 450 yr. It seems to have originated in observations of local human populations "struggling for existence" in the face of limited resources. The first formulations were crude and partially incorrect.

It was Pearl's work in the 1930s that established the generality of compensation among diverse types of living organisms. Common to all these perceptions was the realization that populations possessed a potential to increase at a much more rapid pace than was realized, except possibly when they were so small that the resources upon which they depended were, for all practical purposes, infinite in extent.

To appreciate the reality, pervasiveness, and imminence of operation of compensation within a population, one should look first to this "biotic potential" as it is sometimes called and then envision as a population grows in size "the absorption of the potential increase by innumerable checks (in the shape of mortality)... is the struggle for existence," The survivors flourish by the deaths of their brothers and sisters, and the stable numbers must be the result of a fine control of mortality, perhaps a density-dependent one" (Cushing 1975). Approaching population processes from this perspective, one envisions the established population as one in which survival or reproduction (or both) have been vastly suppressed--precisely for the reason that the population has become large. The natural factors that operate to suppress the biotic potential are many and are complexly intertwined--availability of food, predators, disease, and physical factors such as temperature. Many of them (probably all of them under certain conditions) have greater suppressive effect when the population is large than when it is small. If some new effect that kills off part of the population is introduced, in so doing it reduces the suppressive effect of many factors in the population's environment. As a consequence, survival rate or reproductive rate becomes higher--the population <u>compensates</u> in part for the reduction in size. When something causes a population to either increase or decrease in size, there is a tendency for eventual return to average size. "Populations do not usually become extinct or increase to infinity. This is what is loosely termed the 'balance of nature'" (Krebs 1972).

Rather than being a fragile living system then, the population typically is vigorous and resilient. This sense was captured admirably by that eminent interpreter of marine science, the late Rachel Carson, who, in describing the life of the seacoast, wrote, "Whenever the sea builds a new coast, waves of living creatures surge against it, seeking a foothold, establishing their colonies. And so we come to perceive life as a force as tangible as any of the physical realities of the sea, a force strong and purposeful, as incapable of being crushed or diverted from its ends as the rising tide" (Carson 1955).

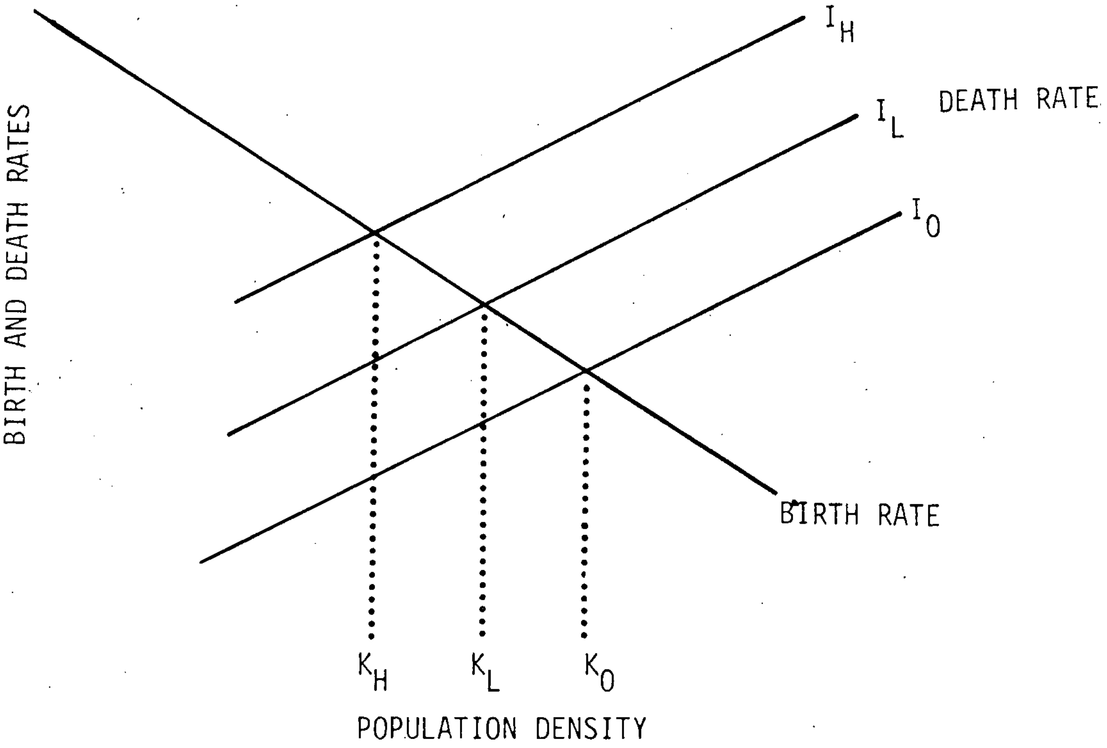
The 10 yr span from the mid 1960s to the mid-1970s has seen an impressive and timely increase in public awareness of environmental problems. With this awakening has come an accurate perception of the fragility of the ecosystem, which may seem at first to conflict with the description of life as "...a force...as incapable of being crushed or diverted from its ends as the rising tide." The apparent conflict is easily explained. Populations of most living organisms have little means of coping with wholesale destruction of environmental resources upon which they depend. If specific foods or narrow temperature ranges to which they are highly adapted are destroyed, the population perishes. Likewise, exposure to toxic substances such as the many organic compounds introduced into the environment by man, with which a natural population has no evolutionary experience, is likely to prove disastrous. Most of the current environmental awareness is built on public recognition of these two classes of problems--wholesale destruction of environmental resources and the release of exotic toxic substances. A third class of man-caused problems--the imposition on a population of increased mortality that takes a form similar to natural predation--has an entirely different effect on most species. This is the kind of impact to which the population has been adapted by thousands or millions of years of evolutionary experience. The agent of mortality--predatory fish, commercial or sport fishermen, or power plant--is an indifferent matter from the standpoint of population response. When the population is reduced in numbers, the survival rate or reproductive rate among the remaining members tends to increase: a compensating response is generated. This is the reality upon which successful management of agriculture, forestry, wildlife, and fisheries is carried on today. The population has a measurable and often impressive capacity to persist in a healthy state in the face of deliberate removals by man. Populations of most species, while fragile when deprived of basic life requisites or exposed to exotic toxicants, are robust in the face of this predation-type mortality.

10.2 A GENERAL CASE ARGUMENT

A formal argument for the general operation of compensation in animal populations can be developed as follows. It is generally observed that populations fluctuate within some more or less well-described bounds, i.e., they neither increase without limit nor commonly decline to extinction during the normal time span of human observation.

A useful simplification is to represent a population as persisting at or near some average level of abundance or equilibrium level represented by K_0 (Fig. 10.2-1). As a generalization, the birth rate is expected to decline and the death rate to increase as a population becomes larger and larger. Linear relationships are used to simplify the illustration, even though the real relationships would almost certainly be nonlinear. Death rate would reflect the combination of natural deaths and any deaths imposed on the population by activities of man. In Figure 10.2-1, the equilibrium population density K_0 is maintained, on the average, by the balance between the death rate (I_0, representing the prevailing natural death rate + 0 level of man-caused deaths) and the birth-rate characteristic of the population at density K_0. If a low level of man-induced mortality is added to the baseline natural mortality, the overall death rate would increase to a level I_L (Fig. 10.2-1). The population would then decline and the birth rate would consequently increase until a new equilibrium density had been reached (K_L) at which the birth rate equaled the new death rate I_L. Imposition of a still higher man-induced mortality would increase the total death rate to I_H, and the population would equilibrate eventually at a still lower average density

K_H. Thus, one can think of the population as fluctuating through time around some average level of abundance determined by the overall death rate (Fig. 10.2-2). For a 0-level man-induced environmental impact, this would be population density K_0; for a low level of environmental impact, population level K_L; and for a high level of environmental impact, at a still lower level of abundance, K_H.



Death rate I_0 and population density K_0 represent zero environmental impact; death rate I_L and corresponding population density K_L represent low level of environmental impact superimposed on fish population; death rate I_H and corresponding population density K_H represent fish population subjected to high level of environmental impact. In each case, the population equilibrates at that density at which birth rate and death rate are equal.

Figure 10.2-1 Relationship of Birth Rates and Death Rates to Population Density

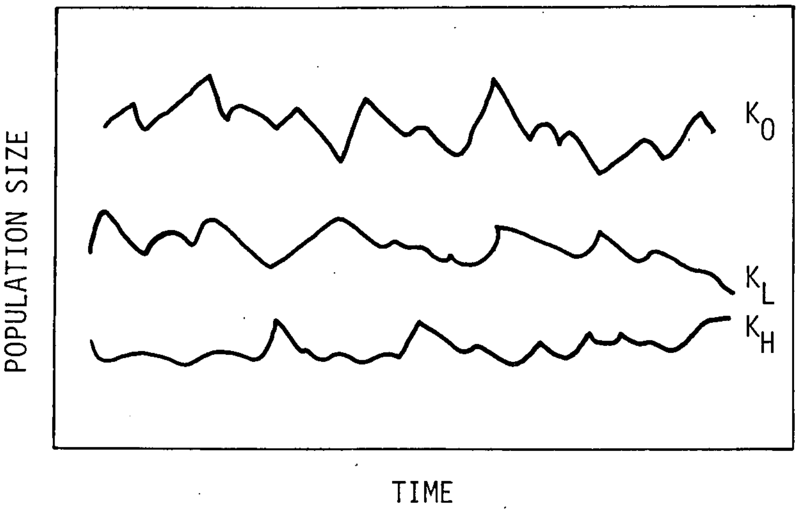


Figure 10.2-2 Hypothetical Population Histories Corresponding to Zero, Low, and High Levels of Environmental Impact Represented in Figure 10.2-1

This example was chosen to illustrate as simply as possible the relationship among death rate, birth rate, and average population density where compensation is operative. The increase in total mortality depicted in this example could have been offset at lower population levels by an increase in survival among members of the population not killed by the man-induced impact rather than by the increase in birth rate; the principle would be the same.

Referring again to the example in Figure 10.2-1, the initial condition postulated is a population fluctuating around an average equilibrium level K_0; for this population, the birth rate (b) and death rate (d) on the average are equal. Thus, the rate of population increase (r) is 0:

$$r = b - d = 0$$

When the population is first subjected to additional mortality (no matter how slight) caused by man, the death rate is increased and exceeds the birth rate. The population's rate of growth (r) becomes negative; i.e., the population declines in numbers:

$$b - d < 0$$

If the increment of mortality is sustained, the population eventually will dwindle to extinction unless the birth rate increases or the natural mortality rate decreases sufficiently to allow the overall birth and death rates to again become equal. This would be true if the removal is sustained over a long enough period, even if only a single organism per year is killed over and above the pre-impact natural mortality rate. Therefore, every population that is subjected to sustained additional mortality through man's activities and does not become extinct must possess some compensatory capacity. The list from everyday observation is impressively long. Species of birds and mammals commonly killed along highways--raccoons, squirrels, skunks, deer, pheasants, woodpeckers, sparrows--must have some compensatory capacity or the new predator, the automobile, by now would have pursued them far down the trail toward extinction. The same can be said for pest insects attacked with weapons ranging from rolled newspapers to organic chemicals. Any wild plant or animal harvested by man for sport or subsistence--and many have been pursued since antiquity--must have some form of compensatory capacity to have survived. However, this compensatory capacity is not unlimited, as proven by the extinction or near extinction of a number of species caused by man's predatory activity. Ecologists now understand that compensatory capacity is most limited in species having relatively low maximum reproductive rates.

A simulation model and appeal to real-world experience support the argument just developed. If the striped bass population model presented in Section 12 of this report or the model developed by the NRC staff is operated from an initial state representing a population at a stable equilibrium or one fluctuating around an average equilibrium level and if removal of a single additional fish per year is simulated over a long period, the population will dwindle to extinction unless compensatory processes are simulated as well. The extinction case clearly is not a realistic simulation of commonly observed population performance. The NRC model's incorporation of a compensatory fishery function is the minimum conceivable capitulation to the reality of compensation. Its operation can steer the population away from unlimited decline under trivial levels of exploitation but fails to cover the case where no fishery exists but some compensatory process must still operate to effect a realistic simulation. The general case argument requires that some natural compensatory process be operative to represent realistically and logically the performance of a population of living organisms.

10.3 COMPENSATION IN FISH POPULATIONS

Both the historical development of the general concept of compensation presented in Section 10.1.2 and the formal argument development in Section 10.2 support the view that compensation is operative in fish populations. This section supports this view with three additional lines of evidence:

- The historical development of the concept is traced through its applications in fishery management, and the present-day consensus held by the world's leading fishery scientists is summarized (10.3.1).

- A selection of compensatory mechanisms that have been convincingly demonstrated to operate in fish populations is reviewed (10.3.2).

- A large number of cases in which substantial levels of exploitation by sport or commercial fisheries have been sustained by fish populations without serious depletion are cited (10.3.3).

10.3.1 HISTORY OF CONCEPT OF COMPENSATION IN FISHERIES. Historically, the formal foundation of modern fish population dynamics was laid down in the mid-1930s. Picking up the thread of historical development of the concept of compensation with the rediscovery of the logistic curve by Pearl and Read in 1920 (Section 10.1.2), the first explicit application of the concept in this form to fisheries seems to have been in 1933 when a parallel between the sigmoid population growth form in yeast and growth in numbers in a fish stock was noted (Hjort, Jahn and Ottestad 1933). The first formal application of the logistic to management problems in a major fish stock was Graham's application (Graham 1935) in 1935 to the plaice stock of the North Sea.

The logistic and its various modifications such as the "Schaefer model" (Schaefer 1954) have since been applied to such important fisheries as the Antarctic blue whale (Chapman 1964), Icelandic cod (Gulland 1961), Pacific halibut (Schaefer 1954) and Icelandic haddock (Gulland 1961). "The development of the logistic curve in fisheries and in other fields implied that loss of stock with increased mortality was compensated by increased recruitment" (Cushing ~~1974~~ 1975:237). Thus, since the publication of Graham's work in 1935, the concept of compensation clearly has been a basic tenet of scientific management for the world's major fish stocks.

Interpretation and application of the logistic curve to fishery management is conveniently summarized in a recent book, The Management of Marine Fisheries, by J.A. Gulland, an internationally noted scientist with the Food and Agricultural Organization of the United Nations (Gulland 1974: 68-86). He makes the following points about compensation from the basis of the logistic model:

> "Though the curves ~~of Figures 3 and 10~~ and the model on which they are based are highly simplified descriptions of the changes in a fish stock under exploitation, they do illustrate most of the biological features important to fishery management. The first is that it is impossible to exploit a fish population without causing some change. This may seem obvious, but with the present day concern

> with the natural environment, and the desire to minimize ecological disturbance, there may be a feeling that a well-managed fishery should cause no changes, which is impossible...The second important point is almost the converse of this. That is, provided the catches are not too great, the decline in abundance is not continual. After a time the population will reach a new equilibrium, at which the same catches can be maintained indefinitely year after year. Finally, if the stock is allowed to be depleted too far, though still without driving it to extinction, its productivity and the catches that can be taken will be reduced."

Ricker's commentary (1958:250) on the same basic compensatory principle applied in fishery management is:

> "The principal reasons for lessened surplus production at higher stock densities are three:
>
> "1. Near maximum stock density efficiency of reproduction is reduced, and quite commonly the actual number of recruits is less than at smaller densities. In the latter event, reducing the stock will increase recruitment.
>
> "2. When food supply is limited, food is less efficiently converted to fish flesh by a large stock than by a smaller one. Each fish of the larger stock gets less food individually, hence a larger fraction is used merely to maintain life, and a smaller fraction is used for growth.
>
> "3. An unfished stock tends to contain more older individuals, relatively, than a fished stock. This makes for decreased production in at least two ways: (a) Larger fish tend to eat larger foods, so an extra step may be inserted in the food pyramid, with consequent loss of efficiency of utilization of the basic food production, (b) older fish convert a smaller fraction of the food they eat into new flesh--partly, at least, because mature fish annually divert much substance to maturing eggs and milt.
>
> "Under reasonably stable natural conditions, the net increase of an unfished stock is zero, at least on the average: its growth is balanced by natural deaths. Introducing a fishery increases production per unit of stock by one or more of the methods above and so creates a surplus which can be harvested. In these ways 'a fishery, acting on

> a fish population, itself creates the production by which it is maintained' (Baranov 1927). Notice that effects 1 and 3 above may often increase the *total* production of fish flesh by the population--it is not merely a question of diverting some of the existing production to the fishery, although that also occurs."

The logistic-type models have been used successfully in fishery management since their inception and are still used today, but they have long been recognized to embody important basic principles in an over-simplified way. For example, they do not distinguish the contributions of growth and recruitment of new individuals; they assume that the entire population is involved equally in compensatory response; they represent density-related changes in populations as occurring instantaneously and continuously. A very important advance in conceptualizing fish population dynamics in a more realistic way is Ricker's (1954) exposition of the problem of stock and recruitment; it emphasized the compensatory nature of the numerical relationship between parent fish and the progeny they produced and the importance of the earlier life history stages in compensation and formulated a mathematic model embodying these concepts, which has been applied to major fish stocks throughout the world. Ricker's model operates on the same basic principles as the formal argument of Section 10.2 and the logistic model - but in a much more refined and realistic way. It is explained here in graphical form because of its usefulness in clarifying the compensatory responses of fish populations to new increments of mortality such as that caused by fisheries, power plant operations, ~~pollutional~~ pollution kills, etc., and as a foundation for using the Ricker model in equational form (Section 10.6) to estimate the compensatory capacity of the Hudson River striped bass population.

Consider a parent stock of fish and the stock of progeny that it produces, expressing both the parents and progeny in the same units of measurement. If the *rate* of future replacement of the present population is independent of the *size* of the population, the relationship between parental stock and progeny will be described by a 45° diagonal line as shown in Figure 10.3-1 (replacement reproduction) and this will be referred to as a *density-independent* relationship between parents and progeny. If

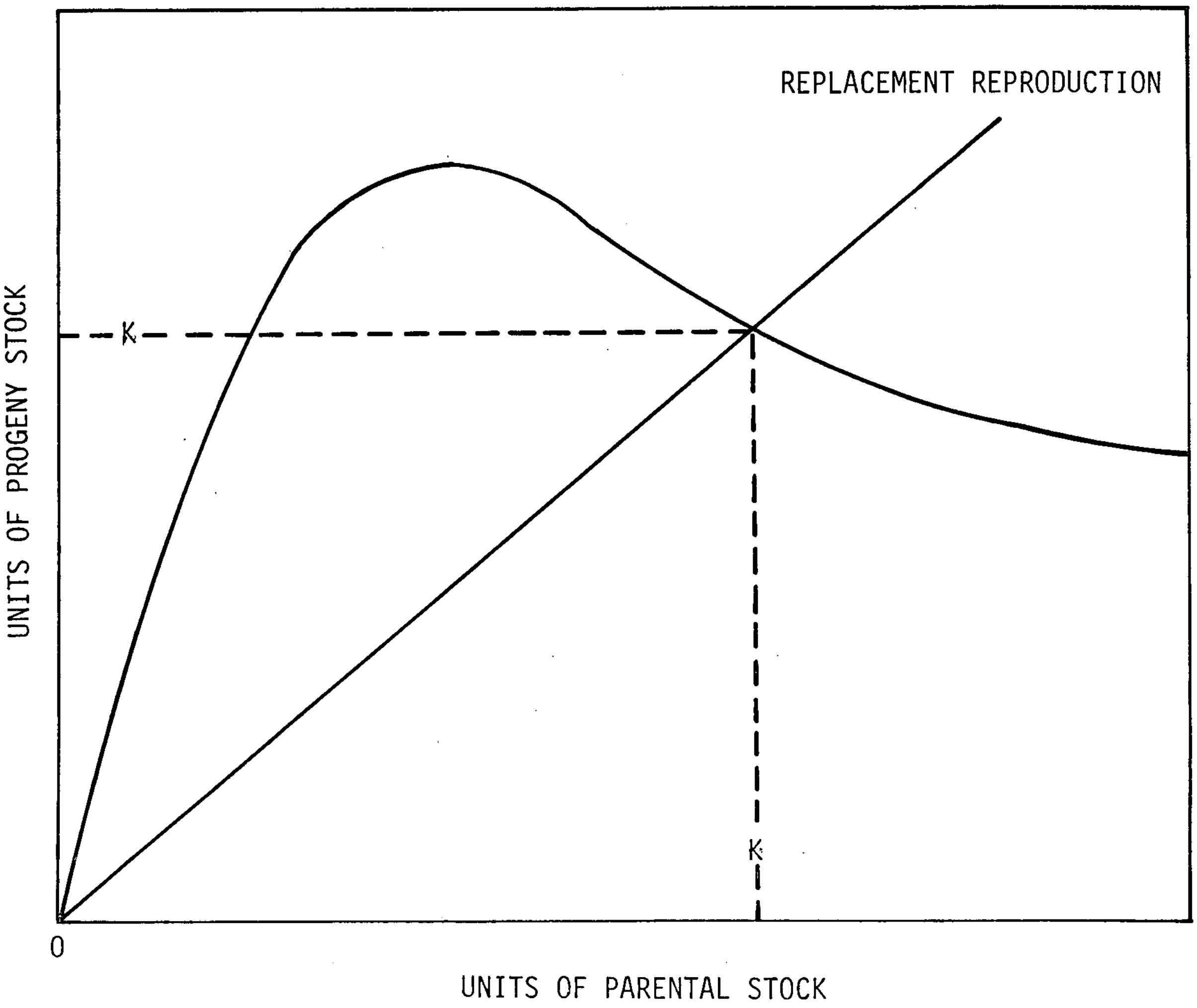


Figure 10.3-1 Relationship between Parental Stock density and Production of Progeny for Hypothetical Fish Population

environmental conditions permit survival of a very large parental stock, that stock will produce a generation of progeny equal in size to itself; by the same token, if unfavorable environmental conditions reduce the parental stock to some very low density, it will produce again a generation of progeny equal to itself. Under these situations the size of the population could, by chance, increase without limit or dwindle to extinction; no compensatory process operates to increase the rate of population growth at low levels of density, thus deflecting it from decline to extinction, or to decrease the rate of population growth at very high levels of population density, thus deflecting it from unlimited expansion. To persist within some more or less well-defined limits of abundance, a fish stock must have some compensatory (density-dependent) processes.

The curve in Figure 10.3-1 represents a density-dependent relationship between parental and progeny stocks. At very low levels of parental stock, the population tends to increase severalfold in the progeny generation. At point K, the parental stock is replaced by exactly the same size progeny stock (the reproduction curve intersects at ~~45°~~ the 45° diagonal), and this density is the equilibrium point or replacement level of reproduction. If no environmental fluctuation deflects the stock from point K, it will remain perpetually at that density, exactly replacing itself over each succeeding generation. At densities above replacement reproduction, the parental stock will fail to replace itself and the population will decline back toward equilibrium level. If stock density is deflected by environmental conditions below the equilibrium level, the parental stock will more than replace itself; i.e., the population will tend to increase back toward replacement level over succeeding generations. At replacement level, the parental stock exactly replaces itself in the face of baseline natural mortality, producing no surplus progeny as a buffer against removal by an environmental impact such as power plant operation, a fishery, or pollution.

Figure 10.3-2 explores the situation in which an increment of mortality is imposed on the population of Figure 10.3-1, thus deflecting it away from the replacement level of parental stock. Let us say, for example, that an amount of parental stock equal to the line segment $\overline{cK}$ is removed from the population before reproduction. The parental stock now consists of $\overline{0c}$ units, and this parental stock produces $\overline{ca}$ units of progeny. At this stock density, the parents produce $\overline{cb}$ units of offspring (sufficient to replace themselves) plus a surplus $\overline{ab}$, which may be removed by the fishery or killed by power plant operations or pollutional inputs but still leave the population equilibrated at a density $\overline{0c}$. For this situation, the removal, $\overline{ab}$, from the population is about 28% of the total stock, $\overline{ac}$.

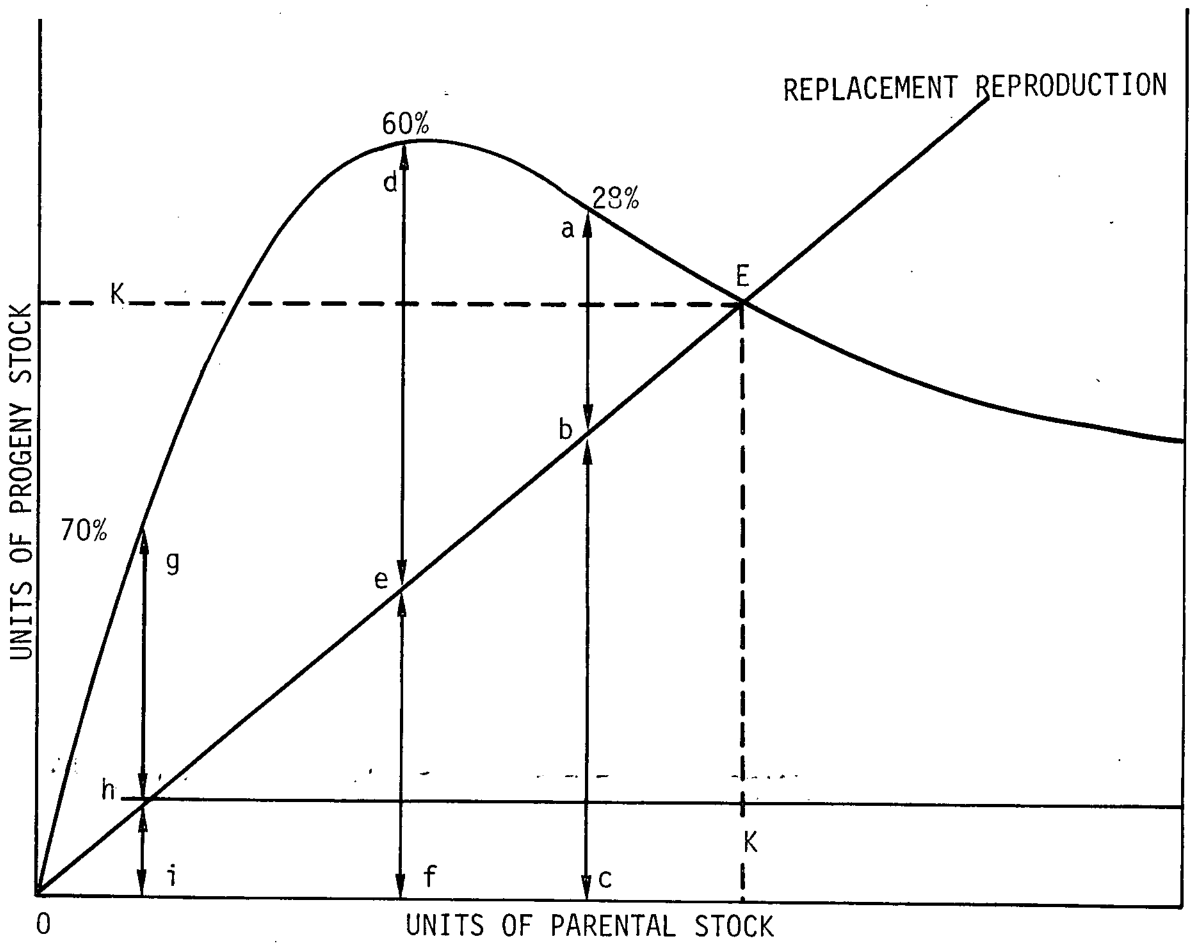


Figure 10.3-2 Equilibrium Exploitation Rates for Parent-Progeny Relationship of Figure 10.3-1. (Equilibrium at c units of parental stock is maintained with exploitation rate of 28%; a level of f units of stock by an exploitation rate of 60%; and a level of i units of stock by an exploitation rate of 70%)

If an additional increment of removal is imposed on the stock (e.g., a total of $\overline{de}$ units of progeny stock), the removal rate ($\overline{de} \div \overline{df}$) will be 60% and the population will sustain this level of removal, equilibrating at density $\overline{0f}$. To hold the stock at this reduced density, 60% average removal must be sustained. If this rate of removal is reduced, the parental stock will more than replace itself and succeeding generations will tend to increase until the population equilibrates once again at a higher level of density. A still higher percentage removal, (70% [$\overline{gh} \div \overline{gi}$] for example) if sustained will reduce the population to the density $\overline{0i}$.

Two important points emerge. First, an increment of removal imposed on a fish stock drives the stock to a lower average density at which the population once again equilibrates, but the increment of mortality imposed and sustained does not drive the population into a steady downward spiral leading to severe depletion or extinction. This point was advanced earlier in summarizing compensation concepts from Gulland (1974) and Ricker (1958). Second the rate of removal must be sustained from generation to generation if the stock is to be held at a reduced level of abundance; increasingly higher percentage removals must be sustained if the stock is to be driven to successively lower levels of density.

Cushing (1975:238) states:

> "The equation relating recruitment to parent stock used initially by Ricker and later by Beverton and Holt is a convenient summary of present opinion on the natural regulation of numbers in a fish population. Recruitment depends on stock modulated by density~~-dependent mortality."~~ - independent and density-dependent mortality."

Gulland (1974) also reflects on the widespread acceptance of this type of formulation of compensation:

> "Other curves could be derived with other assumptions, but so far for all stocks the observations of stock and recruitment, though often scattered, have been consistent with at least one of the theoretical curves."

To promote discussion of the present state of knowledge and of future research requirements in the face of the large post-war increase in global fishing intensity and problems in world food supply, a symposium on fish stocks and recruitment was convened in 1970 by the International Council for the Exploration of the Sea, the International Commission for North Atlantic Fisheries, and the Food and Agricultural Organization of the United Nations. There were 82 participants from 20 countries. The published proceedings (Parrish 1973) recorded the following scientific opinions on the importance and prevalence of compensation or density dependence in fish populations:

"When J. Tanner (1966) concluded after ~~the~~ an analysis of density dependence in 111 different populations representing 71 species, "It is significant that the processes known to regulate vertebrate populations affect either reproduction or the survival of juveniles;...", he could have been reciting from the current litany of fisheries biology" (Paulik 1973:302).

"The papers and discussions indicate that recruitment... in both marine and freshwater fish and shellfish populations is determined by a complex of density-dependent and density-independent factors. The former may act as the main source of control governing the form of the relationship between recruitment and spawning stock size (egg production), and the latter give rise to the well known short-term, irregular fluctuations in recruitment characteristic of some teleost species having high fecundity. The papers and discussions indicate further that in most species for which detailed information is available these factors operate mainly during the early stages of development (i.e. between the egg and the end of the first year of life) so that year class strength is determined and population control mechanisms for most fish stocks operate before the individuals enter the exploited phase" (Parrish 1973:5).

"It was the consensus of the meeting that density dependence does occur in all fish stocks at some point, and this is itself a major transition from earlier dogma. As R. Jones and Bowers pointed out, the precise age at which density becomes of major significance varies from stock to stock so that, for example, the plaice may have properties that are different from haddock. Plaice growth may be density-regulated while they are in the plankton, and a relatively constant number may transform to the demersal habitat.

Dr. LeCren pointed out that freshwater species such as trout and salmon are really not very different in their fundamental biological machinery from the marine ones and that the same kind of density dependencies probably occur in marine and fresh water. The general acceptance of density dependence as relevant to all marine stocks is probably of great value since it avoids the nasty theoretical problem, specifically, that the absence of any density-dependent feedback system implies a random walk process in stock size which would predict much greater temporal variations in population size than are actually observed" (Slobodkin 1973:10).

10.3.2 COMPENSATORY MECHANISMS. As discussed earlier for animal populations in general, a wide range of environmental agents and compensatory mechanisms may be involved in the overall compensatory response generated by a fish population. Different mechanisms may operate at different levels of population density or under different environmental conditions, and the effect of one compensatory mechanism may preempt the activation of alternate mechanisms that are potentially available. A wide range of population processes also may play a significant role in the compensatory response. Furthermore, compensation may be masked statistically either by its own effectiveness, which may so stabilize some fish populations that observations on population processes at very different levels of density are hard to obtain, or by the imposition of a large amount of random variation in population parameters caused by density-independent factors. Thus, it is usually not profitable to focus on a single mechanism of compensation or on even a small complex of mechanisms to test the reality or extent of the phenomenon. However, this is not to say that the existence of such mechanisms is a matter of theory, speculation, or mystery; on the contrary, the compensatory operation of many different mechanisms ~~machanisms~~ and population processes has been proven in fish populations. The following 17 examples drawn from the scientific literature provide a concrete understanding of the remarkable resilience of fish populations in the face of increases in mortality caused by man:

- A dense population of perch in Lake Windermere was subjected to an extensive experimental fishery for 5 yr (LeCren 1958; 1964); reduction of the population to 3% of its original density resulted in a fourfold increase in both mean weight and fecundity of adults.

- Brown trout populations in a small Swedish lake were compared for 6 yr before and 6 yr during exploitation with gill nets and sport fishing gear (Lindstrom, Fagerstrom, and Gustafson 1970). Although mean size decreased, the individual growth rates (lengths) increased an average of 10.5% after exploitation.

- Bluegills in three large Michigan ponds were subjected to annual reductions of 0, 60, and 90% in young-of-the-year during a 5-year experiment (Beyerle and Williams 1972). Survival averaged 0.5, 8.1, and 12.2% respectively. Growth of fish in all three ponds was similar evidently as the result of compensatory survival rates.

- Commercial exploitation of plaice off the coast of Scotland increased greatly after 1956 (~~Begenal~~ Bagenal 1963). Fecundity increased from 137,000 eggs per female in 1956-57 to 157,000-161,000 eggs per female in 1958-61. The data suggest that heavy fishing reduced the population size but that survivors had proportionately more food, resulting in higher fecundity.

- Large brook trout in a Canadian lake were subjected to 90% experimental exploitation by gill nets (Smith 1956). Survival of planted fingerlings was two times that existing before gill netting of large trout. Although growth data are not easily interpreted, the growth rate of fingerlings appeared to have decreased after exploitation.

- Data from seven brook trout populations were studied to compare fished and unfished populations (Jensen 1971). Fishing resulted in more young and fewer old fish. Increased age-specific fecundity compensated for increased mortality from fishing. Since fecundity increased with size, the data suggested that growth may be the most important variable in a fish population's adjustment to exploitation.

- Reductions in numbers of adult pike were observed in Lake Windermere (Kipling and Frost 1969). There was a significant increase in eggs per gram of fish after the population density had been falling for several years, suggesting a compensatory response in fecundity.

- Ciscoes in three Canadian lakes were subjected to varying degrees of exploitation (Miller 1950). Total mortality averaged 61 and 60% in two mildly exploited lakes; 70.5% in an unfished lake. Under moderate and then heavy exploitation, total mortality in one lake averaged 80 and 94% respectively.

The comparison suggests that fishing mortality reduces natural mortality but that the overall effect of moderate to heavy exploitation is an increase in total mortality.

- Brook trout in a Wisconsin stream were subjected to varying amounts of sport fishing (McFadden 1961). There was a significant regression of natural mortality on angling mortality so that exploitation reduced natural mortality. Total mortality increased with exploitation, but there was a broad range in the number of spawners and size of the egg complement, which would result in adequate numbers of progeny.
- Rainbow trout populations maintained by stocking were compared in five New Zealand lakes (Fish 1968). In three of the lakes supporting 7-18 fish acre^{-1}, growth in weight was two to three times that in two lakes supporting 31-35 fish acre^{-1}. The inverse relationship between number of trout and their average weight suggests that the lakes would produce large trout if the population were kept small.
- Rainbow trout in a New Zealand lake were subjected to a sport fishery of increasing intensity for 14 yr (Percival and Burnet 1963). The growth of 2- and 3-yr-old fish was negatively correlated with population size. The data suggest that an increase in exploitation increases the survival rate of juveniles. The larger number of surviving juveniles resulted in a reduction in growth rate and maximum size of the fish.

- Catch and escapement of an exploited sockeye salmon population were studied in Bristol Bay, Alaska (Mathisen 1969). Growth in length of smolts could be expressed as a negative exponential function of population density. A similar relationship exists for maturing salmon during their migration toward fresh water. Thus, as exploitation increases, the growth in individual fish increases.

- Records of 111 animal populations representing 71 species were analyzed to determined the relationship between the rate of increase of a population and the population density (Tanner 1966). Of the seven fish species examined, Atlantic salmon, yellow perch, walleye, and northern pike showed a statistically significant negative correlation of population growth rate with population density; freshwater drum and goldeye showed a negative and lake trout a positive correlation, but these were not statistically significant. The data strongly support the concept of a compensatory increase in survival and/or fecundity following reduction in the size of a population.

- Populations of rainbow and brook trout were compared among New York ponds (Eipper 1964). Growth rates of both trout species were inversely related to population density.

- The number of spawners was compared with the number of progeny for haddock, Pacific herring, and coho, sockeye, and pink salmon (Ricker 1954). The data suggest that the survival rate of progeny increases as the number of spawners decreases. Within limits, a reduction in spawners can also result in increased numbers of surviving progeny.

- Plaice, haddock, sole, turbot, and cod in the North Sea were subjected to varying degrees of exploitation (Beverton and Holt 1957). Survival, particularly of plaice, was strongly inversely correlated with the size of the adult population.

- The size of young sockeye salmon in a British Columbia lake was compared with population density for 11 yr (Foerster 1944). There was a statistically significant negative correlation ($r = -0.82$) between the density of the lake population and the mean weight of migrants.

10.3.3 CAPACITY OF FISH POPULATIONS TO WITHSTAND MORTALITY. While it is clear that the concepts in fisheries science were developed through experience with stocks subjected to exploitation by man, nothing explicit has yet been stated here about the degree of resiliency possessed by these stocks. Remaining unanswered are such questions as how large an annual removal can be sustained, at what level of added mortality will the population be drastically reduced in numbers, at what level of added mortality will it be threatened with extinction, and what would constitute an intolerable or irreversible reduction of a fish population. As a foundation for responding to these questions from a basis of empirical evidence, the principles unfolded through the arguments and historical accounts previously presented are summarized as follows:

- An undisturbed or unexploited population (one at the maximum equilibrium level on the average) produces enough new individuals to just replace natural losses; there is no surplus production.
- A population, if it is to be held at maximum size, cannot be exposed to any additional mortality either from natural causes or from man's activities because, at maximum stock size, no surplus production is available to absorb an increment of mortality.
- At the opposite extreme, as a population approaches 0 size, surplus production approaches 0. In very small populations, the rate of surplus production per individual is very high; however so few individuals are present that the overall rate of increase for the population is very low.
- Should exploitation or some other form of environmental impact occur, population size will be reduced. At levels of density lower

than equilibrium, surplus production will be available to absorb the environmental impact while maintaining the population at the new but reduced level.

- Maximum surplus production occurs at some intermediate level of stock density.

- If an added mortality is large enough, population size will be reduced to a level at which the fish may become undesirably scarce, and the population vulnerable to accidental or even inevitable extinction and able to generate only a small surplus production for the benefit of man or as a cushion against further decline.

In ecological terms, the significance of an impact imposed by man on a fish population is not a matter of "good" or "bad" but rather one or more states of reality defined by the average level of abundance of the impacted stock and the magnitude of its surplus production. Increasing overall impact on the fish population decreases standing stock, increases resource utilization, causes maximum surplus production at an intermediate level of exploitation, and varies the potential for disposition of the surplus production as, for example, between fisheries and kills resulting from power generation. Because the objective of fisheries management is to maximize some form of productivity on a sustained basis (often the total weight of the fish harvested), identification of the fishing rate that will produce the greatest yield on a long-term basis has usually been emphasized. There has been no particular value attached to building up the population to maximum size; unlike esthetically valued species such as brightly feathered birds, fish are rarely accessible to the admiring gaze of the public and none has a reputation for song.

The emphasis on maximizing harvest has led to a wide range of historical experience with initially unexploited fish populations that have been subjected to harvest by sport and commercial fisheries and have persisted in a healthy ecological state despite increased overall mortality. This experience constitutes unassailable proof of the general operation of the phenomenon of compensation in fish populations. If the natural death rate had not declined or the birth rate increased as population density was reduced, the large removals by fishing would quickly have driven these populations to extinction.

In reviewing a substantial number of published estimates of exploitation rates (Table 10.3-1), it becomes clear that cases in which ≥ 25% of the exploitable age groups in a population have been removed annually are common. The figures generally represent situations in which substantial exploitation has been underway for fairly long periods (usually for decades) and is continuing. Clearly then, many populations possess compensatory reserve sufficient to offset very substantial increments of man-induced mortality. The repeated removal of 25-50% of a fish population and the sustained reduction of abundance of the fish to a level well below the pre-fishing stock size, with hopes for survival of the stock dangling by the seemingly precarious conceptual thread of compensation, may at first seem a drastic proposition to the interested layman or the scientist lacking a background in scientific management of fisheries. However, such treatment, rather than being an extreme to which populations can at great peril be pushed, is a normal and ecologically sound treatment that permits fish stocks to operate at maximum productivity. Earlier management models (e.g., the logistic model) predicted that maximum sustained yield would be obtained at an average population level of 50% of the virgin stock; current more flexible and realistic models (e.g., that of Ricker) indicate that, for the stock recruitment relationship characteristic of many important fish, maximum sustained yield would be obtained under exploitation rates of 25-75% and that the average equilibrium level of the populations would be less than half the virgin stock level (Ricker 1958:239, 268). The broad experience sampled in Table 10.3-1 confirms these management tenets, and the tenets provide a basis for assessing the limits within which fish populations can be managed safely by man. It is not suggested here that harvest of fish by power plants up to the level of maximum sustained yield is socially desirable, but simply that it is ecologically safe.

Table 10.3-1 Summary of Published Estimates of Exploitation Rates in Fish Populations

Exploitation Rate (%)	Name of Species		Location	Reference
	Scientific	Common		
25	*Lepomis macrochirus*	Bluegill	Sugar Loaf Lake, Mich.	Cooper and Latta 1954
36			Spear Lake, Ind.	Ricker 1955
35			Gordy Lake, Ind.	Gerking 1953
15-20			Muskellunge Lake, Ind.	Ricker 1945
29	*Lepomis microlophus*	Redear sunfish	Gordy Lake, Ind.	Gerking 1953
23			Muskellunge Lake, Ind.	Ricker 1945
11	*Pomoxis nigromaculatus*	Black crappie	Oliver Lake, Ind.	Gerking 1953
36	*Micropterus salmoides*	Largemouth bass	Gordy Lake, Ind.	Gerking 1953
12			Shoe Lake, Ind.	Ricker 1945
17			Oliver Lake, Ind.	Gerking 1950
20-48			Southerland Res., Calif.	LaFaunce et al. 1964
20			Clear Lake, Calif.	Kimsey 1957
14			Gladstone Lake, Minn.	Maloney et al. 1962
22	*Micropterus dolomieui*	Smallmouth bass	Waugoshance Point, L. Mich.	Latta 1963
05-18			Oneida Lake, N.Y.	Forney 1961
16	*Ambloplites rupestris*	Rock bass	Oliver Lake, Ind.	Gerking 1950

Table 10.3-1 (Contd)

Exploitation Rate (%)	Name of Species		Location	Reference
	Scientific	Common		
05	*Stizostedion vitreum*	Walleye	Fife Lake, Mich.	Schneider 1969
15-28			Spirit Lake, Ia.	Rose 1947; 1955
20-40			Escanaba Lake, Wis.	Patterson 1953; Niemuth et al. 1959
27			Many Point Lake, Minn.	Olson 1957
32	*Esox lucius*	Northern pike	Murphy Flowage, Wis.	Snow 1958
50			Wisconsin waters	Threinen et al. 1966
14			Lake George, Minn.	Groebner 1964
32-49			Grove Lake, Minn.	Groebner 1964
23			Ball Club Lake, Minn.	Johnson and Peterson 1955
22-28			Grace Lake, Minn.	Wesloh and Olson 1962
38			Fletcher Floodwater, Mich.	Christensen and Williams 1959
40	*Coregonus clupeaformis*	Lake Whitefish	Georgian Bay, L. Huron	Cucin and Regier 1965
21			Lake Superior	Dryer 1964
13-17	*Salmo gairdneri*	Rainbow trout	New York streams	Hartman 1959
20-26			New York lakes	Hartman 1959

Table 10.3-1 (Contd)

Exploitation Rate (%)	Name of Species		Location	Reference
	Scientific	Common		
19-75	*Salvelinus fontinalis*	Brook trout	Lawrence Creek, Wis.	McFadden 1961
30	*Ictalurus punctatus*	Channel catfish	Sacramento Valley,Calif.	McCammon and LaFaunce 1961
25	*Ictalurus nebulosus*	Brown bullhead	Shoe Lake, Ind.	Ricker 1945
49	*Pleuronectes platessa*	Plaice	North Sea, 1929-38	Beverton and Holt 1957
33			1950-64	Gulland 1968
31	*Hippoglossoides platessoides*	American plaice	Gulf of St. Lawrence	Poweles 1969
	Clupea harengus	Atlantic herring	South coast, Ireland	Burd and Bracken 1965
29			1906-36	
10			1951-55	
42			1956-60	
25			1961-63	
19	*Cynoscion nebulosus*	Spotted seatrout	Pine Island Fla., 1961	Iversen and Moffett 1962
40	*Pseudotolithus typus* *Pseudotolithus senegalensis*		Coast of Nigeria, 1961-62	Longhurst 1964

Table 10.3-1 (Contd)

Exploitation Rate (%)	Name of Species Scientific	Common	Location	Reference
11 25	*Gadus morhua*	Atlantic cod	Gulf of St. Lawrence, 1949-52 1955-65	Paloheimo and Kohler 1968
49 42 32 34	*Tilapia esculenta*		L. Victoria, Africa, 1958-59 1959-59 1959-60 1960-60	Garrod 1963
25	*Alosa sapidissima*	American shad	Connecticut River, Conn.	Walburg 1960
47 58 31	*Aplodinotus grunniens*	Freshwater drum	Upper Miss. R. impoundments, 1944-48	Butler 1965
11	*Micropterus salmoides*	Largemouth bass	Browns Lake, Wis., 1953	Mraz and Threinen 1957
66	*Salmo salar*	Atlantic salmon	Little Codroy River Nfld, 1955-63	Murray 1968

Table 10.3-1 (Contd)

Exploitation Rate (%)	Name of Species		Location	Reference
	Scientific	Common		
59	*Salvelinus fontinalis*	Brook trout	Sydenham River, Ont., 1966-67	Marshall and MacCrimmon 1970
23	*Salmo trutta*	Brown trout	Sydenham River, Ont., 1966-67	Marshall and MacCrimmon 1970
	Stizostedion vitreum	Walleye	Nipigon Bay,	Ryder 1968
07			L. Superior, 1955	
13			1956	
34			1957	
14-70	*Esox masquinongy*	Muskellunge	Nogies Creek, Ont., 1952-60	Muir 1963
29	*Stizostedion vitreum*	Walleye	Escanaba Lake, Wis. 1946-69	Kempinger et al. 1975
46	*Esox lucius*	Northern pike		
27	*Esox masquinongy*	Muskellunge		
15	*Perca flavescens*	Yellow perch		
29	*Lepomis gibbosus*	Pumpkinseed		

Table 10.3-1 (Contd)

Exploitation Rate (%)	Name of Species Scientific	 Common	Location	Reference
21	*Amboplites rupestris*	Rock bass	Escanaba Lake, Wis. 1946-69	Kempinger et al. 1975
42	*Lepomis macrochirus*	Bluegill		
26	*Pomoxis nigromaculatus*	Black crappie		

Yield statistics from commercial and sport fisheries provide another reflection of the capacity of fish stocks to sustain themselves in the face of substantial man-induced mortalities. The relatively unproductive Great Lakes of North America have produced yields from 1 to 7 lb $acre^{-1}$ yr^{-1}, a productive North Sea fishery has yielded about 27 lb $acre^{-1}$, Escanaba Lake in Wisconsin has yielded 4-41 lb $acre^{-1}$ over a 24-yr period (the overall average being 20 lb $acre^{-1}$), the Gulf of Mexico's fin-fish catch attributable to estuarine production has averaged about 50 lb $acre^{-1}$ in recent years, and commercial fishing in Chesapeake Bay has yielded about 155 lb $acre^{-1}$. Clearly, these substantial removals would deplete fish populations rapidly were those populations unable to compensate through increased survival or reproductive rates.

Experience with the world's major stocks has proven that they have both the capacity to withstand impressively high levels of exploitation and produce a substantial surplus at population levels well below their pre-exploitation abundance; and the ability to rebound to higher levels of abundance after being heavily exploited if fishing intensity is reduced. This is entirely in keeping with the concepts of population dynamics, and there is important empirical proof of this recovery capacity. Fishing reduced the plaice stock in the southern North Sea to one-third or one-half its original abundance, but relaxation of fishing during wartime rapidly doubled its size (Cushing 1975:135). The Pacific halibut population decreased by a factor of 7 during a 20-yr period of fishing, then increased in size when protected by a closed season (Fukuda 1962). A North Sea herring stock was reduced to one-tenth its previous abundance during a 12-yr period and subsequently began to increase as a result of reduced fishing pressure (Cushing 1975:136). Sturgeon fishing in the Amur River basin was banned for 12 yr to restore overfished stocks; by the end of the ban, the proportion of sexually mature fish had increased sixfold and the average size and age of fish had increased as well -- evidence of restoration of the stock (Krykhtin 1972). Similar examples are reported for the white fish of Lake Wabamun (Miller 1949) and for lake trout of Lake Opeongo (Fry 1949). Thus, reductions in fish stocks caused by exploitation have commonly been proven to be reversible.

10.3.4 APPLICABILITY OF FISHERY EXPLOITATION PRINCIPLES TO POWER PLANT IMPACTS. Cushing (1975:138-139) points out that "Many populations of wild animals are exploited but the commercial fish stocks are numerous.... No other wild populations have been so well documented for such long periods of time." This accounts for the imposing body of accumulated experience with fish populations and the development of successful management principles in fishery science. However, are these principles and the experience from which they are derived, based as they are on fishery exploitation of the (usually) mature age groups of a stock, applicable to the situation in which some fraction of the earliest life stages (eggs, larvae, and juveniles) is cropped by entrainment and impingement? Can the contention in Section 10.1 i.e., that "The agent of mortality - predatory fish, commercial or sport fisherman, or power plant - is an indifferent matter from the standpoint of population response" be sustained? The questions are important ones: if answered affirmatively, the empirical evidence for compensation in Hudson River striped bass to be presented in Sections 10.5 and 10.6 can be developed upon the entire foundation of fishery mangement science laid out in Sections 10.1, 10.2, and 10.3. This would greatly increase the certainty with which the important question of compensation could be addressed.

The question whether it is different (or possibly worse) to kill young fish than to kill older fish is answered in Section 10.6.4: insofar as population response is concerned, no different principles are involved. Killing some fish during the egg, larval, and juvenile stages (which is what power plants do) is equivalent to killing the parents that would have produced these young (which is what fisheries do). The entire foundation of fishery mangement experience and principles, therefore, can be applied with confidence to problems of power plant impact. It can be reasoned that fish populations can readily sustain "exploitation" by power plants at levels comparable to those experienced in commercial and sport fisheries. In a well-managed fishery, an annual exploitation rate of 50% or more for some species might well be a goal eagerly sought rather than a threat to be guarded against; even for species with rather low compensatory capacity, an exploitation rate of approximately 30% and reduction of the stock to about 46% of its pre-exploitation abundance would be necessary to achieve the very conventional goal of maximum sustained yield (Ricker 1958:268).

As has been pointed out, the workability of such management plans, based on current fishery concepts and models, has been directly proven by empirical data such as that summarized in Table 10.3-1. A 50% exploitation rate in a fishery, however, is not likely to be comparable to a 50% exploitation rate caused by a power plant. Once a particular year class of fish becomes vulnerable to a fishery, it is likely to be exploited during each remaining year of its life, although the rate may vary with age; a 50% exploitation rate in a fishery could well mean that half the members of each year class are captured at age IV, half the survivors are captured at age V, half the age VI, VII, and VIII fish are caught in successive years, etc. Compared with this annually repeated fishery mortality, a 50% exploitation rate caused by a power plant, which would affect each year class only once during its lifetime (during the first year when the young are entrained or impinged), would represent a very much smaller impact.

In most real-world situations, power plant impact would be added to a pre-existing fishery exploitation rate rather than applied to an unexploited stock; even here, the addition of an exploitation rate >25% to a pre-existing fishery exploitation rate of 25% would not endanger the stock of many species.

10.4 GENERAL EVIDENCE FOR COMPENSATION IN STRIPED BASS POPULATIONS

Striped bass have an impressive potential for population growth (biotic potential). Artificially simplifying the life history, assume that each fish spawns once in its lifetime at age VI; half are females, each producing 700,000 eggs; each fish reaches 457 mm in length; and all the eggs survive to become mature fish. These assumptions cause the biotic potential to be seriously underestimated since some females spawn at an earlier age and many live to spawn again at older ages. Beginning with one spawning pair, such a striped bass population would grow to astronomical numbers by the end of three generations (18 yr); at the end of the third generation, all of the fish laid end to end would encircle the earth at the equator 500,000,000 times or stretch from the earth to the sun and back again 60,000 times. This is the biotic potential, which is increasingly suppressed by density-related mortality factors as a striped bass population grows from some minimal initial density toward an upper limit set by the carrying capacity of the environment. In 1879-81, 435 striped bass were transplanted from the east coast to San Francisco Bay; within 20 yr, annual catches were 500 tons (Merriman 1941). Under minimal densities, the population grew explosively; within a relatively short time, numbers became large enough that population growth leveled off. The innate capacity for growth is the foundation of the compensatory capacity possessed by striped bass.

Beyond the inference from biotic potential, two of the major striped bass stocks, that from Chesapeake Bay and that from San Francisco Bay, have been shown empirically to be regulated by compensatory processes. Koo (1970:92) states "...that there is an inverse relationship between size of parent stock and recruitment is hardly to be questioned in the case of Chesapeake Bay striped bass." His statement must refer to observations that lie along the descending right limb of a Ricker-type stock recruitment curve. A statistically significant inverse relationship between stock and recruitment was found in the striped bass population of San Francisco Bay, and a Ricker-type curve was successfully fitted to the data (Sommani 1972).

Observations of the Chesapeake and San Francisco Bay stocks indicate somewhat convex rather than flat-domed stock recruitment curves, which is consistent with the substantial fecundity of the species. Cushing (1975:155-159), by comparing salmon, haddock, and cod, has shown that "...increasing convexity indicates increasing density-dependent mortality, and it rises in the order, salmon, haddock, and cod, which also represents an increase in fecundity." He postulates that the more fecund fishes generally have greater compensatory reserve.

10.5 COMPENSATORY MECHANISMS IN HUDSON RIVER STRIPED BASS

Compensatory mechanisms, which allow a population to persist in the presence of exploitation by man, have been observed in many animal populations. Although a compilation of compensatory responses by fish populations appears in Section 10.3, identification and evidence of the existence of one or more compensatory mechanisms in the Hudson River striped bass population is desirable as a rational basis for estimating its compensatory reserve. As Ricker (1975: 277) points out, "An observed correlation gains vastly in acceptability if the implied biological process can be demonstrated to occur, even if only qualitatively", i.e., the demonstration of compensatory processes in this population makes estimation of compensatory reserve more acceptable.

Among the mechanisms that may be considered for striped bass are cannibalism, density-dependent predation by other organisms such as fishes or fishermen, and intraspecific competition. Cannibalism has been found in at least one other striped bass population--the Sacramento-San Joaquin population (Stevens 1966, Thomas 1967)--and may well be an important regulatory mechanism in the Hudson River. Predation by other fishes and by fishermen may also operate in a density-dependent manner, since population regulation by predators is a well-known ecological phenomenon. Certainly, striped bass may compete for food while they are residing in the Hudson River estuary, and this is most likely to be evinced by density-dependent growth rates (Weatherley 1963). Density-dependent growth has been reported previously for Hudson River striped bass (TI 1975b:VIII-11) and for California striped bass (Chadwick 1964).

These processes in the Hudson River have been investigated by examining available literature and data on the Hudson River striped bass population. Intraspecific competition, cannibalism, and predation by other fish species have been empirically demonstrated for the Hudson River striped bass population. Density-dependent fishing mortality has been identified as another regulating mechanism (USNRC 1975b).

10.5.1 INTRASPECIFIC COMPETITION. As a method of investigating intraspecific competition in terms of growth, 9 yr of striped bass juvenile catch per effort (C/f) data from the area of Indian Point were used as a measure of population density and changes in mean length of striped bass juveniles from July to August compared (Fig. 10.5-1). The resulting inverse relationship was significant at the 1% level (r = -0.85). This relationship most probably was the result of intraspecific competition among juveniles, which causes numerically larger-than-average year classes of striped bass to experience a smaller increment of growth during the early juvenile stage than numerically smaller year classes.

10.5.2 CANNIBALISM AND PREDATION. Juvenile striped bass are the prey of at least four Hudson River fish species - bluefish, white perch, Atlantic tomcod, and yearling striped bass (Table 10.5-1). This predatory and cannibalistic impact on juvenile striped bass was discovered during programs primarily restricted to the Indian Point and Cornwall vicinities. Previous studies of the food habits of striped bass and white perch (TI 1974a:IV-44) indicate that white perch are rarely piscivorous but that striped bass are commonly piscivorous during their second year of life. Unfortunately, only scant data on striped bass yearling food habits in the Hudson River are available. Studies of Atlantic tomcod food habits indicate some piscivorous behavior including cannibalism, but their primary food items are invertebrates during most of the year (TI 1975e). Young-of-the-year bluefish are almost entirely

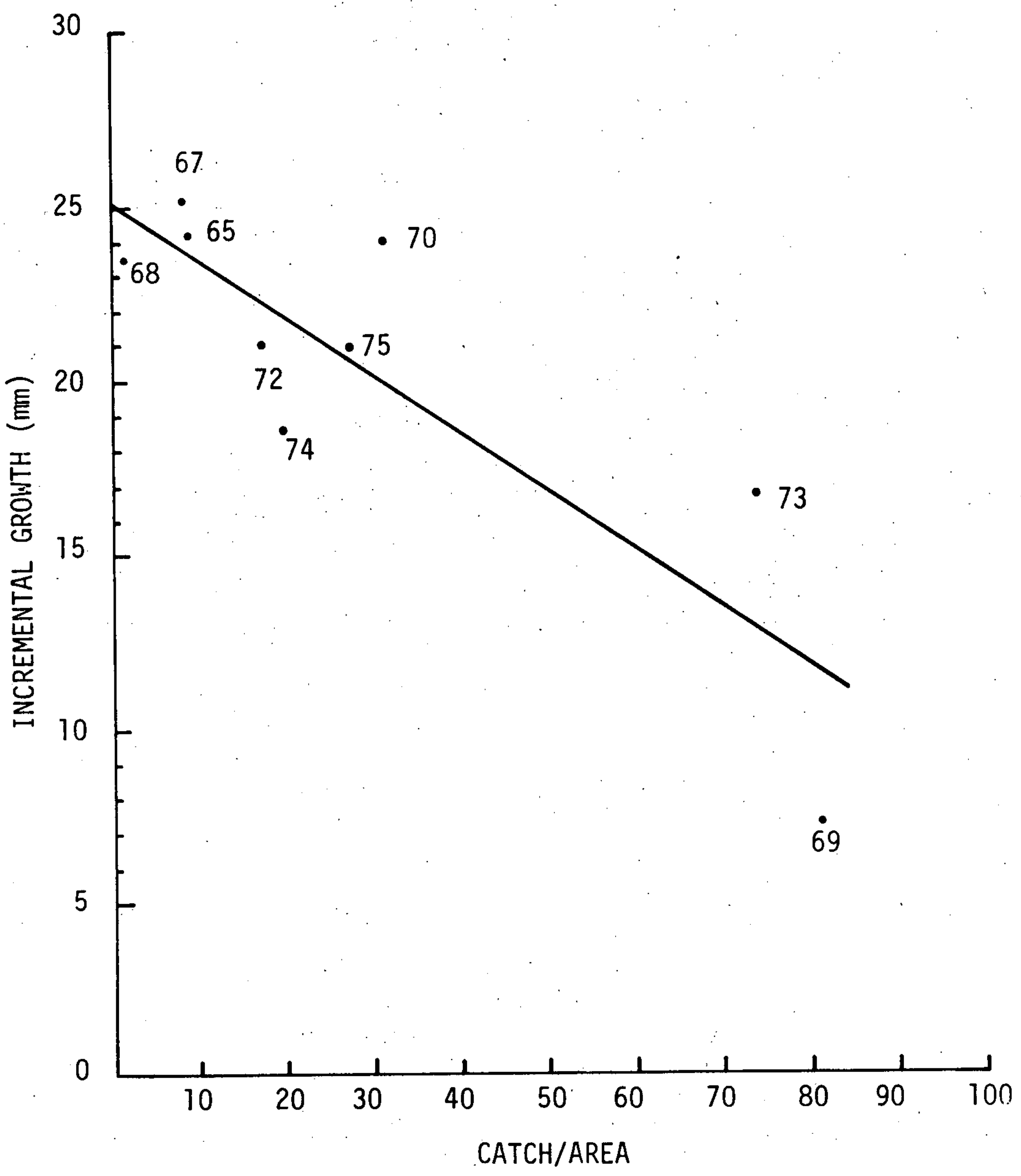


Figure 10.5-1 Relationship of Juvenile Striped Bass Density in Indian Point Area to Changes in Mean Lengths (Growth) from July to August, 1965-75

Table 10.5-1 Cannibalism and Predation on Striped Bass

Consumer	1972	1973	1974
Striped bass*	X	X	X
White perch	X	X	
Atlantic tomcod		X	
Bluefish		X	X

* Yearling striped bass consume juveniles

piscivorous by mid-July (TI 1976a), preying on many of the fishes found in the estuary, including striped bass; there is some evidence that the incidence of striped bass in bluefish stomachs is related to the density of striped bass (TI 1976a), suggesting that bluefish predation may operate in a density-dependent manner.

10.5.3 COMPENSATORY OPERATION OF FISHERY. Based on an assessment of the sport and commercial fisheries for striped bass, the U.S. Nuclear Regulatory Commission (USNRC) staff has concluded that the combined fishery will operate in a compensatory manner that will partially offset the increased mortality caused by power plants. The following statements summarize the staff's position (USNRC 1975b:Vol. I, p. x.):

> "...fishing mortality appears to be a more important source of mortality than natural causes for adult striped bass once they enter the fishery,
>
> "...the striped bass sport catch substantially exceeds the commercial catch,
>
> "...the fishing effort, particularly the sport fishing effort, is dependent in part on the size of the striped bass population,
>
> "...the staff assumed that the combined fishery will respond in a compensatory manner, with or without new fishing regulations, so as to partially offset the increased mortality due to the power plants."

The staff included a density-dependent fishing mortality function based on this assessment in its life-cycle model. The staff's conclusion that the fishery will operate in a compensatory manner is very likely true, but the exact functional relationship between stock size and fishing mortality is still arguable (see USNRC 1975c:Volume II, Appendix B, for the model used by the USNRC). Thus, the combined sport and commercial fishery for striped bass can be considered to be a density-dependent source of mortality.

10.5.4 CONCLUSIONS. Several compensatory mechanisms have now been identified for Hudson River striped bass, including cannibalism, predation by three different companion species of fish, density-dependent growth (competition), and a fishery that appears to operate in a compensatory manner. The operation of these compensatory processes agrees with studies of striped bass in Chesapeake Bay and San Francisco Bay as cited in Section 10.4. The existence of such mechanisms certainly provides a reasonable background against which compensatory reserve can be estimated.

Given the mechanisms found to operate in the Hudson and in other populations of striped bass, as well as the inverse relationships between stock and recruitment observed for other populations, it seems likely that the Ricker stock recruitment curve would be the most appropriate tool to use in estimating the compensatory reserve of the Hudson River stock. This approach is developed in Section 10.6.

10.6 COMPENSATORY RESERVE IN HUDSON RIVER STRIPED BASS

10.6.1 INTRODUCTION. Given that compensatory mechanisms exist in the Hudson River striped bass population (Section 10.5), it is important to estimate the level of compensatory reserve in the population and to determine how much of a density-dependent change in natural mortality is necessary in order to compensate for power plant impact. These two objectives are met in this section, and the results are applied to estimation of power plant impact in Sections 11 and 12. Previous analyses (TI 1975b:VIII-2 to VIII-7; and Section 10.5) indicated the applicability of a Ricker stock recruitment curve in describing the overall effect of density-dependent processes operating in the Hudson River striped bass population; simulations in the TI report just cited showed that only a small change in the natural mortality rate was needed to offset a significant man-caused impact. The analyses of this report refine and extend the earlier analyses.

If the abundance of spawners in different years can be measured on some absolute or relative scale for the Hudson River striped bass stock and if the abundance of recruits can be similarly measured, a curve reflecting the compensatory reserve of the population can be fit either graphically or by using a mathematical expression. The representation and interpretation of a compensatory relationship through the use of such a curve has been explained in detail in Section 10.3.1 using a graphical approach. In this section, empirical data representing spawning stock and recruits in the Hudson River are described and then used to estimate by nonlinear least square techniques the parameters α and β of the mathematical expression developed by Ricker (1975):

$$R = \alpha \, Pe^{-\beta P}$$

where

R = recruits
P = parents

The expression generates a family of curves, depending on the values of the parameters α and β, which closely approximate a variety of stock recruitment relationships which have been shown to exist in different fish populations.

The basic data from which measures of spawning stock and recruitment in Hudson River striped bass are developed are the yield-per-effort (Y/f) indices of abundance obtained from the commercial fishery. Comparable observations for 1955-75 are available for analysis (Section 7.1).

10.6.2 MATHEMATICAL FITS OF STOCK RECRUITMENT CURVES AND DEFINITION OF BASELINE FOR COMPENSATORY RESERVE. At present, there are two different interpretations as to what segment of the striped bass population is measured by the Y/f data. The first, which has been the working interpretation for some time, is that the Y/f data are an index to the size of the spawning stock and that 5- and 6-yr-old fish dominate this spawning stock. Under this interpretation, the Y/f index in any year t is taken as a measure of abundance of spawners and the Y/f some appropriate number of years later (the lag time corresponding to the average age at which the recruits spawn) is taken as a measure of the abundance of the generation of recruits. For example, striped bass spawning in 1965 produce offspring which make up a major part of the 1970 and 1971 spawning runs. The Y/f statistic for 1965 is then a measure of the size of the parental generation, and the Y/f statistics for 1970 and 1971 measure the size of the progeny generation produced by the 1965 parents. The best approximation to the lag time, 5½ yr, is calculated by averaging the Y/f data for t + 5 and t + 6 (1970 and 1971 in the example above). This produces the stock recruitment curve of Figure 10.6-1, in which a fairly strong negative correlation exists between size of spawning stock and number of progeny produced.

Other analogous indices of spawning stock (P) and recruitment (R) have been compounded using yield-per-effort data from a single year or an average for two adjacent years, with various lag times between parent and progeny generations. For example, the progeny generation corresponding to the 1965 parents could be represented by the 1970 Y/f datum alone, or the 1971 datum alone, or some combination of the two other than simple average. The parameters α and β, the strength of the negative correlation between P and R, and the residual mean square which indicates how well the curve fits the data, quite naturally vary with the choice of index of P and R. However, the value of α, which is a measure of the compensatory reserve of the population, falls within a fairly restricted range for any reasonable interpretation of the Y/f index.

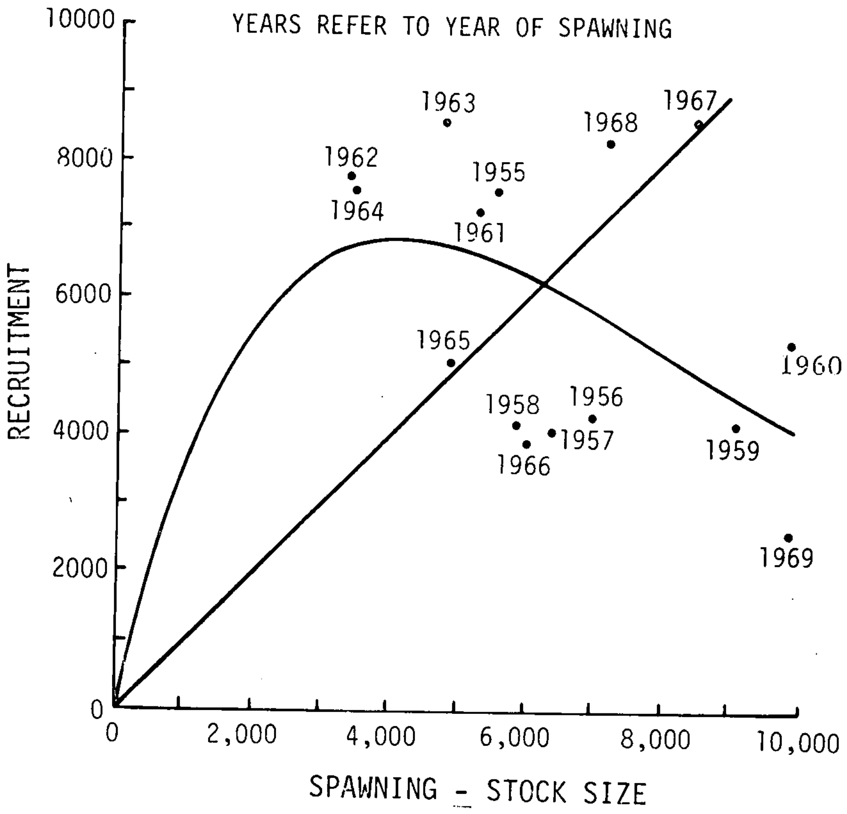


Figure 10.6-1 Stock Recruitment Curve for Hudson River Striped Bass (P = Y/f at t; R = Average Y/f 5 and 6 yr after t)

~~The second interpretation of the Y/f data was based on preliminary evidence obtained recently about the age structure of the Hudson River striped bass population, age composition of the commercial catch, and age at sexual maturity. Thus far, the new data have been analyzed only on the basis of fish lengths; age-specific analysis using scale samples must be completed before it can be accepted with confidence. The new data suggest first that the actual adult mortality rate in the striped bass population is lower than the rate hypothesized earlier (TI 1975b). Second, up to the present time, estimates of the proportion of females in each age group that are sexually mature have been based on small sample sizes and have changed considerably with the addition of more data. Consequently, older age groups may contribute more to the spawn in any year than previously supposed (Section 7.8).~~ deleted

~~A third perspective, based on preliminary analysis of the commercial catch of striped bass sampled in 1976, suggests that the commercial fishery may harvest primarily 3-, 4-, and 5-yr olds, with 4-yr olds comprising the bulk of the catch.~~

~~These three concepts, as yet unconfirmed, were used in the following way to estimate the abundance of spawners and recruits.~~

~~For fish that are multiple-age spawners, Ricker (1973) recommended plotting total egg production by the spawning stock against the expected lifetime egg production by the recruits in the absence of fishing. Therefore, a matrix model that used the commercial fishery Y/f values as an index of 4-yr-old abundance was developed. Annual survival was assumed to be 60% and fishery exploitation rate was assumed to be 10%. Current approximations of individual fecundity and the proportion of mature females were used for each age group. Relative egg production by both spawning stock and recruits was estimated for ages IV through X as an index of egg production. The spawning-stock abundance matrix, recruitment abundance matrix, and age-specific fecundity and maturity model appear in Tables 10.6-1 and 10.6-2. The resulting indices of spawning stock and recruitment were used to fit the Ricker stock recruitment curve of Figure 10.6-2 in exactly the same way as the curve of Figure 10.6-1 was developed.~~

~~Under the second interpretation developed here, year-to-year variations in egg production were greatly damped because seven different age groups participated in each year's spawning. In fact the egg-producing potential of the spawning stock appeared to be remarkably stable, with the effects of strong and weak year classes tending to offset one another. From an analytical viewpoint, this stability was reflected in a rather narrow range of abscissal values against which to plot the more variable ordinate values for recruitment. Thus, while the curve of Figure 10.6-2 was the best fit to the available data, a wider range of spawning stock sizes would have been desirable.~~ deleted

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Table 10.6-1 Spawner Abundance Matrix with Relative Fecundity Index for Each Age Group (4-10) Using Commercial Fishery Yield-per-Effort as Index of 4-Yr-Old Abundance and Assuming 40% Annual Mortality

Year Of Spawning	IV	V	VI	VII	VIII	IX	X
1961	5300	5955	3282	1286	839	547	262
1962	3468	3180	3573	1969	772	503	328
1963	4880	2081	1908	2144	1181	463	302
1964	3567	2928	1248	1145	1286	709	278
1965	4900	2140	1757	749	687	772	425
1966	6091	2940	1284	1054	449	412	463
1967	8511	3655	1764	770	632	270	247
1968	7212	5107	2193	1058	462	379	162
1969	9994	4327	3064	1316	635	277	228
1970	5356	5996	2596	1838	789	381	166
1971	5030	3214	3598	1558	1103	474	229
Proportion Mature	0.05	0.30	0.70	0.85	1.00	1.00	1.00
Individual Fecundity x 10^{-3}	400	600	750	1000	1300	1500	1800
Fecundity Index	0.2	1.8	5.25	8.50	13.0	15.0	18.0

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Table 10.6-2 Recruitment Abundance Matrix Using Commercial Fishery Yield-per-Effort As Index of 4-Yr-Old Abundance and Assuming 32% Annual Mortality in Absence of Fishing

	Age Group						
Year of Recruitment	IV	V	VI	VII	VIII	IX	X
1965	4900	3332	2266	1541	1048	712	484
1966	6091	4142	2816	1915	1302	886	602
1967	8511	5787	3935	2676	1820	1237	841
1968	7212	4904	3335	2268	1542	1049	713
1969	9994	6796	4621	3142	2137	1453	988
1970	5356	3642	2477	1684	1145	779	530
1971	5030	3420	2326	1582	1075	731	497
1972	2831	1925	1309	890	605	412	280
1973	14447	9824	6680	4543	3089	2100	1428
1974	2286	1554	1057	719	489	332	226
1975	3024	2056	1398	951	647	440	299

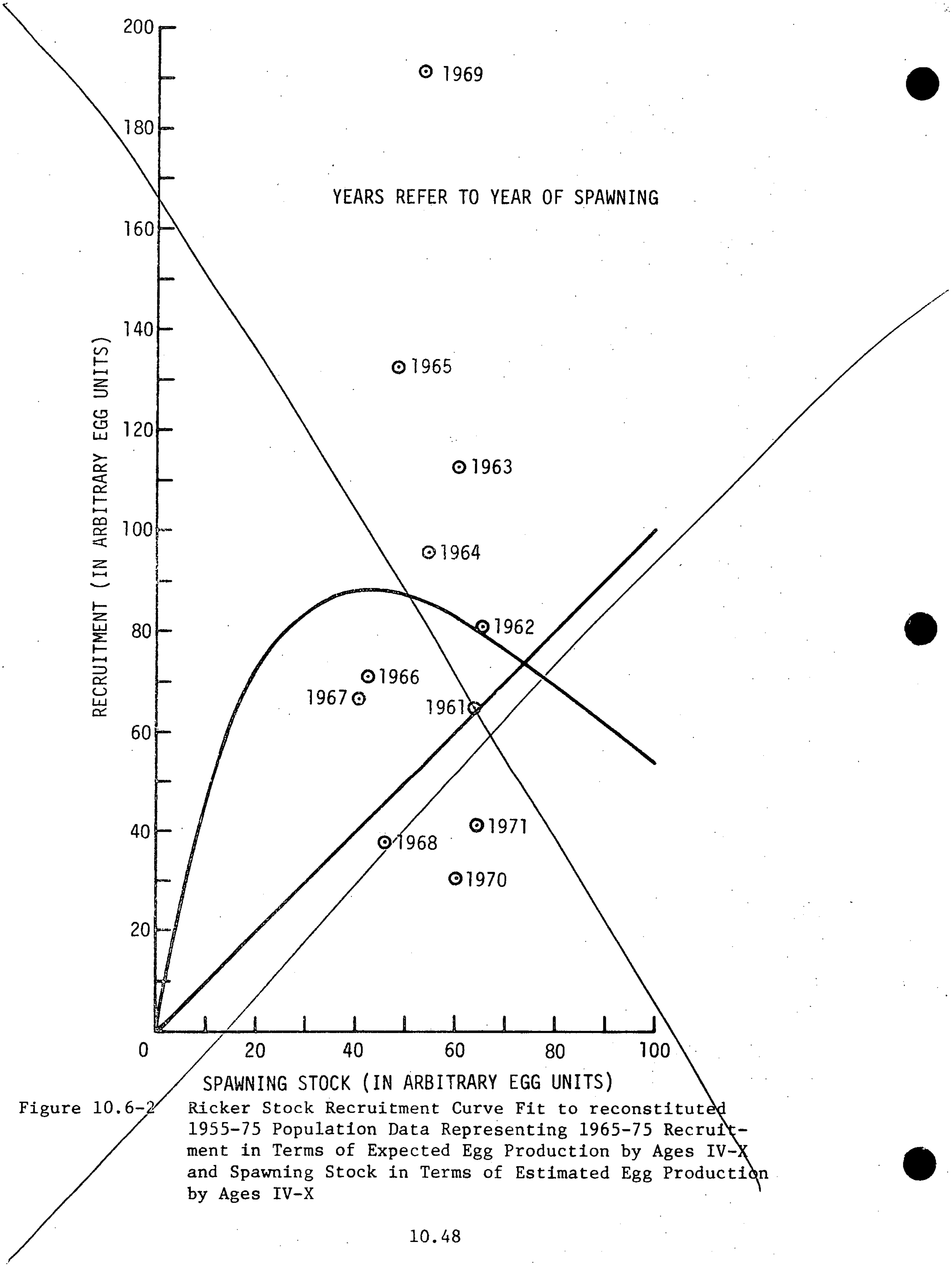

Figure 10.6-2 Ricker Stock Recruitment Curve Fit to reconstituted 1955-75 Population Data Representing 1965-75 Recruitment in Terms of Expected Egg Production by Ages IV-X and Spawning Stock in Terms of Estimated Egg Production by Ages IV-X

~~The shapes of the curves in Figures 10.6-1 and 10.6-2 are similar even though they are based on considerably different interpretation of the commercial fishery yield-per-effort statistics as a measure of spawning stock. The parameter values for the two curves are:~~

~~First Interpretation~~	~~Second Interpretation~~
~~$\alpha = 4.0689$~~	~~$\alpha = 5.7036$~~
~~$\beta = 2.2362 \times 10^{-4}$~~	~~$\beta = 2.3823 \times 10^{-5}$~~

~~The value of α does not differ greatly under the two alternative interpretations of the Y/f statistics. Either value, or some mid-range value, would be an acceptable working approximation of the compensatory reserve of the Hudson River striped bass population.~~ deleted

The most important factor in evaluating the ability of the fish population to withstand impacts from power plant operation is the compensatory capacity not already called into operation by existing fishery exploitation, operation of power plants already on line for some years, and other current man-caused impacts. Without doubt, some of the compensatory reserve originally available to the virgin Hudson River striped bass stock has already been used. If data representing the dynamics of the stock several decades ago comprised the bulk of the empirical observations on stock and recruitment, compensatory reserve might be overestimated since more recent, persisting environmental impacts (e.g., increase in sport fishing) would not be taken into account. However, as can be seen in Figures 10.6-1 and 10.6-2, data from the period 1965-1975 are generously represented among the observations upon which the stock recruitment analyses are based, and tend to be consistent with the observations from earlier years. Therefore, the estimates of compensatory capacity can be used to measure the reserve still available to offset new environmental impacts imposed on the Hudson River ecosystem over and above those already operative roughly during the decade 1965-75. It is clear then that the compensatory reserve estimated in this section is available as a partial cushion against the impact of Indian Point Unit 2 and the other power plant units which have been activated since 1972. The effects of power production units on line prior to 1972 are reflected in the baseline total mortality of the striped bass population upon which new impacts (post-1972) are measured.

10.6.3 POPULATION STATISTICS BASED ON STOCK RECRUITMENT CURVES. Using the estimated parameters (α and β) of the stock recruitment curves, one can generate many population statistics that are useful in managing a population (Ricker 1975: Appendix III). The most interesting statistics for our use are the equilibrium spawning stock size (P_E) resulting from various levels of equilibrium exploitation (U_E); the equilibrium exploitation rate which causes the spawning stock size to approach zero i.e., the limiting exploitation rate; and the replacement level of spawning stock (P_r). The following are the equations for each:

$$P_E = \frac{\log_e(\alpha[1-u_E])}{\beta} \qquad (10.1)$$

$$\text{Limiting } u_E = 1 - \frac{1}{\alpha}\ ; \quad \text{when } P \to 0 \qquad (10.2)$$

$$P_r = \frac{\log_e \alpha}{\beta} \qquad (10.3)$$

Percentage reduction in equilibrium spawning stock for any exploitation rate can be determined as follows:

$$\%\ \text{reduction} = \frac{P_r - P_E}{P_r} \cdot 100 \qquad (10.4)$$

Exploitation rate can be related to power plant mortality for given natural mortality rates by the following equations (Ricker 1975:8-11):

$$A = m + n - mn \qquad (10.5)$$

$$F = -\log_e (1-m) \qquad (10.6)$$

$$Z = -\log_e (1-A) \qquad (10.7)$$

$$u = FA/Z \qquad (10.8)$$

where

A = total mortality rate
F = instantaneous rate of fishing (power plant) mortality
Z = instantaneous total mortality rate
u = exploitation rate
m = conditional mortality rate due to power plants
n = conditional natural mortality rate

The relationship among natural mortality, power plant mortality, and exploitation rate is developed in Table 10.6-3.

Table 10.6-3 Values of Exploitation Rate (u) Corresponding to Various Levels of Natural Mortality (n) and Power Plant Mortality (m)

Power Plant Mortality Rate	Natural Mortality Rate							
	0.5	0.6	0.7	0.8	0.9	0.95	0.99	0.999
0.10	0.073	0.066	0.059	0.050	0.040	0.032	0.022	0.015
0.20	0.146	0.133	0.119	0.102	0.081	0.067	0.046	0.031
0.30	0.221	0.202	0.181	0.156	0.125	0.103	0.071	0.049
0.40	0.297	0.272	0.244	0.212	0.171	0.141	0.099	0.069
0.50	0.375	0.345	0.311	0.271	0.220	0.183	0.130	0.091
0.60	0.455	0.420	0.380	0.334	0.273	0.230	0.165	0.117
0.70	0.539	0.500	0.455	0.402	0.333	0.282	0.207	0.148
0.80	0.629	0.586	0.538	0.480	0.403	0.346	0.248	0.189
0.90	0.730	0.687	0.637	0.577	0.495	0.432	0.333	0.250
0.99	0.865	0.831	0.790	0.740	0.666	0.606	0.500	0.400
0.999	0.908	0.883	0.851	0.811	0.750	0.697	0.600	0.500

$$\% \text{ reduction} = 1 - \frac{\log_e \alpha \quad 1 - \dfrac{(-\log_e (1-m))(m+n-mn)}{-\log_e (1-m-n+mn)}}{\log_e \alpha} \cdot 100 \qquad (10.9)$$

For any Ricker stock recruitment curve, therefore, the percentage reduction in the equilibrium spawning stock size can be estimated if the natural mortality is known (or assumed) and the probability of death caused by power plant operation can be estimated.

Equation 10.9 can be represented also in terms of α and u_E if power plant exploitation rate is estimated by some other method:

$$\% \text{ reduction} = 1 - \frac{\log_e \alpha \, [1-u_E]}{\log_e \alpha} \cdot 100 \qquad (10.10)$$

This equation can be developed simply for other stock-recruitment relations as well.*

Based on the curve fitting done in Section 10.6.2, the estimated value for the critical parameter α ranged from 4.1 to 5.7, and since it is not clear which of the two alternative interpretations of the commercial fishery data is most likely, an intermediate working estimate of $\alpha = 5.0$ was chosen for subsequent analysis. Using the working estimate of α as indicative of the stock recruitment relationship in Hudson River striped bass, reduction in the spawning stock caused by any level of power plant mortality can be readily estimated.

---

*For the Beverton-Holt curve of the type $R = \frac{P}{\alpha P+\beta}$, percentage reduction can be estimated by the following simple equation:

$$\% \text{ reduction} = \frac{u_E}{1-\beta} \cdot 100$$

Percentage reduction in spawning stock size at equilibrium is illustrated in Figure 10.6-3 for representative natural mortality rates during the entrainment and impingement seasons. Natural mortality during the entrainment season is likely to be quite high ($\geq$ 0.999; Section 7.7); thus, the estimated reduction in spawning stock size from a 30% rate of entrainment mortality would be < 4%. For a natural mortality of 80% during the impingement season, a 30% rate of impingement mortality would yield a 10.5% reduction in spawning stock. Obviously, because of the relationship between the conditional mortality rates and the exploitation rate illustrated in Table 10.6-3, lower natural mortality rates result in greater reductions in spawning stock for any given level of power plant mortality. Thus, the effect of entrainment on equilibrium stock size would be much less than the effect of impingement at any equivalent levels of conditional mortality rate caused by power plants.

An approximate estimate of the combined reduction in spawning stock due to entrainment and impingement was obtained by estimating reduction in spawning stock separately for impingement and for entrainment and then summing the two estimates. Alternative procedures probably would not have added much to the accuracy obtained using this method. For the moderate levels of rate of mortality due to power plants estimated for the Hudson River striped bass population (TI 1975b, Vol I:VII-15 to VII-44), reduction in equilibrium stock size should be considerably less than 10%, based on the principles developed above.

As an exercise, similar calculations were performed using the family of stock recruitment curves provided by Ricker (1975:286). Percentage reduction values were provided for all six curves under varying levels of natural and power plant mortality (Table 10.6-4) and the entrainment case ($n = 0.999$) illustrated (Fig. 10.6-4). Even for a population with very limited compensatory reserve (curve D of Ricker; $\alpha = 1.948$), the probability of death caused by entrainment (m) must exceed 37% before reduction in equilibrium stock size reaches 10%. Thus, even very low-domed stock recruitment curves represent considerable capacity by a

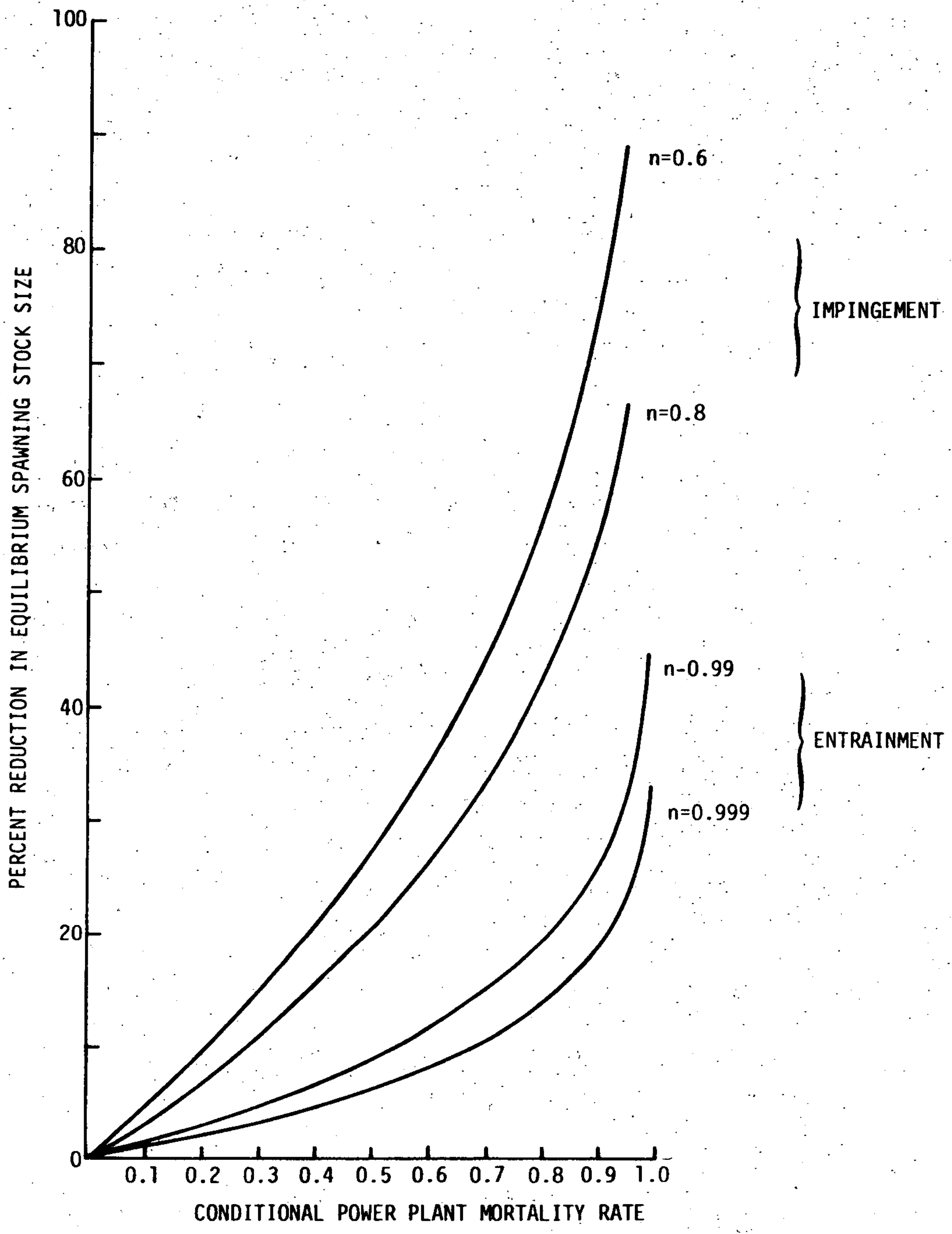

Figure 10.6-3 Relationship between Conditional Power Plant Mortality Rate (m) and Percentage Reduction of Equilibrium Spawning Stock Size for Representative Natural Mortality Rates (n) Based on Stock Recruitment Relationship with $\alpha = 5.0$

Table 10.6-4 Percent Reductions in Equilibrium Stock Size for Ricker (1975) Family of Curves

Curve	Natural Mortality (n)	Power Plant Mortality (m)										
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95	0.99
D α = 1.948	0.999	2.3	4.8	7.5	10.7	14.3	18.7	24.1	31.4	43.1	54.0	76.6
	0.99	3.4	7.0	11.1	15.7	20.9	27.1	34.7	44.8	60.7	75.1	>100
	0.9	6.1	12.7	20.0	28.1	37.2	47.9	60.7	77.4	>100		
	0.8	7.7	16.2	25.4	35.7	47.4	60.9	77.2	98.1	>100		
	0.6	10.2	21.4	33.8	47.6	63.4	81.7	>100				
A α = 2.718	0.999	1.5	3.2	5.0	7.1	9.6	12.5	16.1	20.9	28.8	36.0	51.1
	0.99	2.2	4.7	7.4	10.5	13.9	18.1	23.1	29.9	40.5	50.1	69.3
	0.9	4.1	8.5	13.3	18.7	24.8	31.9	40.5	51.6	68.3	82.7	>100
	0.8	5.2	10.8	17.0	23.8	31.6	40.6	51.5	65.4	86.0	>100	
	0.6	6.8	14.3	22.5	31.8	42.2	54.5	69.3	88.3	>100		
E α = 3.490	0.999	1.2	2.5	4.0	5.7	7.6	10.0	12.9	16.8	23.0	28.8	40.9
	0.99	1.8	3.8	5.9	8.4	11.2	14.5	18.5	23.9	32.4	40.1	55.4
	0.9	3.3	6.8	10.7	15.0	19.9	25.5	32.4	41.3	54.7	66.2	87.7
	0.8	4.1	8.6	13.6	19.1	25.3	32.5	41.2	52.3	68.8	82.6	>100
	0.6	5.5	11.4	18.0	25.4	33.8	43.6	55.4	70.6	92.9	>100	
F α = 4.482	0.999	1.0	2.1	3.4	4.8	6.4	8.3	10.7	14.0	19.2	24.0	34.1
	0.99	1.5	3.1	4.9	7.0	9.3	12.0	15.4	19.9	27.0	33.4	46.2
	0.9	2.7	5.7	8.9	12.5	16.5	21.3	27.0	34.4	45.5	55.1	73.1
	0.8	3.4	7.2	11.3	15.9	21.1	27.1	34.3	43.6	57.3	68.9	89.7
	0.6	4.6	9.5	15.0	21.2	28.2	36.3	46.2	58.8	77.4	92.5	>100
B α = 7.389	0.999	0.8	1.6	2.5	3.6	4.8	6.2	8.0	10.5	14.4	18.0	25.5
	0.99	1.1	2.3	3.7	5.2	7.0	9.0	11.6	15.0	20.2	25.0	34.6
	0.9	2.0	4.2	6.7	9.4	12.4	16.0	20.3	25.8	34.2	41.3	54.8
	0.8	2.6	5.4	8.5	11.9	15.8	20.3	25.7	32.7	43.0	51.6	67.3
	0.6	3.4	7.1	11.3	15.9	21.1	27.2	34.6	44.1	58.0	69.4	88.8
C α = 14.556	0.999	0.6	1.2	1.9	2.7	3.6	4.6	6.0	7.8	10.7	13.5	19.1
	0.99	0.8	1.8	2.8	3.9	5.2	6.7	8.6	11.2	15.1	18.7	25.9
	0.9	1.5	3.2	5.0	7.0	9.3	11.9	15.1	19.3	25.5	30.9	40.9
	0.8	1.9	4.0	6.3	8.9	11.8	15.2	19.2	24.4	32.1	38.6	50.2
	0.6	2.5	5.3	8.4	11.9	15.8	20.3	25.9	33.0	43.3	51.8	66.3

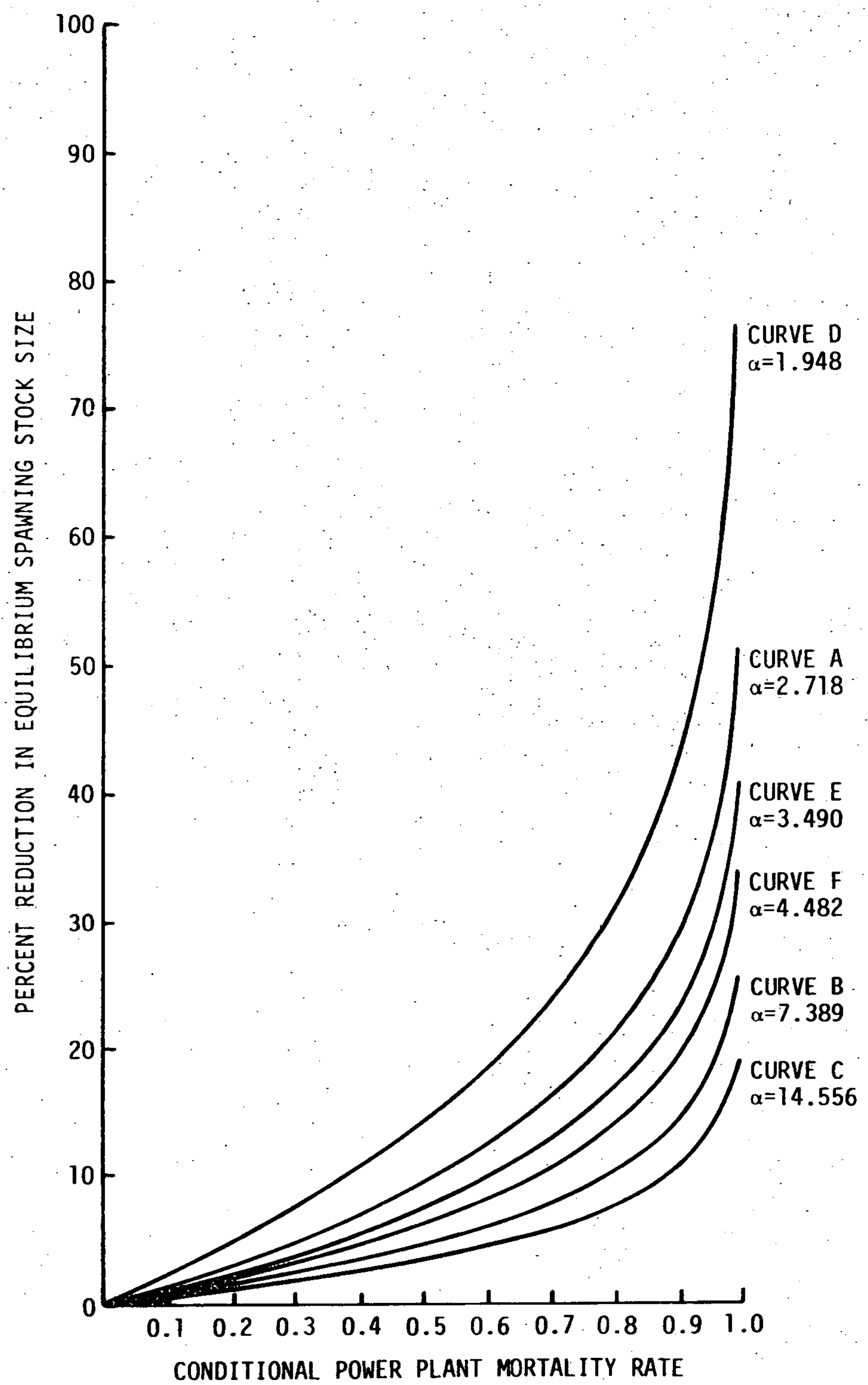

Figure 10.6-4 Compensation by Ricker (1975) Family of Stock Recruitment Curves (Conditional rate of natural mortality n = 0.999)

fish population to compensate for impacts of the kind imposed by power plant operation.

The effect of the parameter α on estimates of percentage reduction is illustrated for fixed values of natural (n) and power plant (m) mortality in Figure 10.6-5. As α approaches infinity, percentage reduction in equilibrium stock approaches zero; conversely, as α approaches unity (from the right), percentage reduction in equilibrium stock approaches infinity. Modest departures from the α values calculated from empirical data for the striped bass of the Hudson River would not substantially change the estimate of compensatory reserve, and even large departures in the direction of smaller α values would not change the conclusion that substantial compensatory reserve exists.

Based on the relationship between spawning stock and recruitment in the Hudson River striped bass, it would appear that the striped bass population can endure rather substantial "impacts" (power plant mortality rates) without suffering nearly so much in terms of reduction to the spawning stock. This is particularly true of the entrainment of eggs and larvae when concomitant natural mortality rate is high. Impingement mortality has more of an effect, but it too is offset considerably by the density-dependent processes that combine to produce the stock recruitment curve.

10.6.4 FISHING VS. PLANT-INDUCED MORTALITY. The mortality imposed on young fish by power plants is not inherently different from that imposed by a fishery on older fish. This idea was first pointed out more than 20 yr ago by Ricker (1954:607):

> "Exploitation that takes fish at an age when natural mortality is still compensatory means, for practical purposes, a fishery for young during the first year or two of their life - the earlier the better. The removal of such young is at least partly balanced by increased survival and/or growth of the remainder; in fact, the effects of removals at this stage are equivalent to

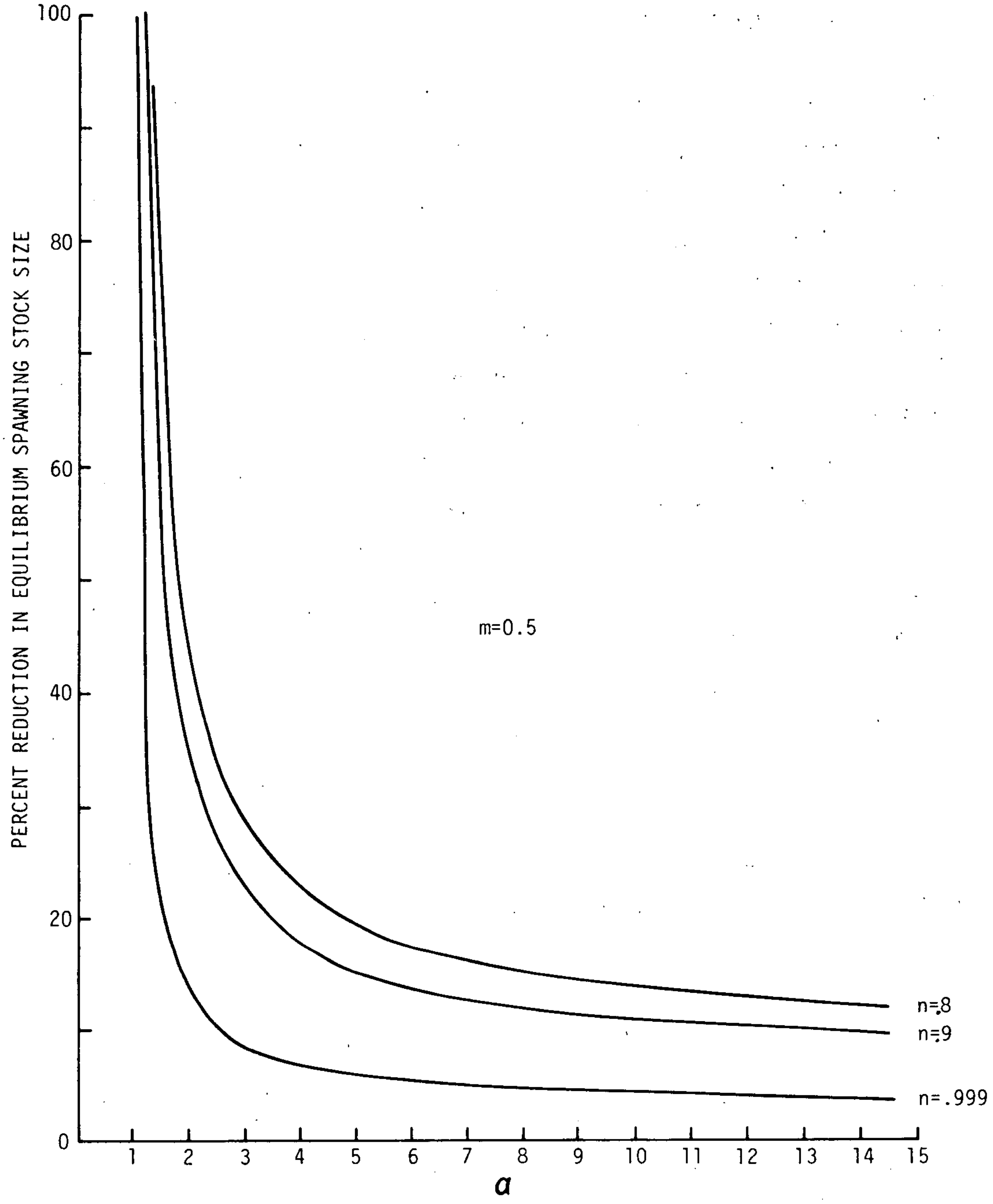

Figure 10.6-5 Effect of Parameter α from Ricker Stock Recruitment Relationship $R = \alpha P e^{-\beta P}$ on Estimates of Percent Reduction in Equilibrium Spawning Stock for Fixed Values of Natural (n) and Power Plant (m) Mortality

> reduction of the spawning stock which produced the brood in question. If the reproduction curve for the population is of any of the types 3-8, such reduction will at first increase net production of recruits, which will produce more eggs and permit a larger catch of young in future years. This ascending spiral of abundance may continue until the level of stock is reached which produces maximum recruits."

Ricker goes on to say "... it is clear that any *general* prejudice against exploiting young fish is unsound." Ricker's analysis of the situation has not been challenged and certainly requires no further embellishment except to say that the reproduction curves developed for Hudson River striped bass are of the type cited above.

10.6.5 CHANGES IN NATURAL MORTALITY NECESSARY TO COMPENSATE FOR POWER PLANT MORTALITY. One reason why compensation can work so effectively, particularly in the first year of life, is that relatively small decreases in natural mortality can offset considerable levels of impact. This simple fact has been illustrated in the following elementary simulation study of compensatory responses.

Changes in natural mortality necessary to offset various levels of mortality due to power plants (impact)[*] are more for high levels of power plant mortality but less for high levels of natural mortality (Tables 10.6-5 and 10.6-6; Figs. 10.6-6 and 10.6-7). This is equivalent to the situation developed from the stock recruitment curves in which

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[*] Conditional power plant mortality (m) may be used as a measure of impact during the first year of life since, for a constant natural mortality (n), i.e., no compensation, population reduction may be expressed as follows:

$$\text{Impact} = \frac{N_1 \text{(without power plants)} - N_1 \text{(with power plants)}}{N_1 \text{ (without power plants)}}$$

Therefore,

$$\text{Impact} = \frac{N_o \ (1-n) - N_o \ (1-m-n+mn)}{N_o \ (1-n)} = m$$

Table 10.6-5 Percent Reduction in Natural Mortality Rate To Compensate for Power Plant Mortality during Period of Impact

	Original Natural Mortality Rates (n)								
Impact(m)	0.80	0.85	0.90	0.92	0.95	0.97	0.99	0.995	0.999
10%	2.8	2.0	1.2	1.0	0.6	0.4	0.1	0.06	0.01
20%	6.3	4.4	2.8	2.2	1.3	0.8	0.3	0.12	0.02
30%	10.7	7.6	4.8	3.7	2.3	1.3	0.4	0.21	0.04
40%	16.7	11.8	7.4	5.8	3.5	2.1	0.7	0.33	0.07
50%	25.0	17.6	11.1	8.7	5.3	3.1	1.0	0.50	0.10
60%	37.5	26.5	16.7	13.0	7.9	4.6	1.5	0.75	0.15
70%	58.3	41.2	25.9	20.3	12.3	7.2	2.4	1.18	0.23
80%		75.0	44.4	34.8	21.1	12.4	4.0	2.01	0.40
90%				78.3	47.4	27.8	9.1	4.52	0.90

Table 10.6-6 Percent Reduction in Mortality Necessary To Compensate for Power Plant Mortality after Period of Impact

	Original Mortality Rates (n)							
Impact	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2
10%	1.23	2.78	4.76	7.40	11.1	16.7	25.9	44.5
20%	2.78	6.25	10.71	16.67	25.0	37.5	58.3	
30%	4.77	10.71	18.37	29.52	42.8	64.4		
40%	7.41	16.66	28.57	44.45	66.66			
50%	11.11	25.00	42.86	66.66				
60%	16.66	37.50	64.29					
70%	25.92	58.34						
80%	44.44							

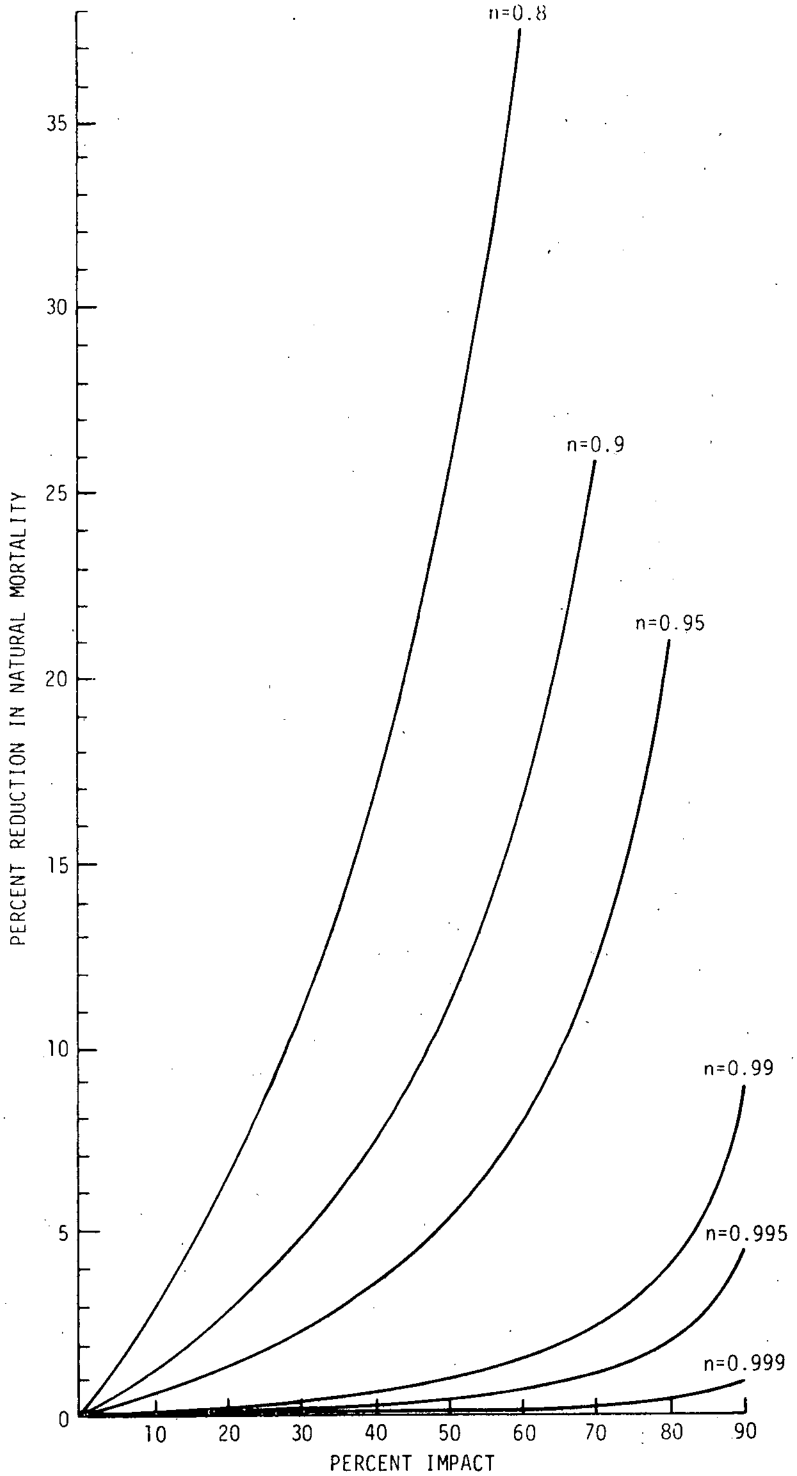

Figure 10.6-6 Reduction in Natural Mortality Rate Necessary To Offset Various Levels of Impact during Impact for Various Original Levels of Natural Mortality

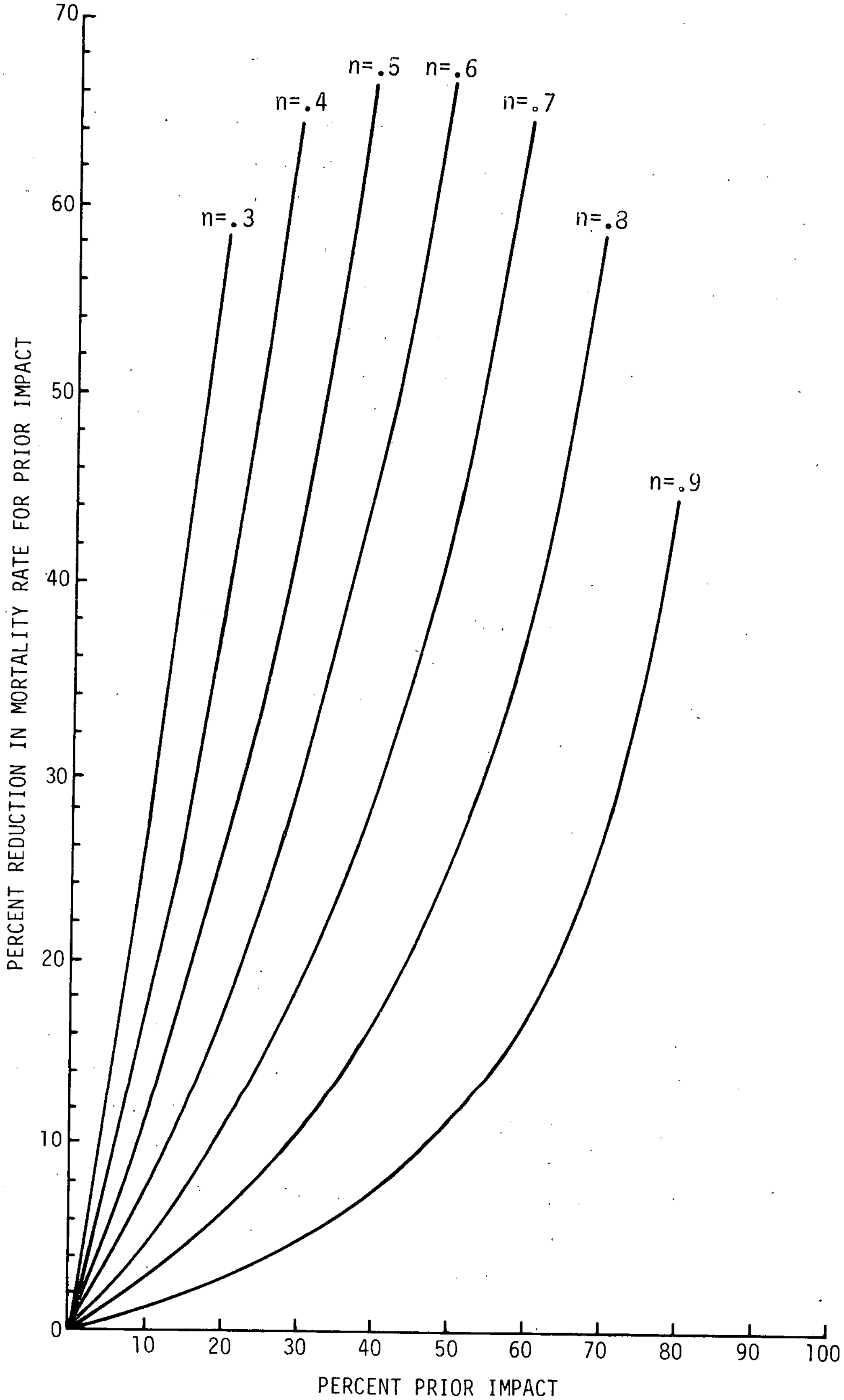

Figure 10.6-7 Percent Reduction in Mortality Rate Necessary To Offset Various Levels of Impact after Impact for Various Original Levels of Mortality

a high power plant mortality during entrainment produced less of an effect on spawning stock size than a high power plant mortality during impingement when natural mortality was lower. At a natural mortality rate of 0.999, a 0.1% reduction in natural mortality to 0.998 can offset a 0.5 power plant mortality rate; at a 0.95 natural mortality rate, however, a 5.3% change would be required to offset the same power plant mortality rate. Percentage reductions in mortality rate required to offset impact after the impact has already occurred are greater than those needed during the impact interval because of the increased survival expected in the older stages of life.

10.6.6 CONCLUSIONS. Based on the analyses presented herein, it seems likely that small changes in natural mortality can compensate adequately for temporary reductions in young striped bass caused by entrainment and impingement and that reductions in equilibrium spawning stock caused by entrainment and impingement impact will be small. Only very large ($\geq$ 80-90%) plant-induced mortality rates imposed on young striped bass will result in a >50% reduction in the equilibrium spawning stock size. As an index of the risk of irreversible effects on the striped bass population, the NRC staff (USNRC 1975b) considered the number of years during which the relative yield (yield to the fishery with power plant impact divided by yield to the fishery without power plant impact) was < 0.50. (It should be noted that any such arbitrary criterion provides only a very crude management tool with very shaky theoretical underpinnings at best.) In most cases, relative yield would be the complement of reduction in spawning stock size caused by power plant mortality (as long as catchability did not change with changes in abundance). Thus, by the staff's criterion, there is little likelihood of any irreversible effects on the population by power plant operation, regardless of the number of years of operation.

The compensation parameters for the Hudson River striped bass population developed in this section are used with the Ricker stock recruitment equation (Section 10.6.1) in the estimates of power plant impact developed in Section 11. The same magnitude of compensatory reserve is used in the impact estimates developed through a different approach in Section 12, but a different mathematical expression for compensation is employed as discussed in the following paragraphs.

10.7 COMPENSATION FUNCTION IN THE REAL-TIME LIFE-CYCLE MODEL

In the real-time model previously described (Section 2), a density-dependent mortality rate for the larval and juvenile life stages was calculated using the function presented in John A. Lawler's Indian Point 2 testimony of October 30, 1972:

$$KD = KE + (KE - KO) \frac{\left(C - C_s\right)^3}{C_s} \tag{10.11}$$

where

KD = natural mortality rate per day

KE = natural mortality rate per day, which applies under theoretical condition of no compensation

KO = minimum natural mortality rate per day approached as C approaches zero

C_s = representative equilibrium population level (fish per unit volume)

C = fish density at any point in time and space (fish per unit volume)

Through proper selection of the parameters KO and C_s, this nonlinear function can be used to reproduce a variety of compensatory population responses ranging from no compensation to very high levels of compensatory reserve. Sections 10.4, 10.5, and 10.6 have demonstrated that there is a compensatory reserve in the Hudson River striped bass population that can be estimated by fitting Ricker curves to commercial fishery data. A calibration procedure was used to determine the parameter values for Equation 10.11 consistent with the compensatory reserve calculated from Equation 10.9 of Section 10.6 with $\alpha = 5.0$. In Equation 10.11, the magnitude of the compensatory reserve is specified by the ratio KO/KE.

This ratio has been referred to as the compensation level in previous studies (LMS 1972; LMS 1975f). Thus, the final goal of the calibration procedure is to determine a compensation level consistent with the compensatory reserve specified in Section 10.6.

The calibration procedure summarized below requires field data collected with power plants in operation. Since it has been demonstrated that there is a compensatory reserve in the striped bass population, it is reasonable to assume that the effects of a compensatory response will be evidenced in field data collected with plants on line. Hence, the calibration procedure is performed with compensation operative in the model. This results in the following iterative scheme:

(1) Assume a value of KO/KE, the compensation level.

(2) Adjust KE to get reasonable agreement between standing-crop estimates from the field data and model output. (Section 12.1 provides further details regarding this aspect of the calibration.)

(3) Execute the real-time model with KE determined from step 2 but with no compensation and no plants on line. This run determines the conditional natural mortality rate (n) and the young-of-the-year populations without power plants in operation. (N_{1wo}).

(4) Run the real-time model with no compensation but with power plants on line to obtain the young-of-the-year population with power plants operating (N_1).

(5) From Section 10.6 calculate the conditional mortality rate due to power plants (m) as follows:

$$m = \frac{N_{1wo} - N_1}{N_{1wo}}$$

(6) Determine the reduction in the equilibrium spawning stock by running the real-time model and life-cycle models with the level of compensation assumed in step 1, K_E determined from step 2, and power plants operating.

(7) Using n and m from steps 3 and 5 respectively, find the percentage reduction in the spawning stock as calculated in Equation 10.9 (Section 10.6).

(8) If the percentage reductions in the equilibrium spawning stock determined in steps 6 and 7 do not agree, specify a new compensation level and begin the procedure again at step 1.

As explained in Section 10.6, the differences in natural mortality rates during the entrainment and impingement seasons require that the compensatory response to these two sources of impact be computed separately. Consequently, the above calibration procedure has been applied individually to the entrainment and impingement periods to determine the KO/KE levels expected during each of these periods. Application of the calibration procedure using field data collected during 1974 and 1975 has resulted in the following:

Entrainment Period	1974	1975
Conditional natural mortality rate (n)	0.998	0.998
Conditional plant mortality rate (m)	0.0848	0.0879
Compensation level (KO/KE)	0.40	0.40

Impingement Period	1974	1975
Conditional natural mortality rate (n)	0.915	0.918
Conditional plant mortality rate (m)	0.0217	0.0096
Compensation level (KO/KE)	0.86	0.80

There are two points to be made concerning the compensation levels produced by the calibration procedure: the close agreement of the compensation levels for the 1974 and 1975 data bases suggests appropriate selection of the C_s values in the compensation function; and the values are close to the high and low levels of compensation (0.5 and 0.8) used in previous studies presenting results from the LMS life-cycle models.

Section 12.3 compares some of the results presented here with those derived from the equilibrium reduction equation method presented in Section 11.

SECTION 11

IMPACT ON STRIPED BASS BASED ON EQUILIBRIUM REDUCTION EQUATION

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SECTION 11

IMPACT ON STRIPED BASS BASED ON EQUILIBRIUM REDUCTION EQUATION

11.1 INTRODUCTION

Two different methods of estimating the impact of power plants on the striped bass population were developed during the course of the research program. Both methods use the same definition of impact, i.e. the percentage by which the pre-impact equilibrium level of the fish population is ultimately reduced as a result of power plant operation.

The method presented in this section is called the "equilibrium reduction equation" method because it consists of entering mortality statistics reflecting power plant operation into an equation that predicts the percentage by which the striped bass population will be reduced on the average. This method is applied to the conditions of power plant operation existing during a particular year and assumes that the same conditions will prevail in future plant operation, but it has not been used to predict the consequences of future changed operational patterns within a plant or the activation of new production units.

The second way to estimate power plant impact, the "real-time life cycle simulation model" method (Section 12), operates on the same kinds of biological data as does the equilibrium reduction equation method but has been used to predict impact caused by plant operating conditions other than those actually observed (e.g., different flow rates or new power production units).

11.2 EQUILIBRIUM REDUCTION EQUATION METHOD

Estimation of impact involves several steps and is somewhat different for the entrainment and impingement problems.

Entrainment impact estimation consists of three steps:

- Estimating the conditional mortality rate (probability of death) due to entrainment at one or more power plants
- Estimating the exploitation rate due to entrainment using as input the conditional mortality rate due to entrainment and the conditional natural mortality rate
- Estimating the percentage reduction in equilibrium stock size due to entrainment on the basis of the compensatory relationship between spawning stock and recruitment developed in section 10.6

TI has previously given many of the equations used in estimating impact (TI 1975b:VII-5 to VII-14), so only a brief synopsis is given here.

For entrainment impact,

$$m_T = 1 - \prod_{i=1}^{k} (1 - m_i) \qquad (11.1)$$

where

m_T = conditional mortality rate due to entrainment
m_i = probability of death from entrainment during i^{th} interval
k = number of intervals (usually weeks) during the period of entrainment

The probability of death from entrainment in an interval is estimated as

$$m_i = \frac{C_i}{N_i^*} \qquad (11.2)$$

where

C_i = estimated number cropped by entrainment during i^{th} interval
N_i^*= adjusted average standing crop during i^{th} interval as measured through field studies (section 7.7)*

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*The standing crop is adjusted by methods given by Texas Instruments (TI 1975b:VII-6, VII-7) to account for recruitment of eggs over a fairly long period of time and thereby assures that m_i is estimated with respect to the entire population rather than only the recruited portion of the population.

Estimation of C_i involves the volume of water pumped by the power plant, the organisms' density in the region of the power plant, the ratio of intake densities to river densities, the proportion of organisms being re-entrained, and the fraction of entrained organisms cropped by the power plant. The last three quantities are analogous to the w ratio, f_3 factor, and f_c factor, respectively, as employed in the life-cycle simulation model and developed in subsection 8.3. The procedures used to calculate them are identical to those previously used by Texas Instruments (TI 1975b).*

Impact estimation using the equilibrium reduction equation was done before the latest refinements in w ratios and f factors and used working estimates of these quantities that were believed at the time to be realistic but that differed somewhat from the final values (section 8.3). The effects on estimates of impact of differences between the parameter values used here in the equilibrium reduction equation method and in Section 12 in the real-time life-cycle simulation model are discussed in Section 12. For the estimates developed here, actual pumped water volumes were used. Recirculation was estimated to be 10%, and the ratio of intake to river densities was estimated to be 0.5. The fractions of eggs, larvae, and juveniles cropped during entrainment were estimated to be 80, 60, and 70% respectively.

Choice of a working estimate of 10% for recirculation was based on the knowledge that some recirculation of cooling water does occur at Indian Point (RM 42; km 68) during flood tides but that the amount is

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*The correspondence between the notations used in this report and earlier TI reports is $w = W$, $f_3 = R$, and $f_c = q_p$. The data from which these factors are estimated are not necessarily the same for each model.

low (Larson 1969) and upon the NRC staff's statement that 10% is probably realistic (USNRC 1975b). The ratio of density of organisms in power plant intake to density in the river in the immediate vicinity of the intake was assumed to be 0.50 because of the nonuniform vertical and lateral distribution of ichthyoplankton in the river (Section 7), the relatively restricted area from which cooling water is withdrawn (LaSalle 1976), and the potential of the more motile life stages to partially escape entrainment because of swimming ability or choice of habitat (Section 7). Preliminary data from studies of striped bass cropping during entrainment at Indian Point (NYU 1974) suggested the mortality values of 80% for eggs, 60% for yolk sac and post yolk-sac larvae, and 70% for early juveniles. At the time these data were used, they were known to cause overestimates of mortality during entrainment because the collecting nets had been shown to cause some of the deaths being attributed to the power plant. The w ratio, and f_3 and f_c factors were expected to vary from one power plant to another but, since detailed data were not available when impact calculations were being made by this method, the values cited here were applied to all power plants as a working approximation.

Exploitation rate is estimated from m_T and n (conditional rate of mortality from natural causes) as follows:

$$u = \frac{FA}{Z} \qquad (11.3)$$

where

u = exploitation rate

A = total mortality rate ($m_T + n - m_T n$)

Z = instantaneous rate of total mortality ($-\log_e(1 - A)$)

F = instantaneous rate of mortality due to power plants ($-\log_e(1 - m_T)$)

These relationships are given by Ricker (1975). The value of n is derived from composite field data in Section 7.7 and is estimated to be ≥ 0.999 during the entrainable stages of the life history.

Using the equation developed in section 10.6, percentage reduction in equilibrium stock size is estimated from the stock recruitment relationship:

$$\text{Impact} = \left(1 - \frac{\log_e\left(\alpha(1 - u_E)\right)}{\log_e \alpha}\right) \cdot 100\% \qquad (11.4)$$

where

u_E = equilibrium level of exploitation
α = parameter of Ricker stock recruitment curve $R = \alpha P e^{-\beta P}$

Estimation of impingement impact is approached somewhat differently:

- Estimating exploitation rate directly from population size at the beginning of impingement vulnerability* and number impinged
- Estimating reduction in equilibrium stock size due to impingement by again using Equation 11.4 based on the stock recruitment relationship

Total impact due to entrainment and impingement is approximated as the sum of entrainment and impingement impacts.

11.3 IMPACT OF POWER PLANT OPERATION ON STRIPED BASS BASED ON 1974 AND 1975 DATA

The statistics necessary for estimating power-plant impact by the equilibrium reduction equation method are summarized for 1974 and 1975 in Table 11.3-1. The impact estimates for Indian Point Unit 2 were 0.76% in 1974 and 0.97% in 1975. The multiplant impact (Indian Point Unit 2, Bowline [RM 37; km 60], and Roseton [RM 65; km 105]) was 2.10% in 1974 and 1.84% in 1975. Thus, if the same plant operational and natural ecological

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*The 1975 estimate of 5,316,000 represents an actual weekly estimate of standing crop. In 1974 the weekly estimates were more variable, but approximately equal to the ~~1974~~ 1975 estimate, so an estimate of 5,500,000 was used as a working estimate of initial standing crop.

Table 11.3-1 Summary, Using Equilibrium Displacement Equation Method, of 1974 and 1975 Input Data and Estimates of Power-Plant Impact on Striped Bass Population of Hudson River

	1974	1975
ENTRAINMENT		
Fraction of organisms withdrawn from river (w)	0.5	0.5
Recirculation (f_3)	0.1	0.1
Fraction of entrained fish cropped by plant (f_c)		
eggs	0.8	0.8
larvae	0.6	0.6
juveniles	0.7	0.7
Conditional natural mortality rate (n)	0.999	0.999
Conditional plant mortality rate (m)		
Indian Point Unit 2	0.0568	0.0586
Bowline	0.0255	0.0295
Roseton		0.0349
Multiplant	0.0811	0.1188
Compensation parameter (α)	5.0	5.0
Impact (%)		
Indian Point Unit 2*	0.52	0.54
Bowline	0.23	0.27
Roseton		0.32
Multiplant	0.76	1.13
IMPINGEMENT		
Initial population size (N_0)	5,500,000	5,316,000
Number impinged		
Indian Point Unit 2 *	21,526	36,762
Bowline	95,027	22,109
Roseton	636	1,631
Multiplant	117,189	60,502
	1974	1975
Exploitation rate (u)		
Indian Point Unit 2 *	0.0039	0.0069
Bowline	0.0173	0.0042
Roseton	0.0001	0.0003
Multiplant	0.0213	0.0114
Compensation parameter (α)	5.0	5.0
Impact (%)		
Indian Point Unit 2*	0.24	0.43
Bowline	1.08	0.26
Roseton	0.01	0.02
Multiplant	1.34	0.71
TOTAL IMPACT (%)		
Indian Point Unit 2*	0.76	0.97
Bowline	1.31	0.53
Roseton	0.01	0.34
Multiplant	2.10	1.84

delete

*Includes 89 fish impinged in 1974 and 204 impinged in 1975 at Indian Point Unit 3.

conditions actually occurring in these 2 yr were to persist through the operating lives of the plants, the striped bass population would be reduced by the given percentages below the average level that characterized the stock before the new power generating units were activated. Indian Point Unit 2, which went on line in October 1973, operated at levels mostly above 80% of full flow during the 1974 and 1975 entrainment seasons; Bowline, for which Unit 1 was activated in September 1972 and Unit 2 in May 1974, operated about half the time in 1974 at >70% of full flow and most of the time in 1975 at >67% of full flow; Roseton, for which Unit 2 was activated in September and Unit 1 in December 1974, operated at >75% of full flow during most of the 1975 entrainment season. The impact estimates apply to these specific cooling-water flows.

For Indian Point Unit 2, the entrainment impact was about the same in both years but impingement impact was considerably higher in 1975 than in 1974:

	1974	1975
Entrainment	0.52%	0.54%
Impingement	0.24%	0.43%
Total	0.76%	0.97%

For the multiplant case, entrainment was higher in 1975 but impingement was higher in 1974, so total impact was nearly the same in both years:

	1974	1975
Entrainment	0.76%	1.13%
Impingement	1.34%	0.71%
Total	2.10%	1.84%

This analysis shows that use of estuary water for once-through cooling, if continued at the levels that prevailed in 1974 and 1975, would result in a reduction of about 1% in the level of abundance of the striped bass population by Indian Point Unit 2 alone and a reduction of about 2% by Indian Point Unit 2, Bowline, and Roseton combined. The 1974 and 1975 plant operating conditions, then, caused only a small impact on the striped bass population. Although cooling-water flows were substantial, actual long-term use of estuarine water by these plants' cooling systems may differ from the 1974 and 1975 levels--and Indian Point Unit 3 will be operating. The equilibrium ~~rduction~~ reduction equation used here to estimate plant impact was not applied to conditions other than those that prevailed during years of actual measurement of abundance of young fish. Therefore, to extend impact estimation to the different plant operating conditions planned for the future on the Hudson River the method of Section 12, the real-time life-cycle model, must be used. In Section 12.3, the methods employed and the results presented here for 1974 and 1975 will be compared with those from the real-time life-cycle model, and the impacts predicted by both approaches will be characterized in terms of ecological consequences.

SECTION 12

IMPACT ON STRIPED BASS BASED ON REAL-TIME LIFE-CYCLE SIMULATION MODEL

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SECTION 12

IMPACT ON STRIPED BASS BASED ON REAL-TIME LIFE-CYCLE SIMULATION MODEL

12.1 INTRODUCTION

Life-cycle simulation models can play an important role in predicting the effects on the striped bass population of the operation of power plants along the Hudson. Unlike the equilibrium reduction equation method (Section 11) which has been applied only to the plant conditions which prevailed during the years that ichthyoplankton samples were collected, the simulation model has been used to predict impacts resulting from plant operational patterns that vary from year to year and from new plants that have not yet commenced operation but for which critical operational parameters are known. In the present study, multiplant impacts for 1974 and 1975 plant operating conditions and for projected operating conditions through the year 2015 are predicted.

Prior to the presentation of impact estimates, the calibration of the model with field data collected during 1974 and 1975 is demonstrated. This calibration procedure results in estimates of survival rates and durations for the early life stages of the striped bass consistent with the 1974 and 1975 field data (Section 12.2) After presentation of the predictions of multiplant impact in Section 12.3, impact estimates derived from the simulation model are compared with those calculated using the equilibrium reduction equation method presented in Section 11.

12.2 MODEL CALIBRATION PROCEDURE

An important step in both physical and mathematical modeling is to calibrate the model with field measurements of the variables being studied. This procedure helps to make the model simulation more realistic and aids in interpreting the field data. The calibration of the real-time model (section 2.2.5) using striped bass field data collected during 1974 and 1975 is examined here.

In calibrating any model, there are two important considerations. First, calibration is an interactive, or trial-and-error, process. The calibration procedure begins with a run of the model using estimates for critical input parameters derived from the best data available. If there are no field or experimental measurements for some parameters, values are assumed. The model is run with the first set of input parameters, and the output is compared with available field observations. The assumed input parameters are then adjusted to attempt to obtain closer agreement of the model results and the field data. This process is repeated until "acceptable" agreement is generated between the model output and field measurements. The second important consideration in the calibration process is the definition of "acceptable" agreement. In nearly all cases, perfect agreement between the model output and field observations is impossible. One consideration in deciding when the calibration is complete is the influence of the degree of calibration on the final model results. Based on sensitivity studies of the real-time model (LMS 1975f) and previous modeling studies (Lawler, 1972; Lawler, 1974), we agree with the position of the Nuclear Regulatory Commission in the Indian Point Unit 3 Final Environmental Statement, i.e., that models can provide meaningful predictions of power plant impact without perfect calibration to field data collected during any single year.

An important justification for this statement is the year-to-year variability of the data. However, the calibration procedure is still of interest because it aids in interpreting and understanding the field data, and assures that critical model parameters approximate true values closely enough to provide a realistic simulation of fish population performance.

Since the field data provide measured estimates of the variables being modeled, another factor that should be considered in defining the acceptable level of calibration is the statistical error associated with field measurements. In the present study, two standard errors on either side of the mean were used to define the statistical error in the field measurements. This resulted in a range of values approximating the 95% confidence interval about each data point. The goal of the present calibration procedure was to adjust the model input parameters until the model results fell within this approximate 95% confidence interval. Two types of input parameters--the survival rates and the life-stage durations of the young-of-the-year striped bass--were used to calibrate the model.

The field data used to calibrate the real-time model were derived from Texas Instruments 1974 and 1975 longitudinal river surveys. The model was first initialized using the egg data from each of these surveys. Temporal and spatial distributions of the egg spawn for input to the model were derived directly from the field data. To be consistent with the design of the sampling program, the spatial distributions were calculated on the basis of the 12 sampling regions selected by Texas Instruments. The number of eggs in each sampling region was then allocated to the 29 segments in the model proportionately according to the segment lengths. Based on the temporal and spatial distribution of the eggs and an estimate of the total egg production, the model generated the temporal and spatial distributions and the abundance of the succeeding life stages. To provide consistency with the sampling design and permit direct comparison with standing crop estimates derived by Texas Instruments, the number of organisms in the 29 segments of the model were combined to give standing crops in the 12 sampling regions.

When a model is being calibrated with a specific set of field data, system conditions during data collection must be simulated in the model. Thus, the calibration procedure was performed with actual plant operating conditions during 1974 and 1975 simulated in the model and with compensation operative (Section 10.7). Other parameters in effect during calibration runs appear in Figure 12.2-1 with references to the sources for the data in parentheses after each item.

Results from the calibration procedure are presented in Table 12.2-1. It must be recognized that the stage durations and the survival rates shown are values that bring the model output within or close to the 95% confidence interval around the field data. In most cases, slightly different values would satisfy the same criteria.

The stage durations determined from the calibration procedure for 1974 and 1975 data were identical. In most cases, these stage durations were within the range of values for those parameters presented in Sections 7.3, 7.4, 7.5, and 7.6. Although the duration determined for the yolk-sac stage was greater than the upper limit of the 4- to 6-day range specified in Section 7.4, the total duration for both yolk-sac and post yolk-sac stages (32 days) fell within the 24- to 36-day range for the total duration of these life stages presented in Section 7.

Survival rates resulting from the calibration procedure can be compared with the estimates presented in Section 7.7. Since the mortality rates presented in Section 7.7 are not separated by individual life stage, the most meaningful comparison between the results presented in Tables 7.7-2 and 12.2-1 can be developed from a computation of mortality over the entire first year of life. The total annual mortality for 1975 computed from the model calibration results (Table 12.2-1) is 0.999980. The comparable figure computed from Table 7.7-2 is 0.999965. Considering the approximations and assumptions required in developing each of these estimates of mortality, the two results agree well.

Survival rates for the egg stage were adjusted in the calibration procedure to produce standing crops of yolk-sac larvae consistent with

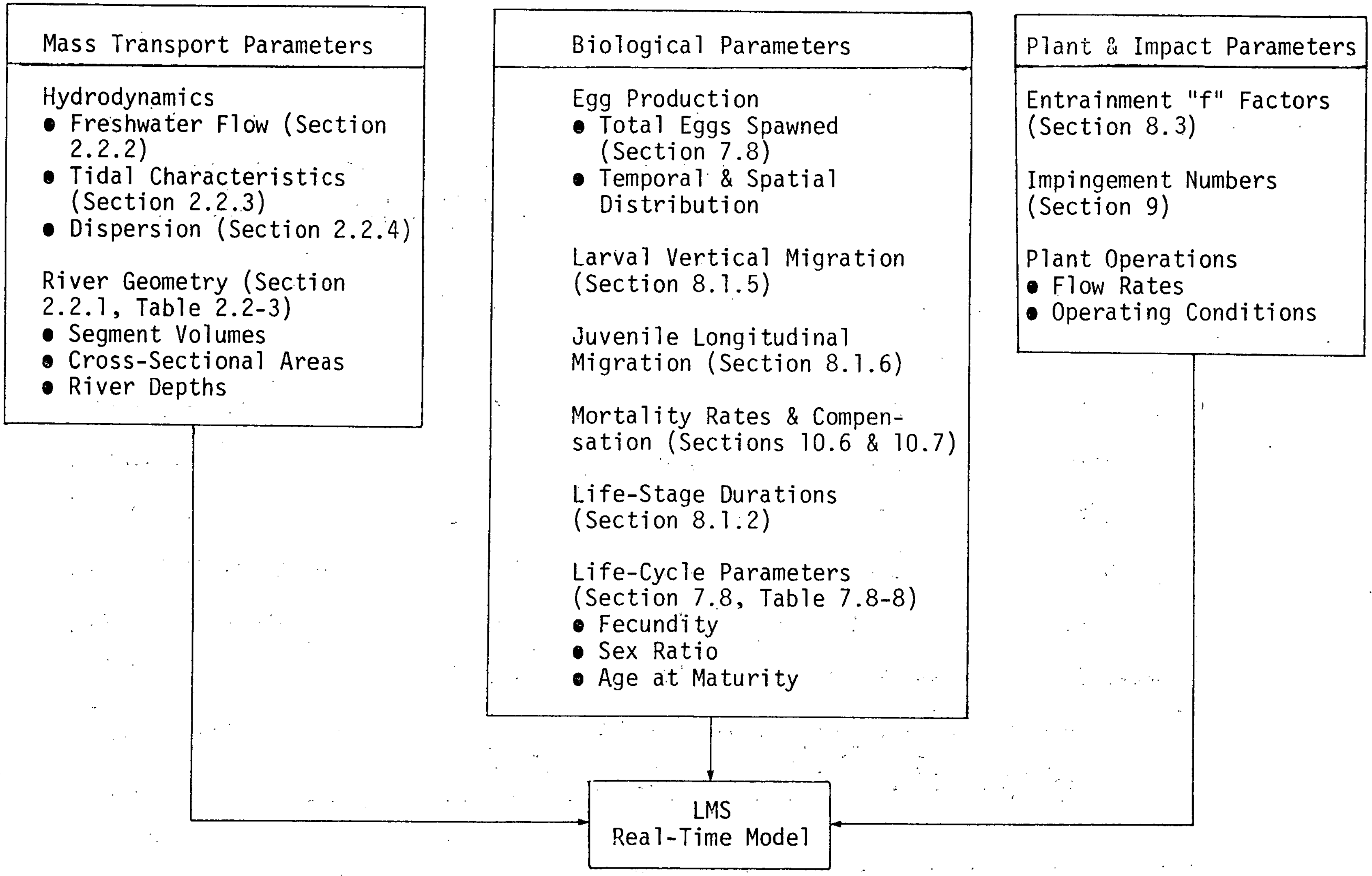

Figure 12.2-1 Hudson River Striped Bass Real-Time Model Data Requirements

Table 12.2-1 Stage-Length Durations and Percent Survival for Striped Bass Life Stages

Life Stages	1974 DATA BASE Stage length Durations	1974 DATA BASE Survival (%)*	1975 DATA BASE Stage length Durations	1975 DATA BASE Survival (%)*
Eggs	Variable**	0.6***	Variable**	2.0***
Yolk-sac larvae	12.0	37.0	12.0	31.0
Post yolk-sac larvae	20.0	72.0	20.0	87.0
Juvenile I	30.0	5.0	30.0	5.0
Juvenile II	145.0	53.0	145.0	51.0
Juvenile III	156.0	16.0	156.0	16.0

*Survival after mortality due to natural causes and plant effects.

**The hatching period for eggs varied as follows:
3.0 days, April 28 to May 15
2.0 days, May 16 to May 30
1.5 days, May 31 to end of spawning period.

***Includes egg retention, lack of fertilization, sampling efficiency, and natural mortality.

the field data. For both the 1974 and 1975 calibration runs, 88 billion eggs, were input, which was consistent with estimates of spawning strength presented in Section 7.8. The survival rates presented here for the egg stage were meant to include all effects such as egg retention, lack of fertilization, and natural mortality, which affect the number of yolk-sac larvae resulting from the total eggs produced. Application of the egg-stage survival rate from 1974 resulted in a total standing crop of eggs closely agreeing with estimates from 1974 field data (Figure 12.2-2). However, the survival rate from the 1975 calibration runs produced a total standing crop of eggs about five times greater than that calculated from field data, suggesting that field sampling in 1975 produced an underestimate of the standing crop of eggs (Section 7.8).

Figures 12.2-3 and 12.2-4 compare field measurements and model predictions of the temporal distributions of yolk-sac larvae during 1974 and 1975. These graphs demonstrate that, with the survival rates and life-stage durations given in Table 12.2-1, model results fell within or very close to the 95% confidence interval about the field data. Figures 12.2-5 and 12.2-6 show similar results for the post yolk-sac stage.

Figures 12.2-7 and 12.2-8 show temporal distributions derived from the field data and model results for the striped bass juvenile I stage during 1974 and 1975. On or about July 1 of both years, model predictions of juvenile I standing crops were at least one order of magnitude greater than the standing-crop estimates derived from the field data. As discussed in Sections 7.5, 8.2.6, and 8.3.1, there is substantial evidence that early juveniles move to shallow areas along the shoreline during this period. The mobility of these relatively small (15-16 mm) organisms could cause considerable undersampling of this life stage for the following reasons:

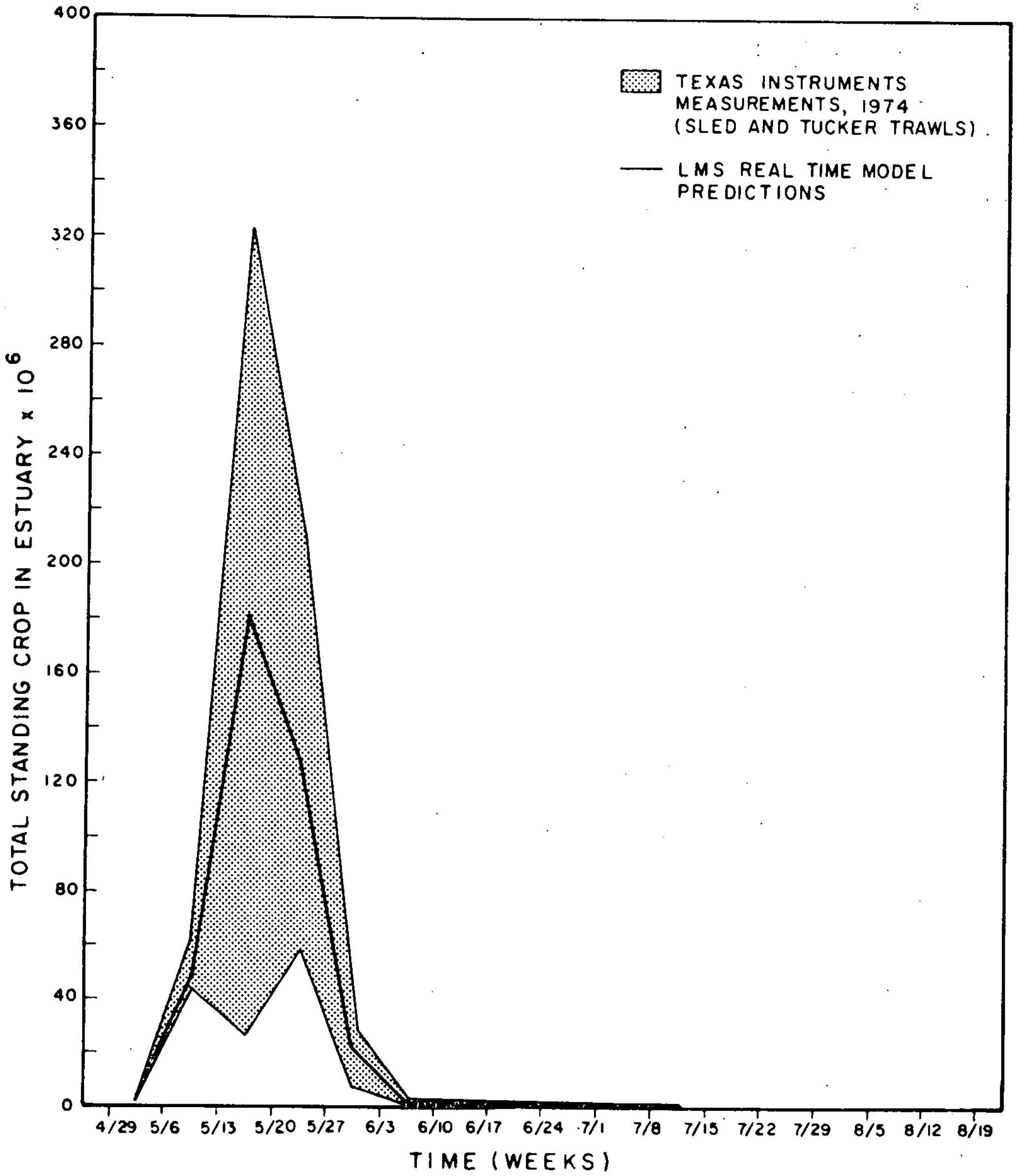

Figure 12.2-2 Comparison of Real-Time Model Predictions with Estimates Based on Field Measurements of Striped Bass Eggs in 1974

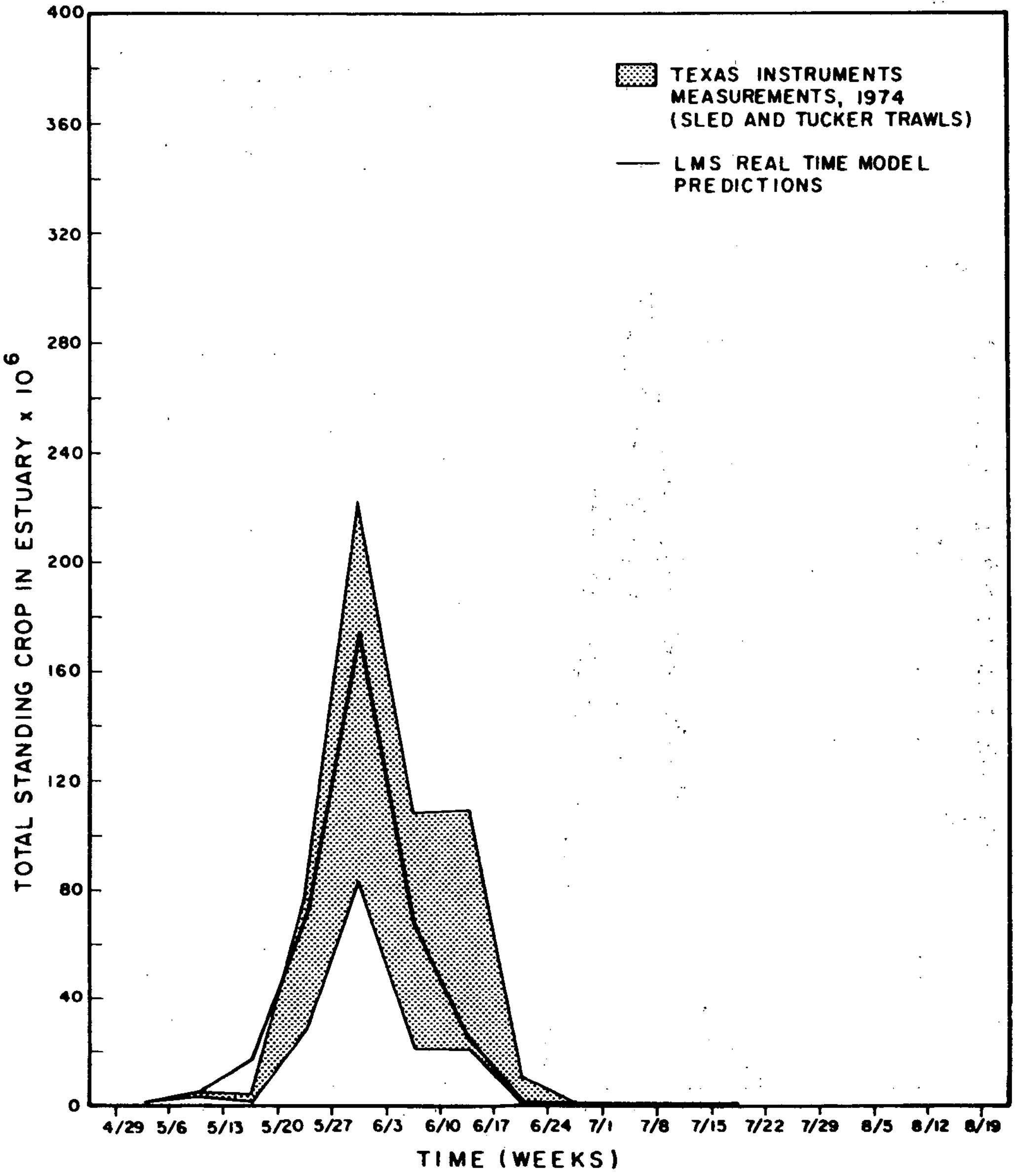

Figure 12.2-3 Comparison of Real-Time Model Predictions with Estimates Based on Field Measurements of Striped Bass Yolk-Sac Larvae in 1974

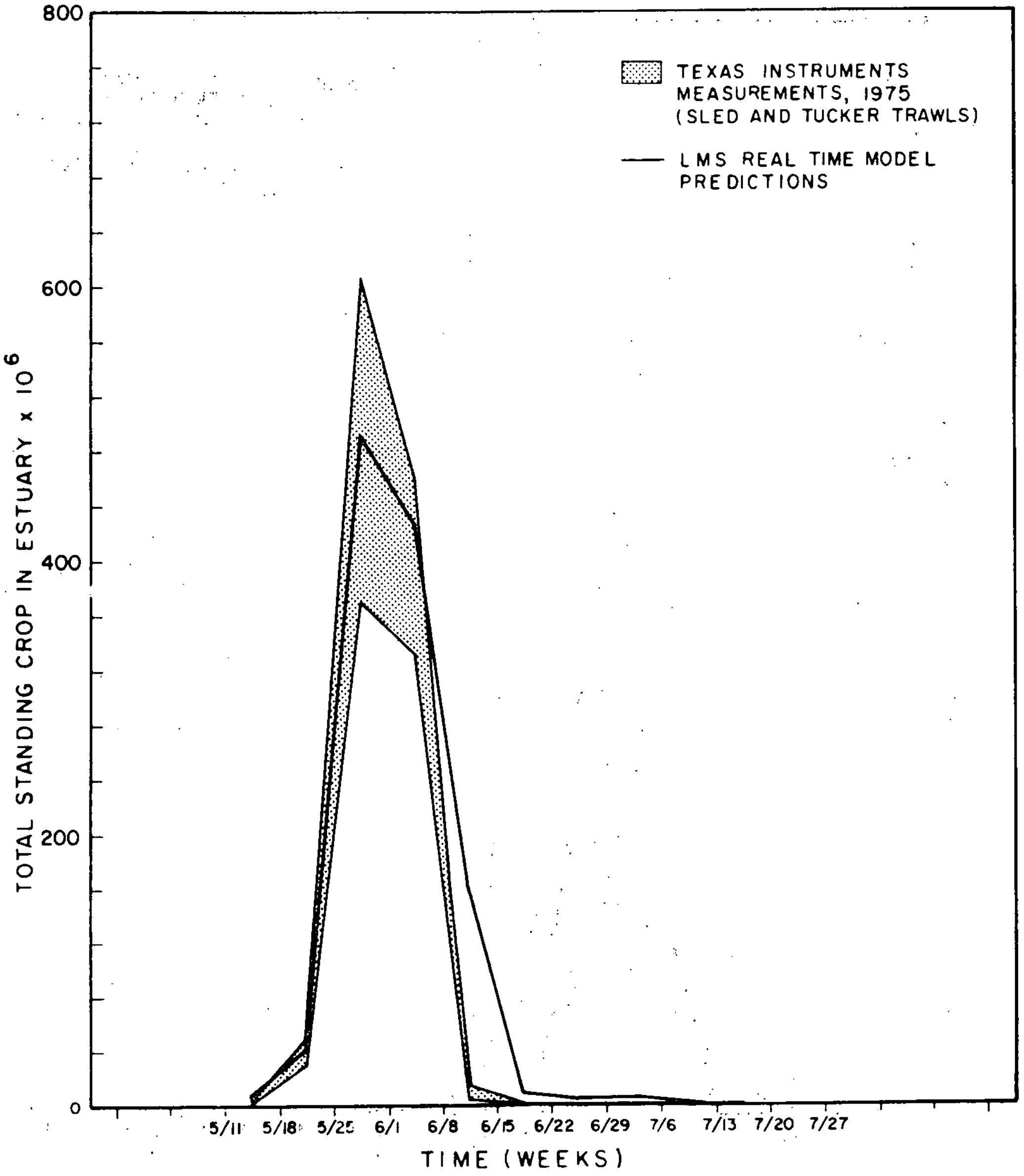

Figure 12.2-4 Comparison of Real-Time Model Predictions with Estimates Based on Field Measurements of Striped Bass Yok-Sac Larvae in 1975

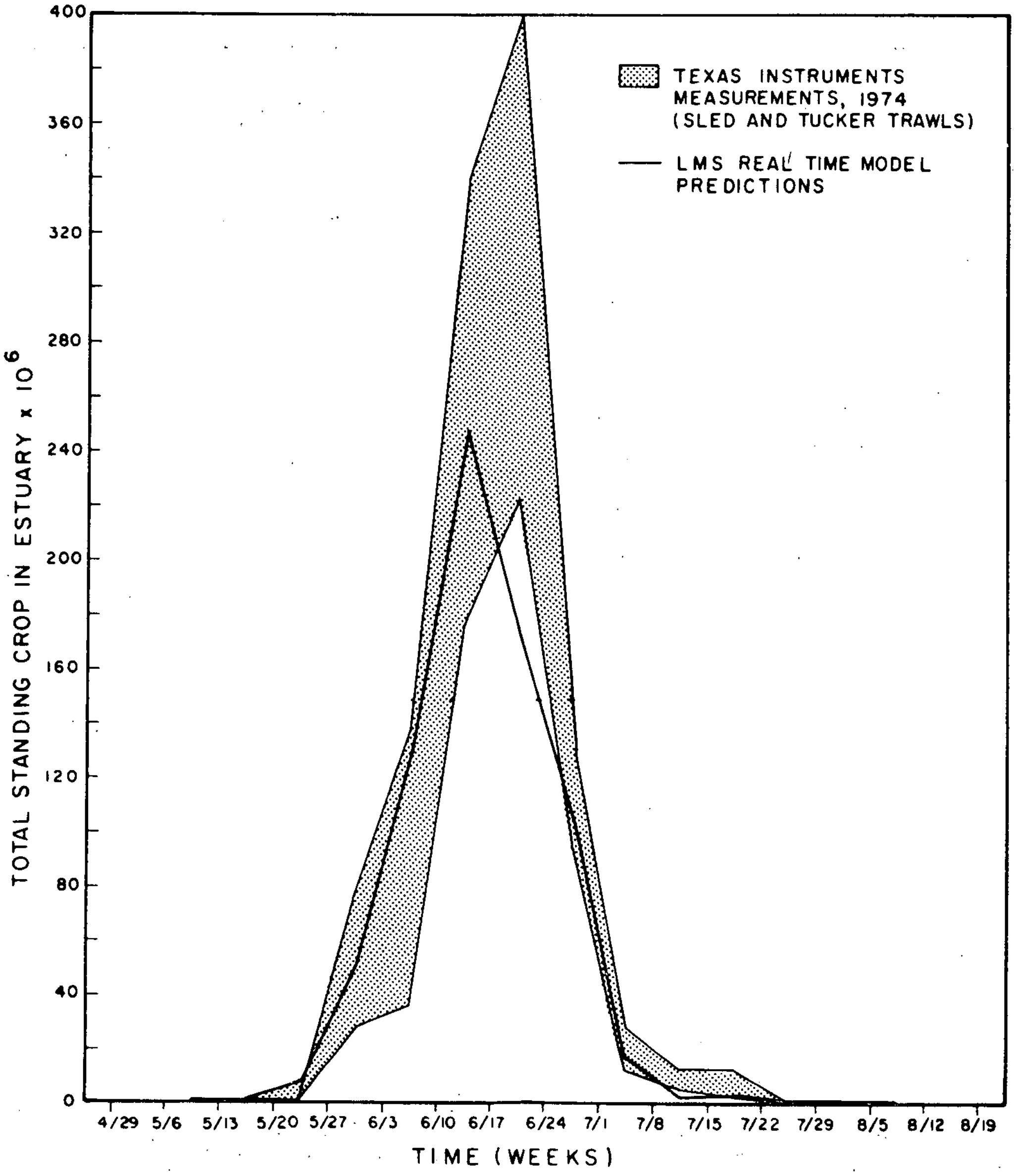

Figure 12.2-5 Comparison of Real-Time Model Predictions with Estimates Based on Field Measurements of Striped Bass Post Yolk-Sac Larvae in 1974

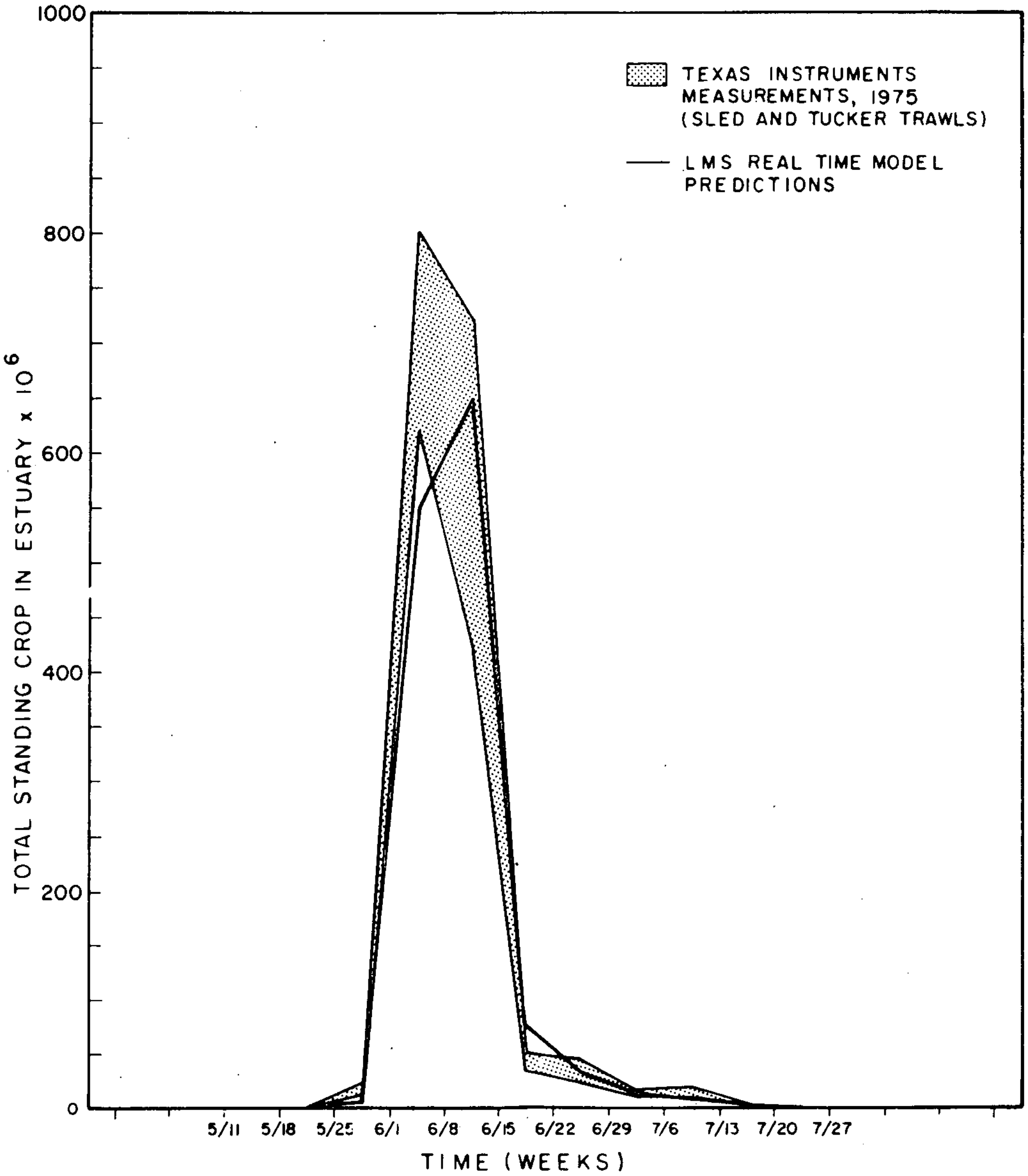

Figure 12.2-6 Comparison of Real-Time Model Predictions with Estimates Based on Field Measurements of Striped Bass Post Yolk-Sac Larvae in 1975

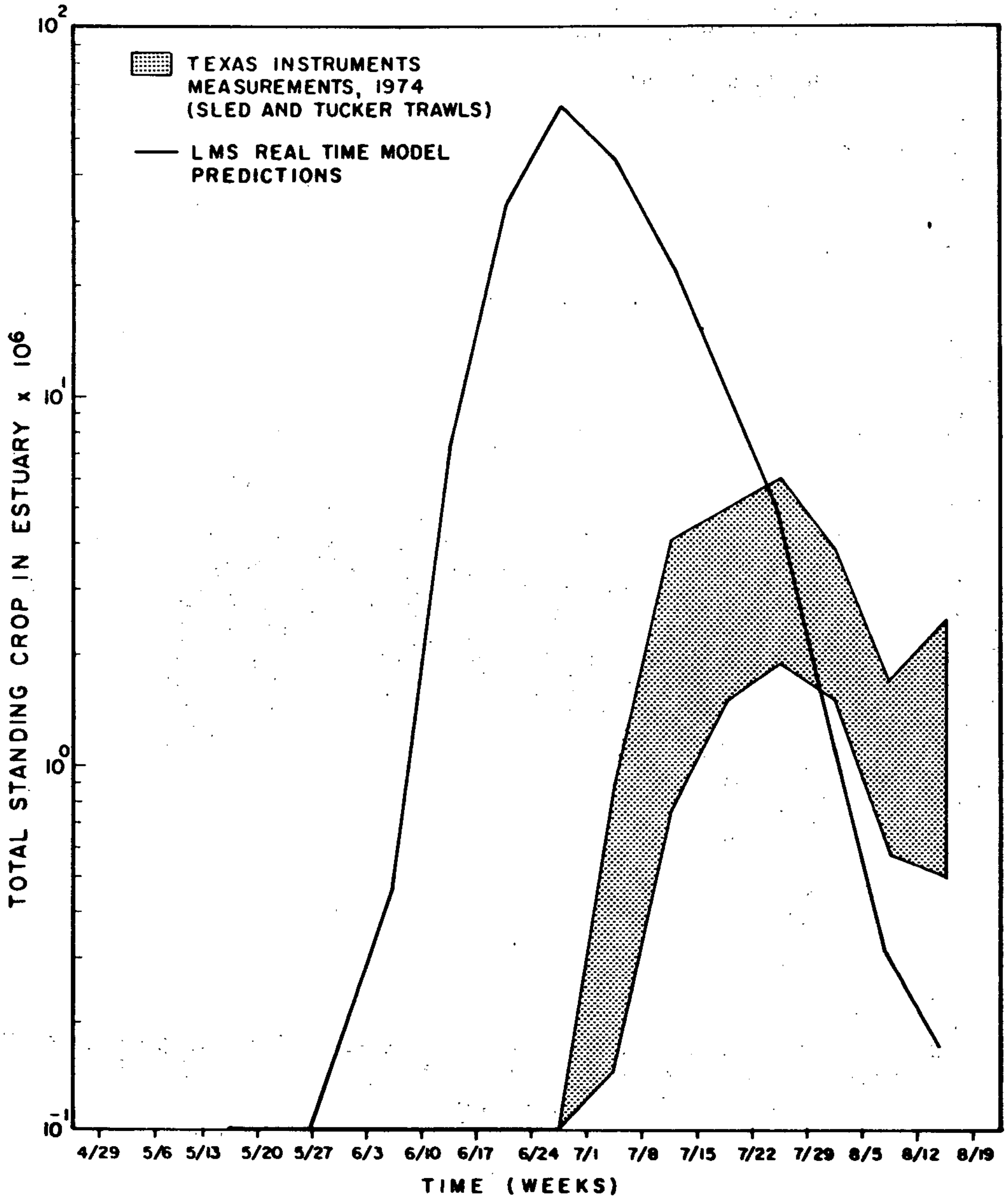

Figure 12.2-7 Comparison of Real-Time Model Predictions with Estimates Based on Field Measurements of Juvenile I Striped Bass in 1974

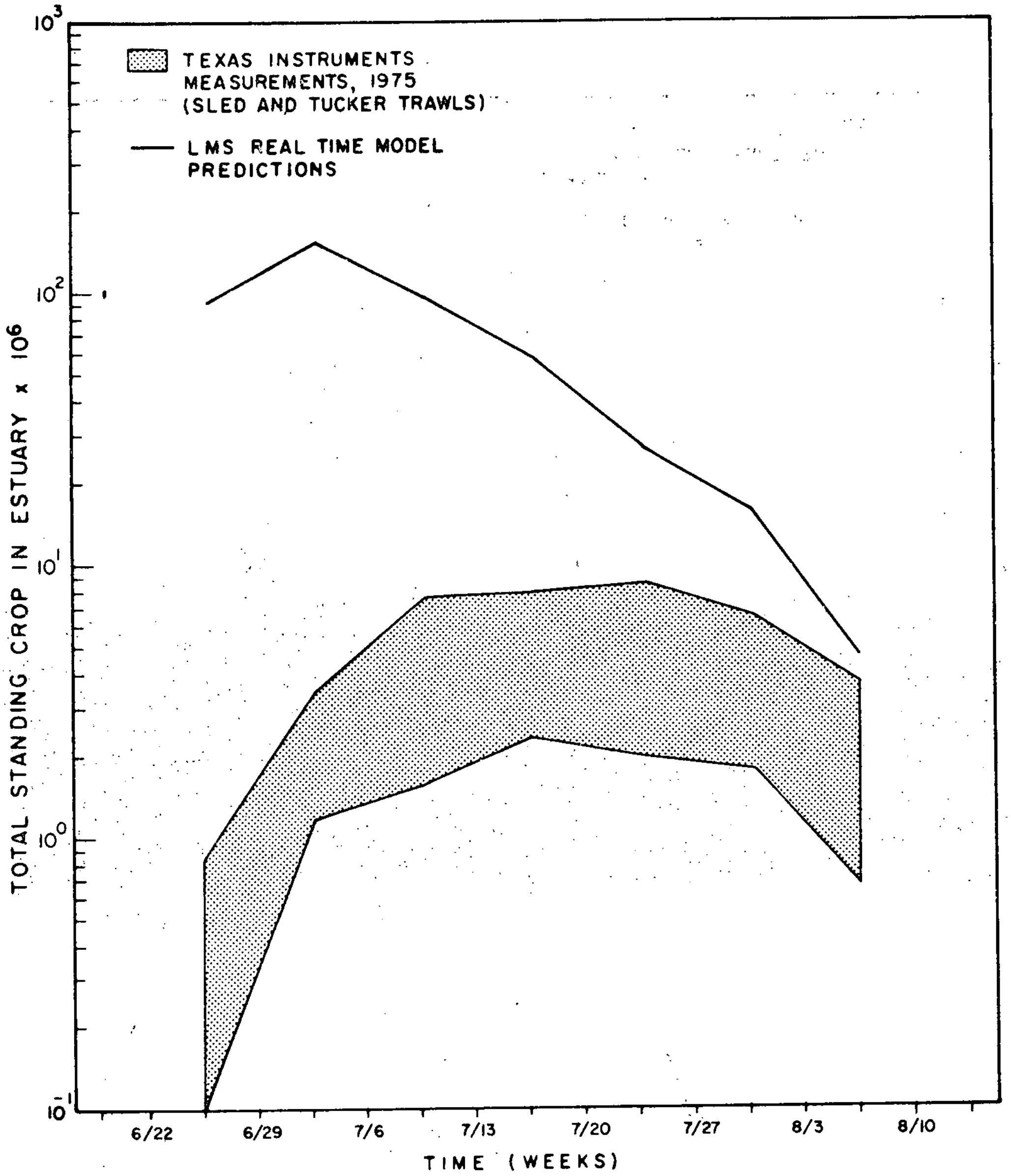

Figure 12.2-8 Comparison of Real-Time Model Predictions with Estimates Based on Field Measurements of Juvenile I Striped Bass in 1975

- Early juveniles may be concentrated in shoal areas where rocks, debris, and heavy vegetation make sampling difficult.

- The organisms may have sufficient swimming ability to avoid ichthyoplankton sampling gear and may be too small to permit efficient sampling with seines.

Comparisons of the field and model estimates of the total standing crop for the juvenile I and II stages combined (Figs. 12.2-9 and 12.2-10) offer further evidence of the possible undersampling of early juveniles. During July and August, model results were considerably higher than the estimates of standing crop derived from the field data; however, during September when mark/recapture data were available to refine the standing crop estimate, model results agreed well with field data. During October, the fall juveniles began their seaward migration out of the sampling region, which probably accounted for the precipitous decline in standing crop during early October, suggesting that the model results probably provided a more accurate estimate of total standing crop during those months.

The comparisons of field and model results that have just been presented demonstrate the calibration of the model in the temporal dimension. Figures 12.2-11 through 12.2-14 illustrate the calibration of the model in the spatial dimension. These graphs demonstrate that the real-time model provides a realistic simulation of the effects of the hydrodynamic transport in the Hudson on the spatial distribution of the yolk-sac and post yolk-sac larvae. Figures 12.2-15 through 12.2-18 show the 1974 and 1975 temporal distribution of abundance of yolk-sac and post yolk-sac larvae in the segment from RM 39 to RM 46 (km 62 to km 75), the Indian Point region. Again, correspondence between the model predictions and the field sample values is good.

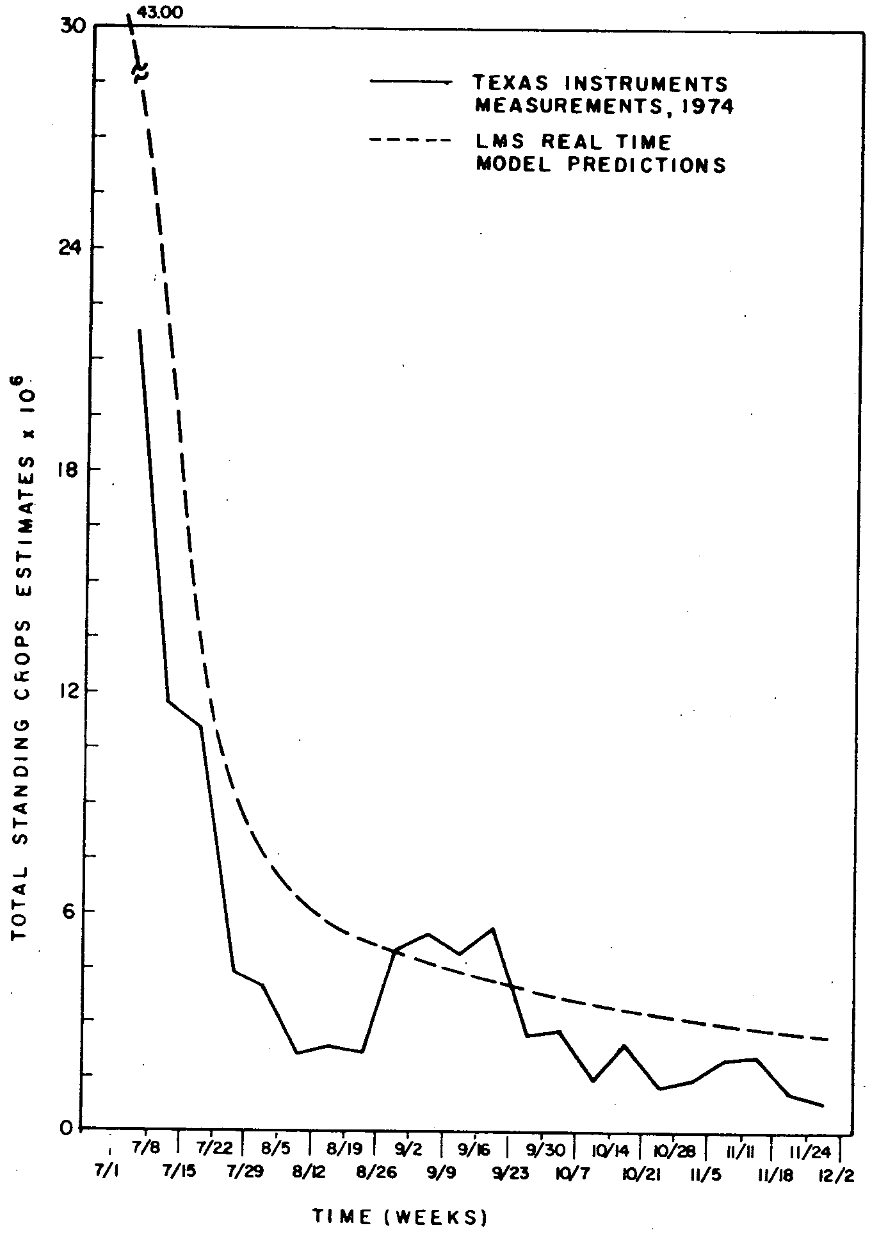

Figure 12.2-9 Comparison of Real-Time Model Predictions with Estimates Based on Field Measurements of Total Number of Striped Bass Juveniles in 1974

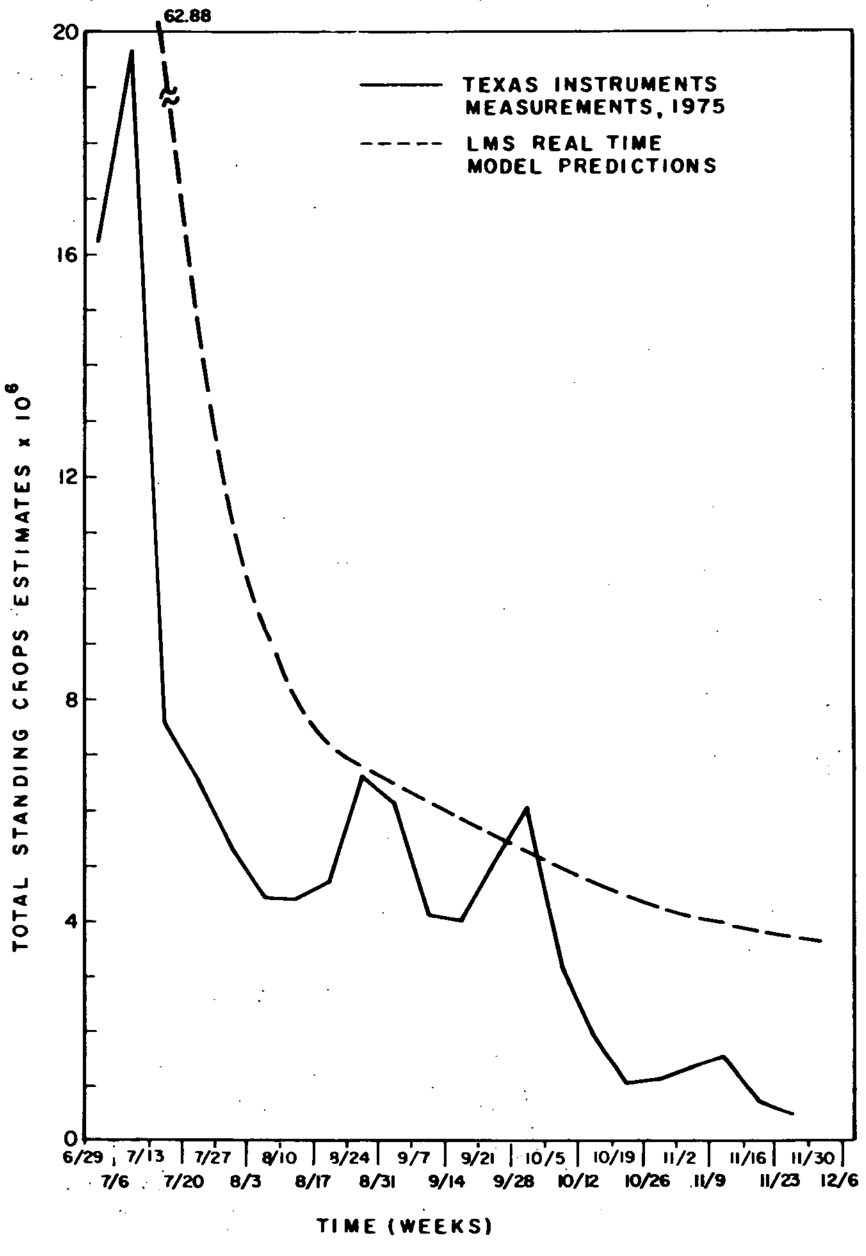

Figure 12.2-10 Comparison of Real-Time Model Predictions with Estimates Based on Field Measurements of Total Number of Striped Bass Juveniles in 1975

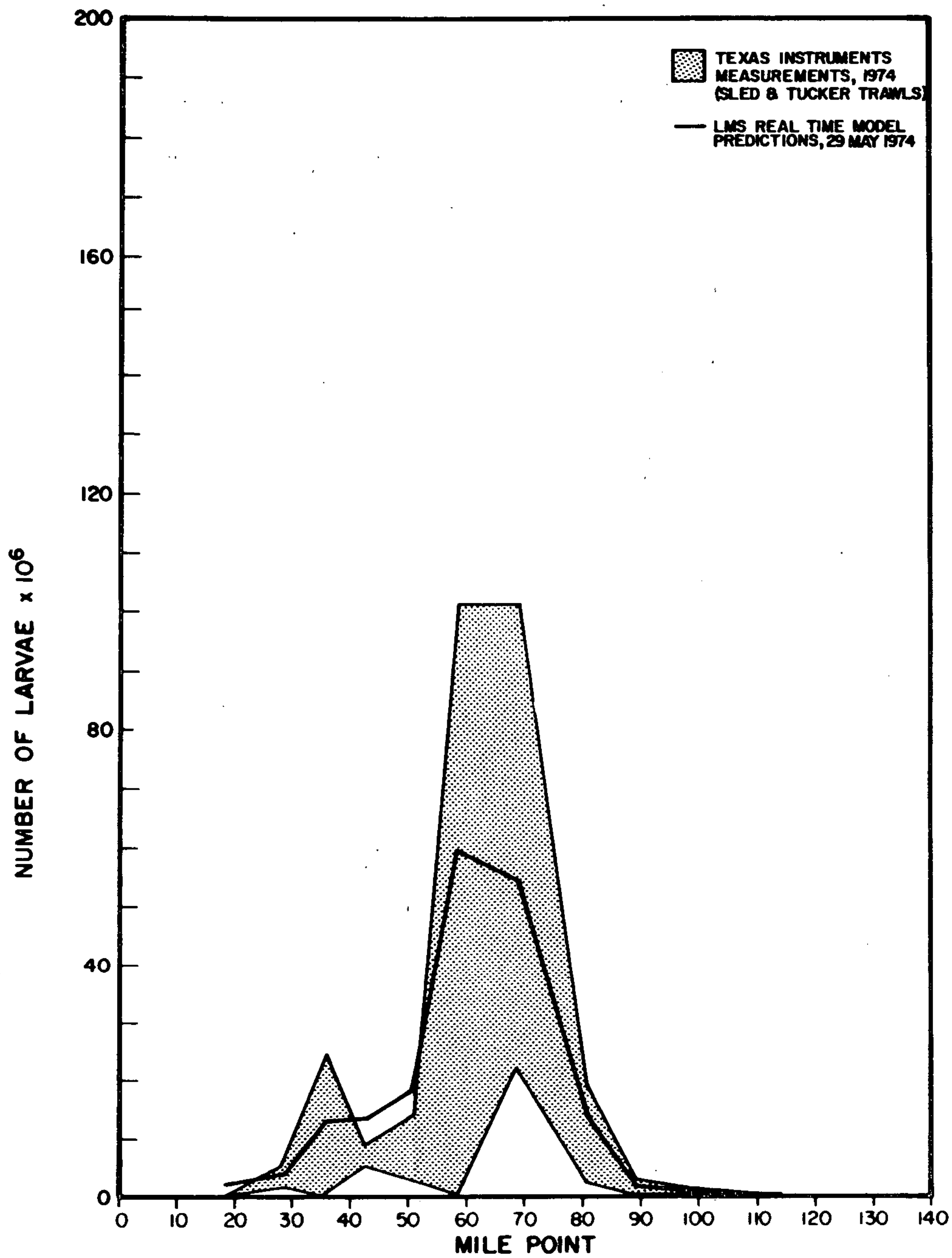

Figure 12.2-11 Comparison of Real-Time Model Predictions with Field Measurements of Spatial Distribution of Striped Bass Yolk-Sac Larvae, May 27-June 2, 1974

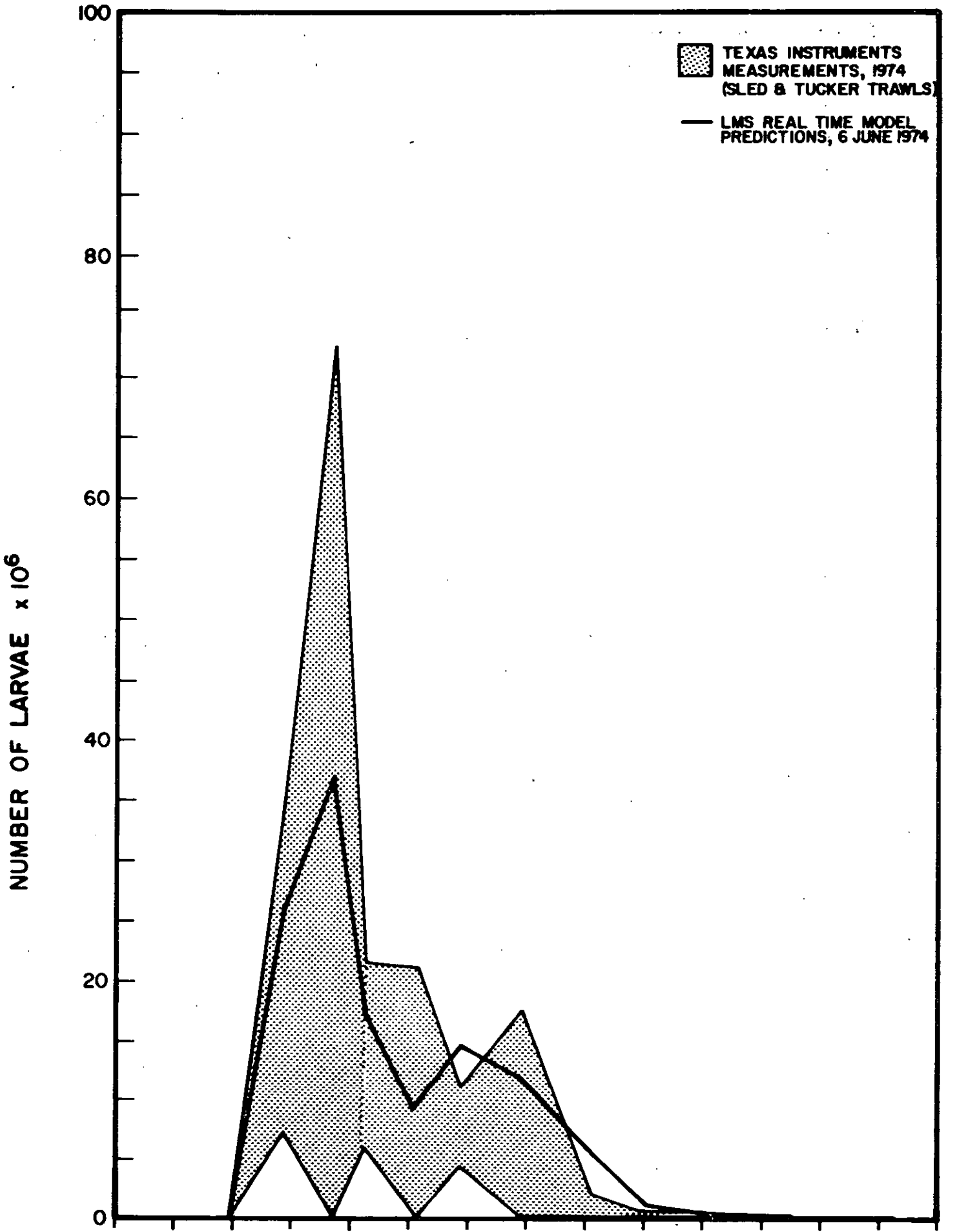

Figure 12.2-12 Comparison of Real-Time Model Predictions with Field Measurements of Spatial Distribution of Striped Bass Post Yolk-Sac Larvae, June 3-9, 1974

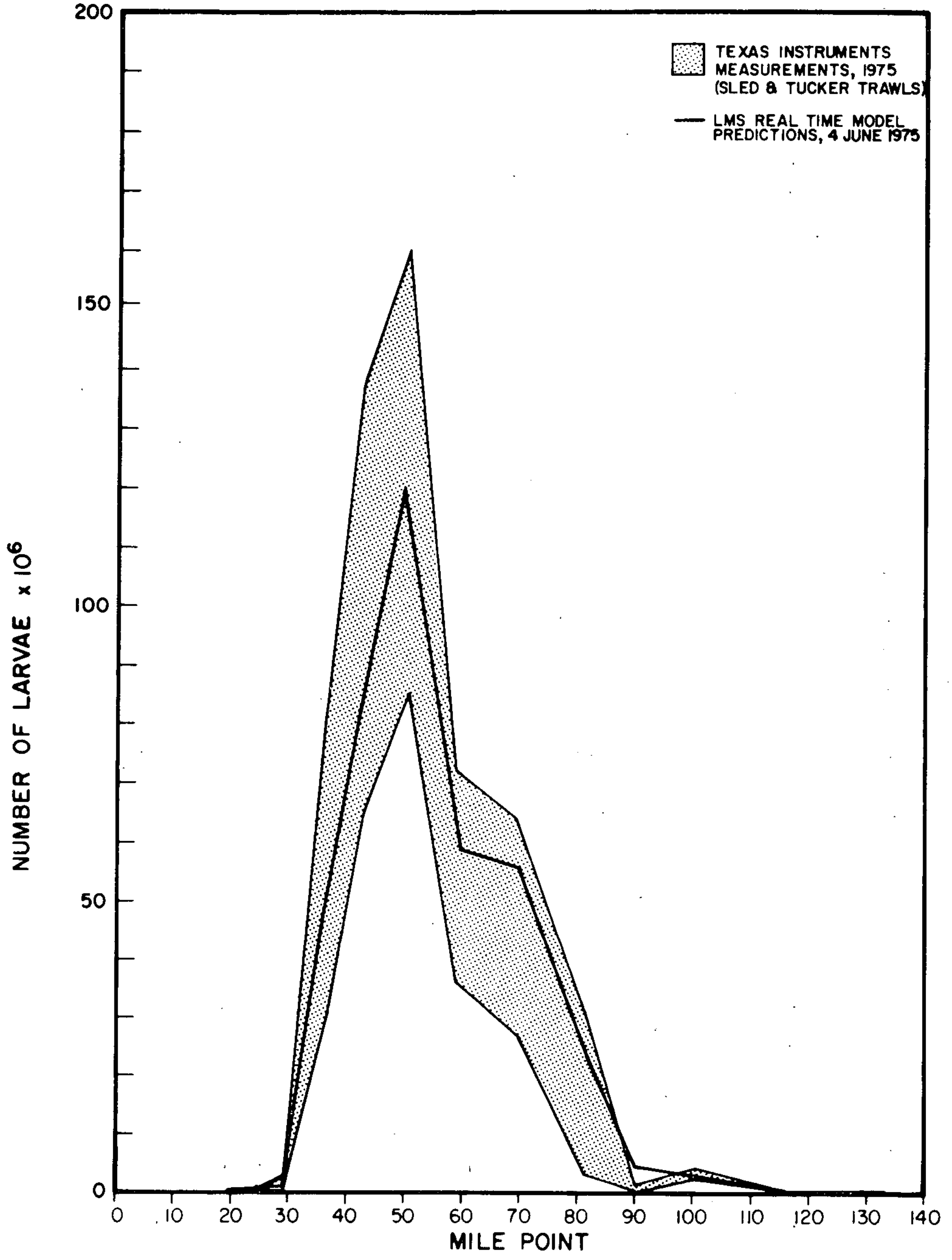

Figure 12.2-13 Comparison of Real-Time Model Predictions with Field Measurements of Spatial Distribution of Striped Bass Yolk-Sac Larvae, June 2-6, 1975

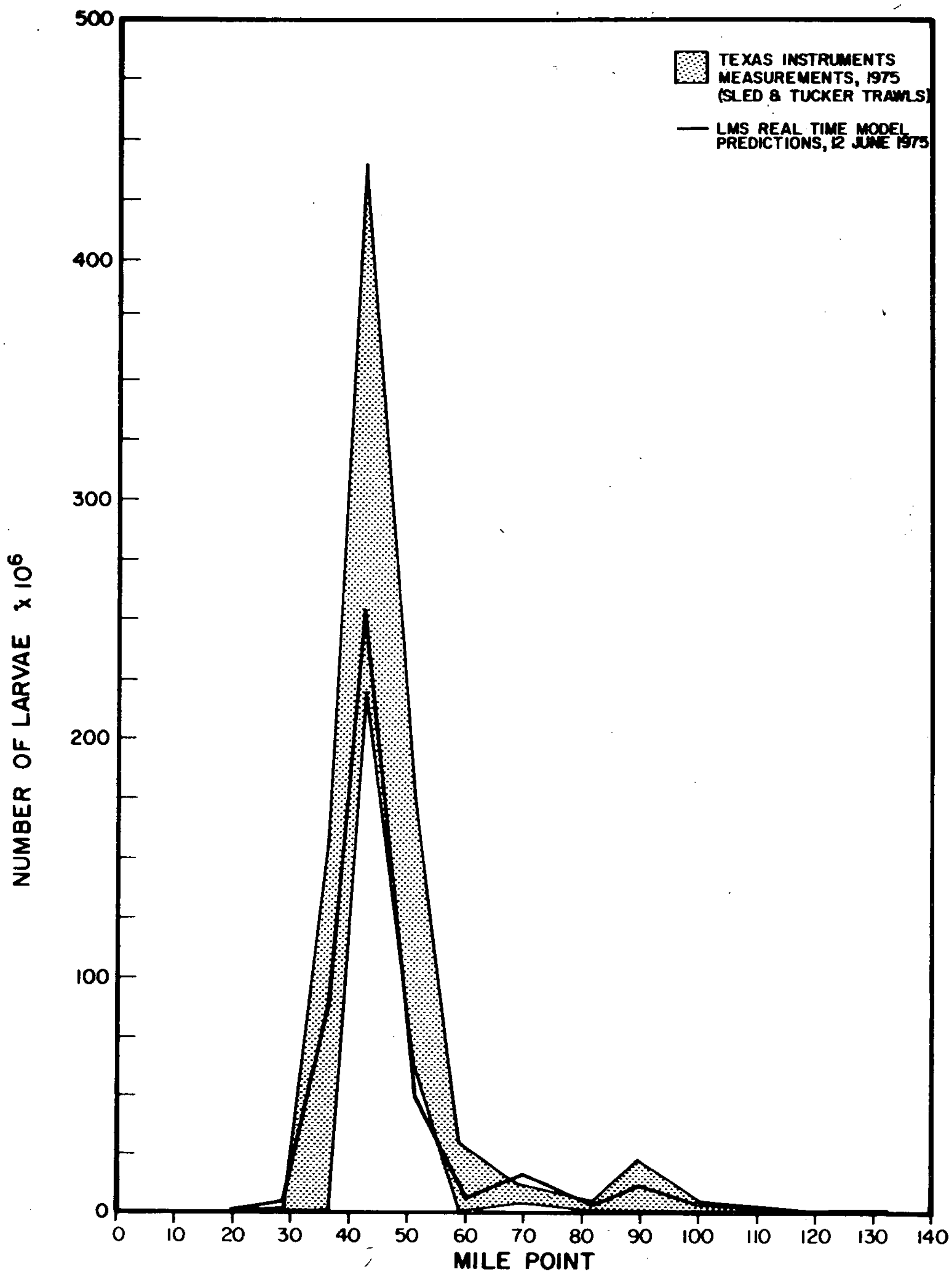

Figure 12.2-14 Comparison of Real-Time Model Predictions with Field Measurements of Spatial Distribution of Striped Bass Post Yolk-Sac Larvae, June 9-14, 1975

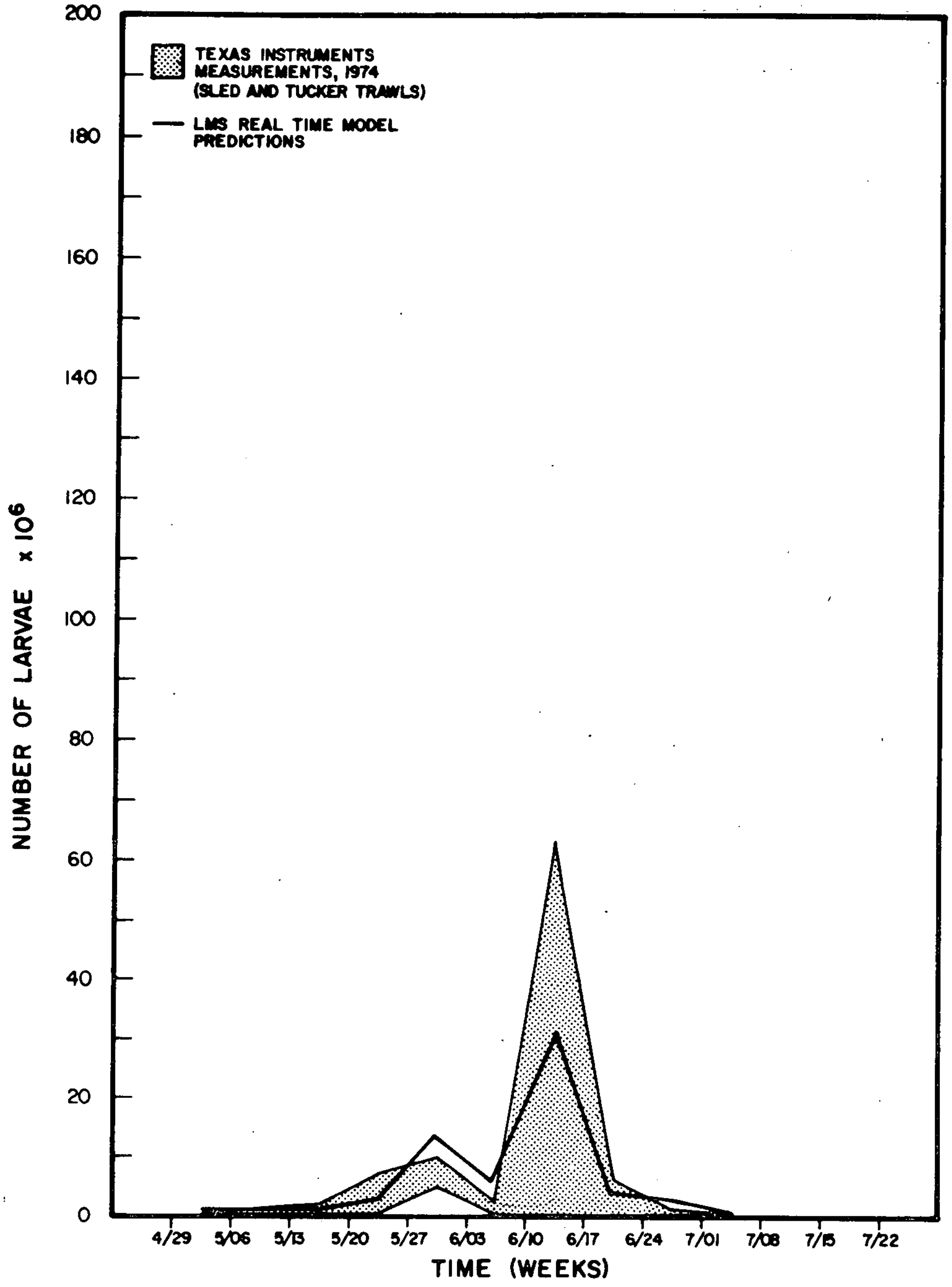

Figure 12.2-15 Comparison of Real-Time Model Predictions with Field Measurements of Temporal Distribution of Striped Bass Yolk-Sac Larvae, RM 39-46 (km 62-75), 1974 Data

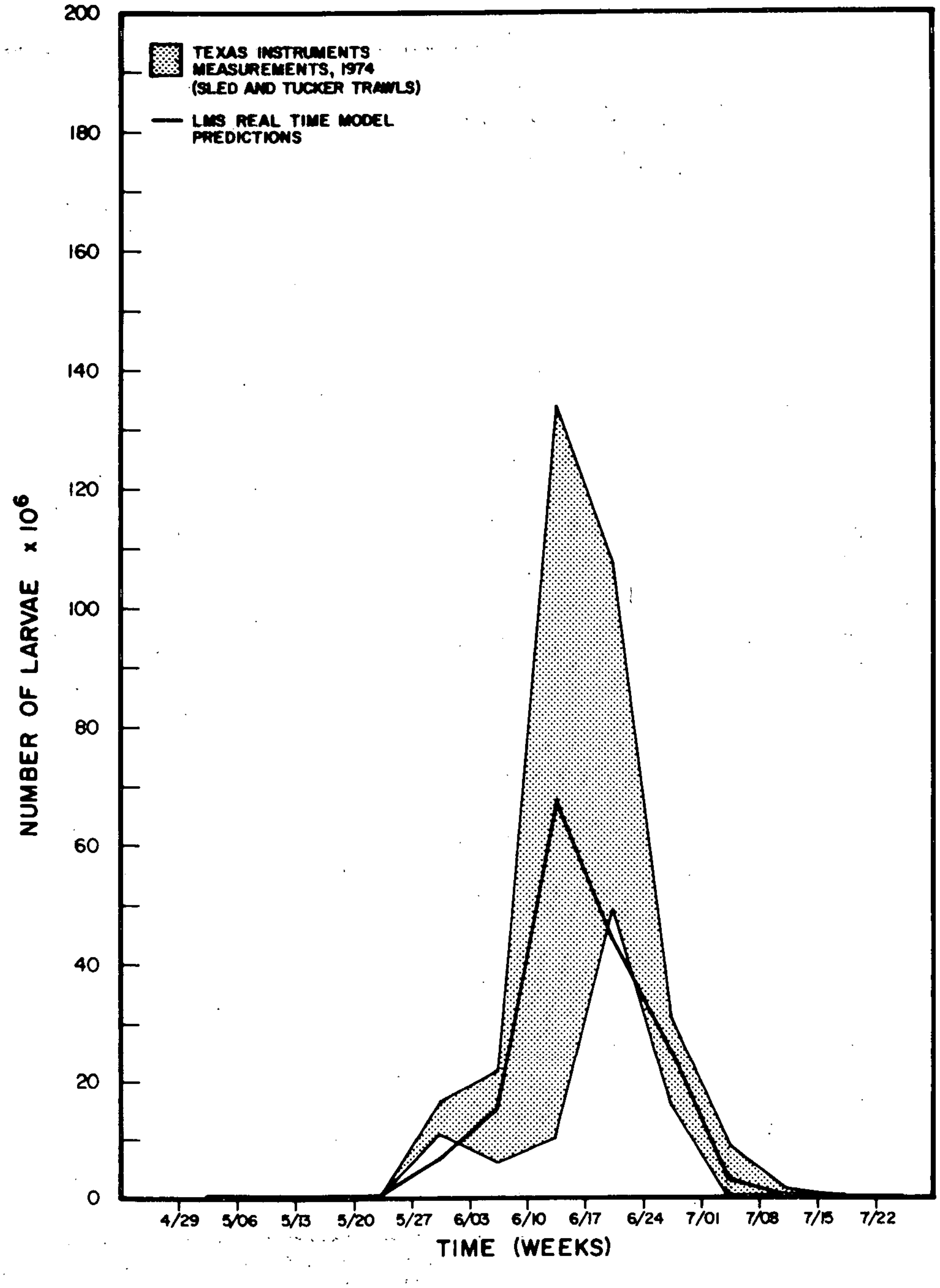

Figure 12.2-16 Comparison of Real-Time Model Predictions with Field Measurements of Temporal Distribution of Striped Bass Post Yolk-Sac Larvae, RM 39-46 (km 62-75), 1974 Data

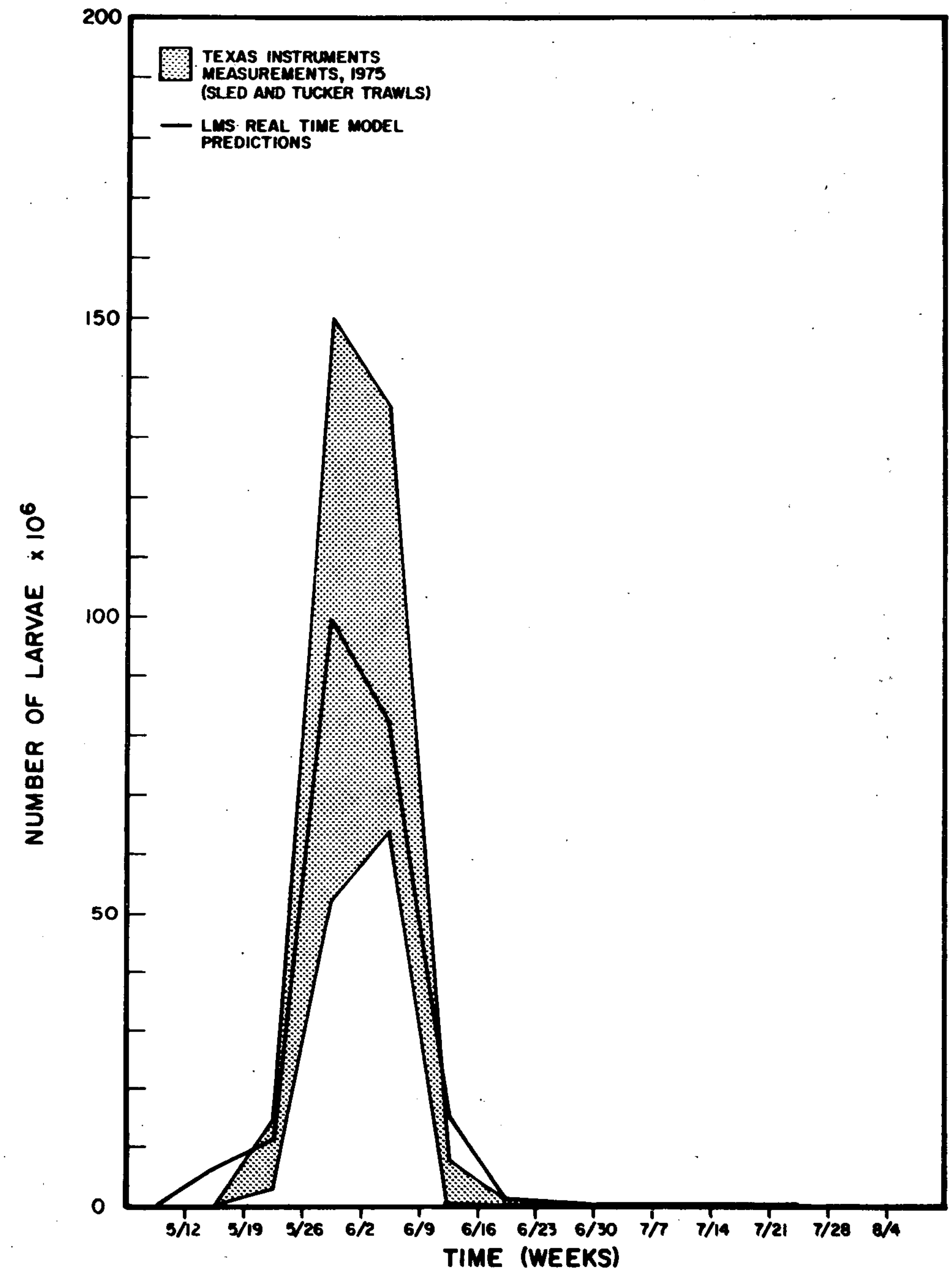

Figure 12.2-17 Comparison of Real-Time Model Predictions with Field Measurements of Temporal Distribution of Striped Bass Yolk-Sac Larvae, RM 39-46 (km 62-75), 1975 Data

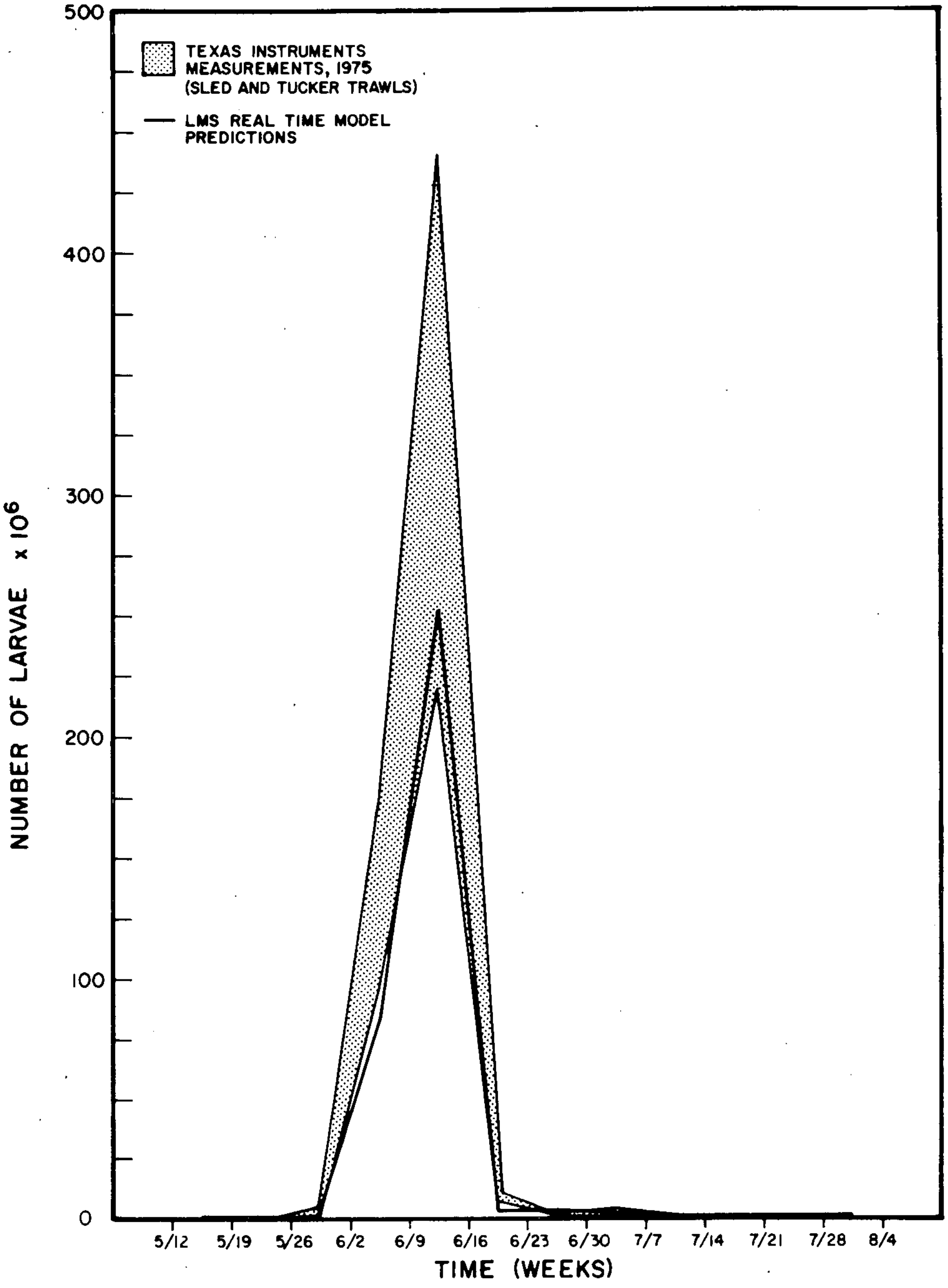

Figure 12.2-18 Comparison of Real-Time Model Predictions with Field Measurements of Temporal Distribution of Striped Bass Post Yolk-Sac Larvae, RM 39-46 (km 62-75), 1975 Data

12.3 PREDICTIONS OF IMPACT ON THE STRIPED BASS POPULATION

Upon completion of the calibration procedure described in the preceding section, the real-time model can be used to obtain estimates of reductions in the striped bass population due to power plant operation.

During the calibration procedure, the actual 1974 and 1975 plant operating conditions at Indian Point, Bowline, Lovett, Roseton, and Danskammer were in effect in the model. However, as explained in Section 10.6.2, Indian Point Unit 1, and all units at the Lovett and Danskammer plants have been operating for a sufficient amount of time so that their impact is reflected in the stock recruitment curve used to estimate the remaining compensatory reserve in the striped bass population. Consequently, these plants are not included in runs used to develop estimates of possible future reductions in the equilibrium spawning stock due to power plant operations.

This section describes how the 1974 and 1975 data bases were used in the real-time model to develop estimates of the impact on the striped bass population due to operation of Indian Point Units 2 and 3, Roseton Units 1 and 2, and Bowline Units 1 and 2, i.e. the post-1972 plants. In each case, the model run began with a prediction of impact during the year in which the data were collected and then continued through 39 yr of additional plant operation. For the predictions of impact during 1974 and 1975, actual operating conditions prevailing at the post-1972 plants were in effect in the model. For all years from 1976 on, plant flow conditions were taken directly from projections of plant operating conditions supplied by Consolidated Edison (Con Edison, 1976). Thus, plant flows were varied from year-to-year to reflect projected changes in the flow requirements at each plant. All other model input parameters were held constant at either the 1974 or 1975 values in the long-range projections of impact. The sources of the parameter values used in the model runs are indicated in Figure 12.2-1. In contrast with previous studies, the estimates of the number of striped bass impinged at each plant (Section 9) were input directly to the model without any correction for gear efficiency. Since the model has been calibrated to give standing crop estimates in close agreement with the field measurements, this approach is tantamount to assuming that the estimates of standing crop derived from the field data are unbiased.

The cropping percentages shown in Table 12.3-1 and 12.3-2 were calculated relative to the 1974 and 1975 baseline populations respectively. For reasons discussed in subsection 10.7 and later in this subsection results were based on a compensation level of 0.40 for the entrainment period and values of 0.86 and 0.80 for the 1974 and 1975 impingement periods respectively. The baseline populations were determined by running the model with the 1974 and 1975 parameter values with no power plants operating; hence, the percent cropping values in Table 12.3-1 represent predicted reductions in the adult striped bass population with respect to an adult population derived from the 1974 data and those in Table 12.3-2 are analogous with the 1975 data as the baseline. The temporal pattern of the percent cropping estimates indicates that the population approaches a new equilibrium value shortly after 20 yr. Consequently, percent cropping after 40 yr of operation is equivalent to the ultimate percent reductions in the size of the equilibrium spawning stock.

Predictions of multiplant impact on the Hudson striped bass population after 40 yr of operation with all plants on once-through cooling are 5.16% (Case 1, Table 12.3-1) and 3.97% (Case 1, Table 12.3-2) as derived from the 1974 and 1975 data respectively. Comparison of these results and all others shown indicates that the impacts derived from 1974 are consistently higher.

Table 12.3-1 Effect of Indian Point Units 2 and 3, Bowline Units 1 and 2, and Roseton Units 1 and 2 on Striped Bass Populations in the Hudson River, 1974 Data Base. Compensation Levels (KO/KE) of 0.40 for the Entrainment Period and 0.86 for the Impingement Period Were Used.

Case 1: WITH ALL THERMAL PLANTS ON ONCE-THROUGH COOLING (FILE M74a).

YEAR CLASS	PERCENT CROPPING AFTER 1 YEAR	AFTER 5 YEARS	AFTER 10 YEARS	AFTER 20 YEARS	AFTER 40 YEARS
ADULT I	3.62	4.63	4.92	5.13	5.16
TOTAL ADULTS	1.76	4.09	4.77	5.12	5.16

Case 2: WITH ALTERNATIVE COOLING AT INDIAN POINT UNIT 2 (1 MAY 1981). INDIAN POINT UNIT 3, BOWLINE UNITS 1 AND 2, AND ROSETON UNITS 1 AND 2 ON ONCE-THROUGH COOLING (FILE M74b).

YEAR CLASS	PERCENT CROPPING AFTER 1 YEAR	AFTER 5 YEARS	AFTER 10 YEARS	AFTER 20 YEARS	AFTER 40 YEARS
ADULT I	3.62	4.63	3.89	4.00	4.01
TOTAL ADULTS	1.76	4.09	3.78	4.00	4.01

Case 3: WITH ALTERNATIVE COOLING AT INDIAN POINT UNIT 2 (15 SEPTEMBER 1981). INDIAN POINT UNIT 3, BOWLINE UNITS 1 AND 2, AND ROSETON UNITS 1 AND 2 ON ONCE-THROUGH COOLING (FILE M74c).

YEAR CLASS	PERCENT CROPPING AFTER 1 YEAR	AFTER 5 YEARS	AFTER 10 YEARS	AFTER 20 YEARS	AFTER 40 YEARS
ADULT I	3.62	4.63	3.89	4.00	4.01
TOTAL ADULTS	1.76	4.09	3.92	4.00	4.01

Case 4: WITH ALL THERMAL PLANTS ON ONCE-THROUGH COOLING WITHOUT INDIAN POINT UNIT 2 (FILE M74d).

YEAR CLASS	PERCENT CROPPING AFTER 1 YEAR	AFTER 5 YEARS	AFTER 10 YEARS	AFTER 20 YEARS	AFTER 40 YEARS
ADULT I	2.53	3.14	3.83	3.94	3.94
TOTAL ADULTS	1.23	2.77	3.71	3.93	3.94

Table 12.3-2 Effect of Indian Point Units 2 and 3, Bowline Units 1 and 2, and Roseton Units 1 and 2 on Striped Bass Population in the Hudson River, 1975 Data Base. Compensation levels (KO/KE) of 0.40 for the Entrainment Period and 0.80 for the Impingement Period Were Used.

Case 1: WITH ALL THERMAL PLANTS ON ONCE-THROUGH COOLING (FILE M75a).

	PERCENT CROPPING				
YEAR CLASS	AFTER 1 YEAR	AFTER 5 YEARS	AFTER 10 YEARS	AFTER 20 YEARS	AFTER 40 YEARS
ADULT I	2.56	3.56	3.83	3.96	3.97
TOTAL ADULTS	1.32	3.31	3.76	3.95	3.97

Case 2: WITH ALTERNATIVE COOLING AT INDIAN POINT UNIT 2 (1 MAY 1981). INDIAN POINT UNIT 3, BOWLINE UNITS 1 AND 2, AND ROSETON UNITS 1 AND 2 ON ONCE-THROUGH COOLING (FILE M75b).

	PERCENT CROPPING				
YEAR CLASS	AFTER 1 YEAR	AFTER 5 YEARS	AFTER 10 YEARS	AFTER 20 YEARS	AFTER 40 YEARS
ADULT I	2.56	3.56	3.02	3.07	3.06
TOTAL ADULTS	1.32	3.31	2.96	3.06	3.06

Case 3: WITH ALTERNATIVE COOLING AT INDIAN POINT UNIT 2 (15 SEPTEMBER 1981). INDIAN POINT UNIT 3, BOWLINE UNITS 1 AND 2, AND ROSETON UNITS 1 AND 2 ON ONCE-THROUGH COOLING (FILE M75c).

	PERCENT CROPPING				
YEAR CLASS	AFTER 1 YEAR	AFTER 5 YEARS	AFTER 10 YEARS	AFTER 20 YEARS	AFTER 40 YEARS
ADULT I	2.56	3.56	3.02	3.06	3.06
TOTAL ADULTS	1.32	3.31	3.14	3.06	3.06

Case 4: WITH ALL THERMAL PLANTS ON ONCE-THROUGH COOLING WITHOUT INDIAN POINT UNIT 2 (FILE M75d).

	PERCENT CROPPING				
YEAR CLASS	AFTER 1 YEAR	AFTER 5 YEARS	AFTER 10 YEARS	AFTER 20 YEARS	AFTER 40 YEARS
ADULT I	1.65	2.41	2.96	3.04	3.04
TOTAL ADULTS	0.85	2.24	2.91	3.04	3.04

The three principal components of the data which are believed to contribute to the differences in impact predictions from the 1974 and 1975 data bases are the w and f factors, the spatial distributions of the various striped bass life stages, and the estimates of impingement rates. The w and f factors evaluated from the 1974 and 1975 data bases and presented in Tables 8.3-25 through 8.3-30 were considerably different. These differences were most important for the Indian Point and Roseton Plants. The composite f factors for 1974 were generally higher at Indian Point and lower at Roseton than the 1975 values. To estimate how these differences in f factors will affect impact predictions one must also consider differences in projected withdrawal rates at the power plants and the spatial distributions of striped bass ichthyoplankton during 1974 and 1975. Long-range projected flows for Indian Point Units 2 and 3 are about 2.5 times greater than those at Roseton. Consequently, f factors at Indian Point have a stronger influence on impact predictions than Roseton values.

The spatial distributions of striped bass ichthyoplankton during 1974 and 1975 indicated that the peaks in the standing crops of eggs and post yolk-sac larvae were exposed to entrainment at Indian Point during both years. At Roseton, the peak numbers of yolk-sac and post yolk-sac larvae were vulnerable to entrainment during 1974; during 1975, however, peaks in the standing crops for all life stages occurred about 10 mi below Roseton. Consequently, the higher w and f factors at Roseton during 1975 had little influence on estimates of multiplant impact derived from the 1975 data base. In summary, due to the higher plant flows at Indian Point and the spatial distribution of striped bass ichthyoplankton during 1974 and 1975, the w and f factors at Indian Point during 1974 resulted in higher estimates of impact.

The estimated total number of striped bass impinged at Bowline, Indian Point Unit 2 and Roseton during 1974 was nearly twice the estimated 1975 total at these plants (Section 9). Due to the lower compensatory response expected during the impingement period, impingement impact may account for a significant portion of the total reduction in the equilibrium spawning stock (see Section 11.2). Consequently, the higher impingement rates derived from the 1974 data are probably the principal reason that impacts derived from the 1974 data base are higher than those based on the 1975 data.

Comparison of Cases 1 and 2 in Tables 12.3-1 and 12.3-2 suggests that implementation of closed-cycle cooling at Indian Point Unit 2 on May 1, 1981, will reduce the long-range multiplant impact from 5.16% to 4.01% based on 1974 data and from 3.97% to 3.06% based on 1975 data, a reduction of approximately 23%. Comparison of Cases 2 and 3 in the same tables indicates that delaying, until September 15, 1981, the implementation of closed-cycle cooling at Indian Point will have an insignificant effect on the reduction in the equilibrium spawning stock due to power plant operations.

Table 12.3-3 estimates the effect that once-through cooling at Indian Point Unit 2 will have on the Hudson striped bass population. These results were derived by taking the difference between predictions of impact under two conditions: all post-1972 plants on line (Case 1 of Table 12.3-1 and 12.3-2); and all post-1972 plants except Indian Point Unit 2 on line (Case 4 of Tables 12.3-1 and 12.3-3). For results derived from the 1974 data, Indian Point Unit 2 accounted for 24% of the total multiplant impact (Case 1, Table 12.3-3/Case 1, Table 12.3-1). The comparable figure for the 1975 data was 23% (Case 2, Table 12.3-3/Case 1, Table 12.3-2). The slightly higher relative impact of Indian Point Unit 2 from the 1974 data was attributed to the higher f factors at Indian Point, coupled with the other considerations discussed earlier when comparing the results from 1974 and 1975 data. In Table 12.3-3, the decrease in percent cropping for 1-yr-olds (adult I) between 5 and 10 yr was due to a decrease in the projected plant flows at Unit 2 during this period.

Table 12.3-3 Effect of Indian Point Unit 2 Operation on Hudson River Striped Bass Population. Compensation Levels (KO/KE) of 0.40 for Entrainment in Both Years and Impingement Values of 0.86 (1974) and 0.80 (1975) Were Used.

Case 1: WITH 1974 DATA BASE. (FILE M74d).

YEAR CLASS	PERCENT CROPPING AFTER 1 YEAR	AFTER 5 YEARS	AFTER 10 YEARS	AFTER 20 YEARS	AFTER 40 YEARS
ADULT I	1.09	1.49	1.09	1.19	1.22
TOTAL ADULTS	0.53	1.32	1.06	1.19	1.22

Case 2: WITH 1975 DATA BASE. (FILE M75d)

YEAR CLASS	PERCENT CROPPING AFTER 1 YEAR	AFTER 5 YEARS	AFTER 10 YEARS	AFTER 20 YEARS	AFTER 40 YEARS
ADULT I	0.91	1.15	0.87	0.92	0.93
TOTAL ADULTS	0.47	1.07	0.85	0.91	0.93

It should be noted that the long-range predictions of impact presented above for the 1974 and 1975 data bases were each derived from the repeated application of a single year's data on ichthyoplankton distribution and f factors. The f factor calculations presented in Tables 8.3-2 through 8.3-22 indicated that f factors related to the temporal and spatial distribution of the striped bass can vary considerably from year to year. Consequently, the repeated application of a single year's data in order to provide long-range estimates of impact involves the assumption that the year of observation is representative of average conditions over the period of the long range estimate.

12.4 COMPARISON AND CHARACTERIZATION OF IMPACT ESTIMATES DERIVED FROM EQUILIBRIUM REDUCTION EQUATION AND REAL-TIME LIFE-CYCLE SIMULATION MODEL

Estimates of power plant impact on the striped bass population from the equilibrium reduction equation (ERE) were presented in Section 11. The ERE provided an estimate of the long-range reduction in the equilibrium spawning stock due to sustained operation of the power plants at levels in effect during 1974 and 1975.

Results from the real-time life-cycle simulation model (RTLC) presented in Section 12.3 provided estimates of long-range impact based on projected plant operating conditions. The projected total plant flow for Bowline, Roseton, and Indian Point for 1977-2015 is about 1.8 times the 1974 total flow condition and 1.3 times the 1975 total. Due to the higher flow conditions prevalent in the RTLC, one would expect it to give higher estimates of long-range impact than those derived from the ERE. Comparison of the percentage reduction at 40 yr in Case 1 of Table 12.3-1 and 12.3-2 with the total multiplant impact for 1974 and 1975 presented in Table 11.2-1 confirms that the results from the RTLC simulation are higher, as expected:

Striped Bass Population Reduction

	1974	1975
ERE	2.10	1.84
RTLC	5.16	3.97

However, closer examination of the results and the other input parameters to the two computational procedures suggests that the differences in the results are not completely due to the differences in the plant flows used. First, the simulation model results (for the 1974 and 1975 data, respectively) are more than 1.8 and 1.3 times as large as the estimates derived from the ERE.

A more direct comparison of the two impact calculations results from an examination of the conditional mortality rates (m) computed from each procedure for the entrainment period. As shown below, these results are in reasonably good agreement for the 1974 data base. The differences in the results for the 1975 data base are attributed to the differences in the w and f factors used in the two procedures:

Conditional Multiplant Mortality Rates (m) for Entrainment Period

	1974	1975
ERE	0.0811	0.1188
RTLC	0.0848	0.0879

The withdrawal ratios input to the RTLC were computed directly from field data collected during 1974 and 1975, whereas an approximate value of 0.5 was used in the ERE. Similarly, the entrainment mortality factors (f_c) input to the RTLC reflected data collected during 1974 and 1975, whereas the values input to the ERE were based on 1973 data. Given the differences in the computational procedures used in the two approaches and the differences in the data sources for the impact parameters (w and f_c), the agreement in the results is very good.

The above comparisons demonstrate agreement of the ERE and RTLC procedures. The plant mortality rates, in conjunction with the conditional natural mortality rates for the entrainment and impingement periods, are the essential parameters required in the calibration of the RTLC and in the application of the ERE to compute the reduction in the equilibrium spawning stock at a specified level of the compensation parameter. The conditional natural mortality rates used in the two procedures were 0.998 (RTLC) and 0.999 (ERE) for the entrainment period and 0.92 (RTLC) and 0.80 (ERE) for the impingement period. These rates are very similar; therefore, the projected reductions due to the 1974 and 1975 entrainment and impingement impacts are also similar as shown below:

Projected Percentage Reduction in Equilibrium Spawning Stock Due to 1974 and 1975 Multiplant Operating Conditions

	1974		1975	
	RTLC	ERE	RTLC	ERE
Entrainment	0.91	0.76	0.94	1.13
Impingement	0.52	1.34	0.23	0.71

Differences in the projected impingement impacts from the ERE and RTLC approaches are due in part to differences in estimates of natural mortality used in two approaches. In the ERE approach, the total multiplant impact due to entrainment and impingement is approximated as the sum of the entrainment and impingement impacts; in the RTLC, the total impact is derived from runs of the model with entrainment and impingement both occurring. The total impact calculated from these model runs is greater than the sum of the individual entrainment and impingement impacts. This effect and the difference in flow conditions discussed earlier are the principal reasons that the total multiplant impacts derived from the RTLC (Section 12.3) are slightly higher than those resulting from the ERE (Section 11.1).

The close agreement of impact estimates calculated from the approaches presented in Sections 11 and 12 is a cause for confidence in both. Although the same empirical ichthyoplankton data were used in both the ERE and RTLC, these data were used in very different ways and the methods of calculation and the assumptions involved were very different. Impacts based on 1974 and 1975 conditions for Indian Point Unit 2 alone were similar for the ERE and RTLC, as they should have been because the 1974 and 1975 plant flows were fairly comparable to those projected for long-term operation. For the multiplant case, 1974 and 1975 plant flows were substantially lower than those projected for long-term multiplant operation and, consistent with this, the ERE impact estimates were lower than those from the RTLC. Therefore, the continued operation of Indian Point Unit 2 with once-through cooling was shown by both methods to cause an approximate 1% reduction in the striped bass population. Multiplant operation with once-through cooling at 1974-75 levels would cause about a 2% reduction in the striped bass population (ERE), but planned increases in cooling-water flows will increase the long-term reduction to 4 or 5% for the multiplant set treated here (RTLC).

These plant impacts will be manifested as a gradual decline in abundance of striped bass over a period of some 20 yr and establishment of a new average equilibrium level at a density 4 to 5% lower than the density that would prevail in the absence of power plant effects. Percentage-wise, the reduction is small. It certainly would not be expected to be irreversible, because natural variations in the Hudson River striped bass stock many times larger than the 4-5% power plant impact occur regularly, often keep the stock at a level of considerably reduced abundance for a number of years (see Section 7.1), and eventually are reversed upon the return of more favorable environmental conditions. Examples of recovery of major fish stocks following threefold to tenfold sustained reductions by man are cited in Section 10.3-3. If impact were serious enough to warrant mitigation, the potential exists for replacing fish killed by power plant operation by stocking hatchery-reared striped bass or for reducing impingement loss by installing new types of screens at cooling-water intakes (Section 13).

The predicted reduction of 4-5% in abundance of Hudson River striped bass is small when compared with reductions commonly imposed without harm on fish populations by sport and commercial fisheries. As explained in Section 10, such reductions are not damaging in an ecological sense but simply elicit a change in the dynamic state of the stock - changes in death, birth, and growth rates; increased productivity, etc. In the case of the Hudson River fishery, plenty of striped bass would still be available; at worst, a small increase in fishing effort might be required to sustain catches at former levels. It is clear that factors other than abundance of fish (e.g., economic factors) have limited the extent of the fishery in recent years (Section 7.1). In the case of the Atlantic coastal fishery to which the Hudson River contributes some 7% of the stock (Section 7.10), the reduction caused by multiplant impact would be about 0.35% - certainly a change that would not even be discernible.

SECTION 13

MITIGATION OF STRIPED BASS LOSSES

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SECTION 13

MITIGATION OF STRIPED BASS LOSSES

13.1 STRIPED BASS HATCHERY

Artificial propagation has been suggested as a possible mitigative measure to offset losses in the Hudson River striped bass population resulting from power plant operation. Consequently a study was undertaken in 1973 to determine whether Hudson River striped bass can be efficiently produced to stockable size (76 mm) using artificial propagation methods, and to assess the success of stocking as a mitigative measure by developing a stocking and monitoring program to evaluate the survivability of artificially reared striped bass. The following is a summary of the results ~~of the~~ of the 3 yr (1973-75) ~~of the~~ Hudson River striped bass hatchery program. Detailed results of the 1973 and 1974 hatchery programs are addressed in previous reports (TI 1974c, 1975k). Results pertaining to the 1975 hatchery program are summarized from hitherto unpublished TI data.

13.1.1 ARTIFICIAL PROPAGATION

13.1.1.1 Methods. Techniques for artificially propagating Hudson River striped bass were adapted from those developed by Stevens (1966) and refined for mass production by Bayless (1972). Steps included brood fish collection, induced spawning, hatching, shipping larvae to pond culture facilities in southern states for rearing, and marking and transporting fingerlings back to the Hudson River for stocking (Fig. 13.1-1).

Adult striped bass were captured primarily with gill nets set and checked by field crews in the vicinities of Cornwall (RM 56; km 90), Indian Point (RM 42; km 68), and upper Haverstraw Bay (RM 37; km 60)(Fig. 13.1-2) during May 1973, 1974, and 1975. This effort was supplemented with fish purchased from commercial fishermen in 1974 and 1975.

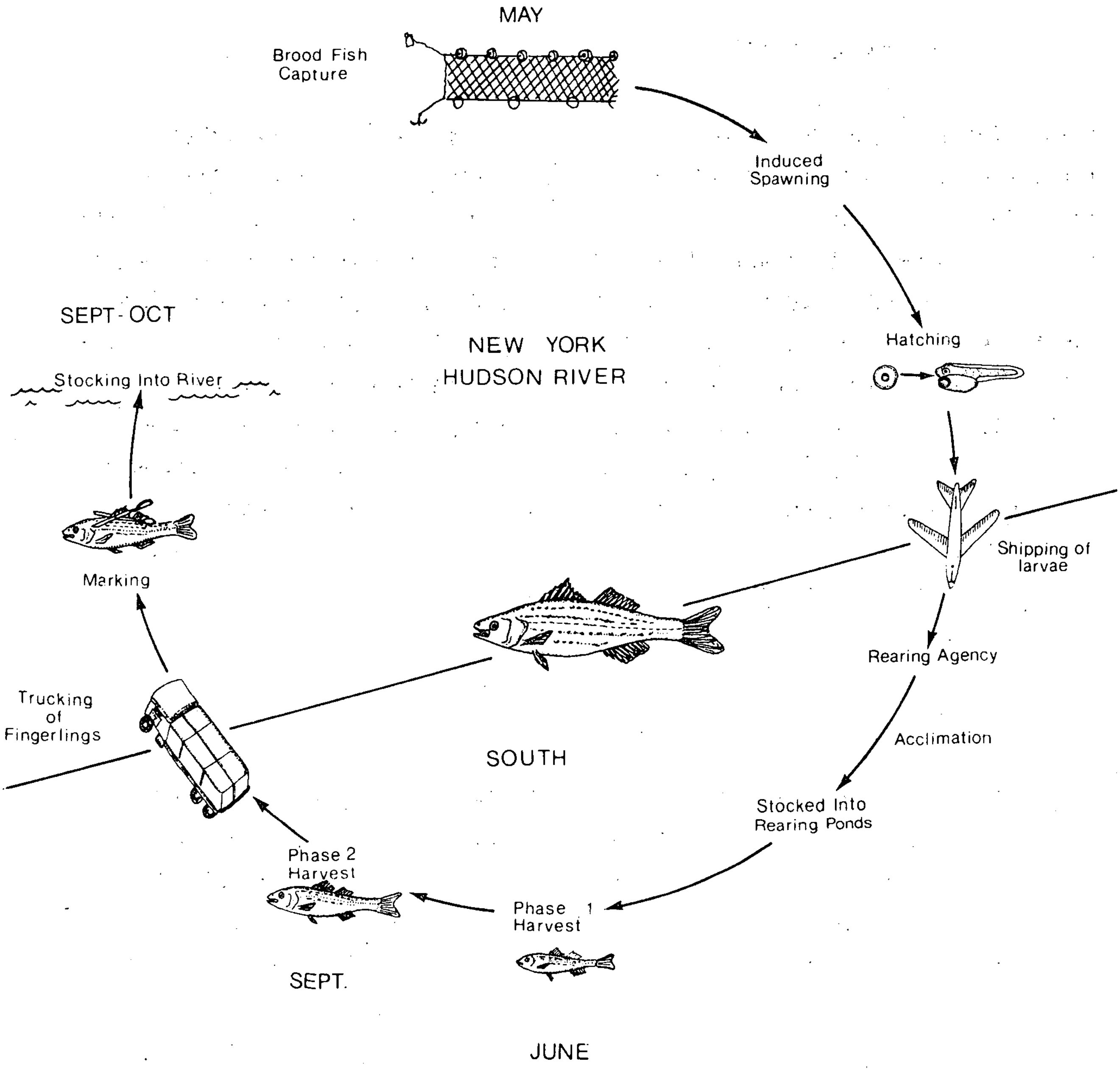


Figure 13.1-1 Major Steps in Artificially Propagating Hudson River Striped Bass for Stocking

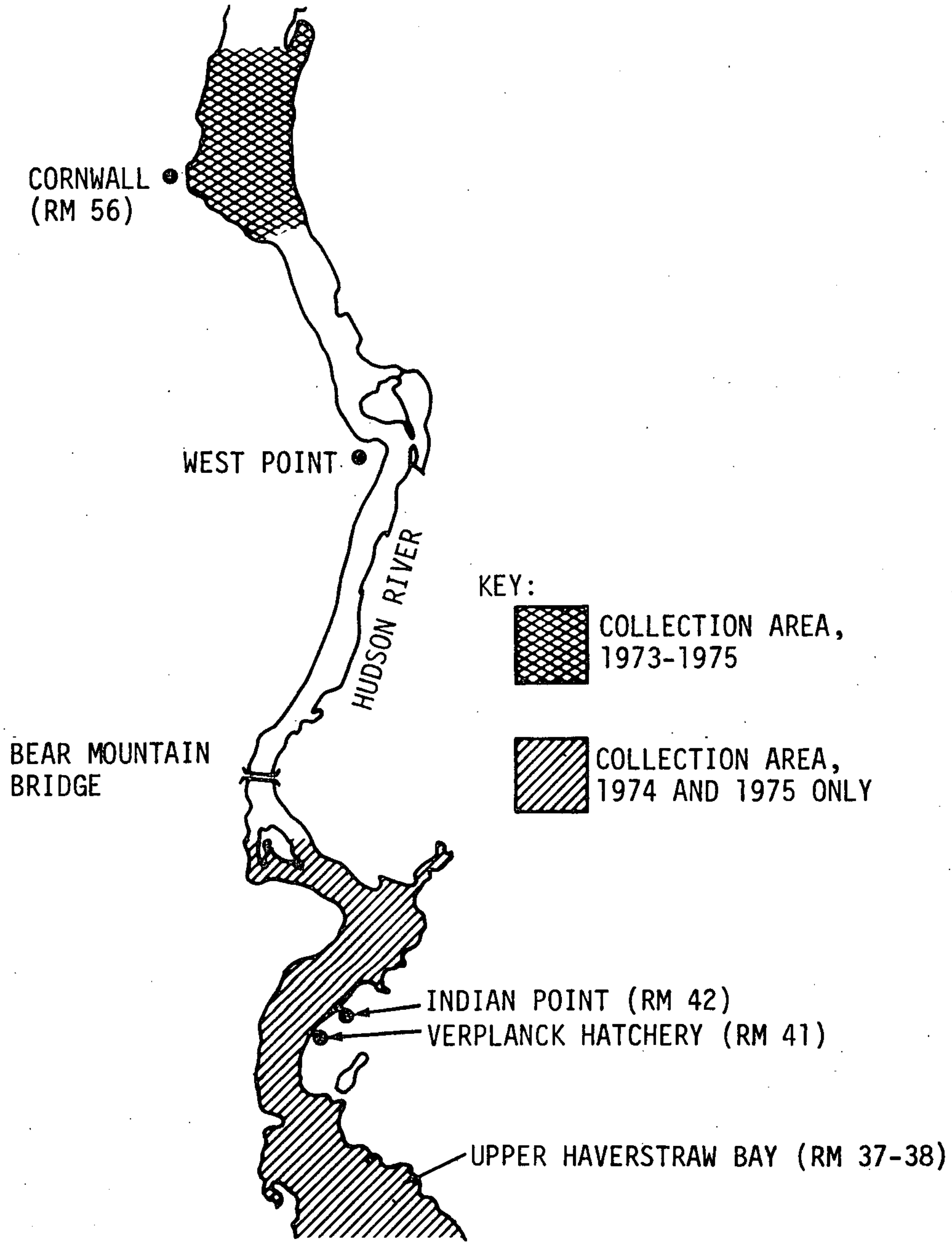


Figure 13.1-2 Collection Areas for Brood Fish Utilized in 1973-75 Hudson River Striped Bass Hatchery Program

Females selected as brood fish were those in good physical condition and having an estimated time to ovulation of not more than 50 h. Ovulation time was estimated using egg sampling and staging techniques described by Bayless (1972: 14-30) adjusted for ambient water temperature. Males selected as brood fish were those producing any quantity of milt upon examination. Striped bass rejected as brood stock were occasionally tagged and released but were usually utilized in other studies (subsections 5.1, 7.1, and 7.8).

Adults selected as brood fish for induced spawning were segregated by sex and held at the Verplanck, New York, hatchery in circular tanks provided with flow-through water from a nearby rock quarry or a mixture of Hudson River and quarry water. Females received intramuscular injections of chorionic gonadotropin at a rate of 275-300 International Units (IUs) kg^{-1} of body weight; males received 110-165 IUs kg^{-1} of body weight if only a small quantity of milt was expelled or a second use planned. Ovarian maturation of each female was monitored, and predicted ovulation time was adjusted by taking one or two additional egg samples for staging. As the predicted ovulation time neared, the female's abdomen was palpated at 30 to 60-min intervals until free-flowing eggs were obtained. The female was then sacrificed and manually stripped of free-flowing eggs, which were collected in pans. Ovaries were removed from the fish and further stripped to maximize egg procurement. Weights of the eggs, stripped ovaries, and fish were recorded for fecundity estimates and determination of the percentage of unripe eggs. Milt from one to three males was stripped onto the eggs which were then agitated with a stream of water to effect fertilization. After 1-2 min, the milt-water mixture was decanted and discarded and the eggs carried to the hatching apparatus where their number was estimated prior to incubation.

The hatching apparatus (Fig. 13.1-3) consisted of racks of modified MacDonald hatching jars supplied with a continuous flow of quarry water.

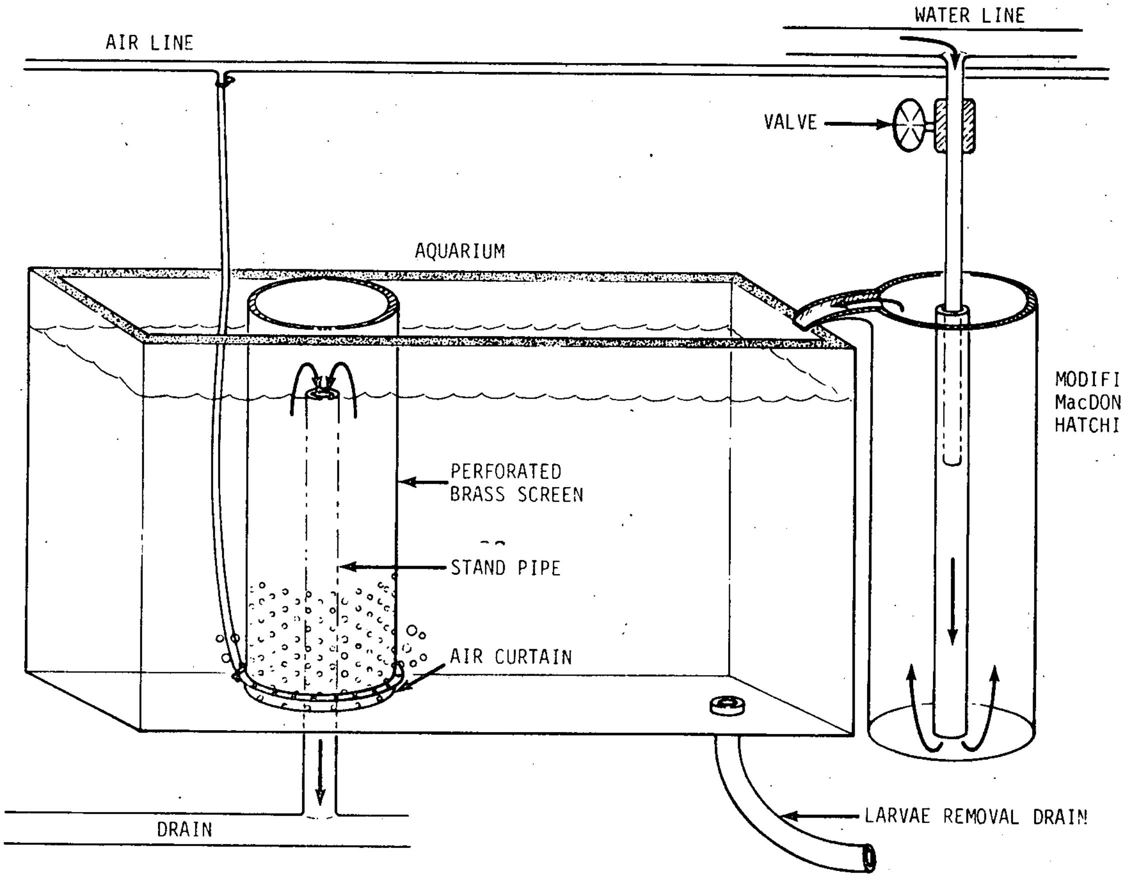


Figure 13.1-3 Hatching System Used for Hudson River Striped Bass Eggs at Verplanck, New York, 1973-75

Larvae, upon hatching, swam upward in the hatching jars and were carried with the water flow into 75 litre receiving aquaria; four or five hatching jars ordinarily supplied each aquarium. The number of eggs poured into the hatching jars, the percent of damaged and/or ~~overripe~~ over-ripe eggs, and the percent of hatch were estimated volumetrically. Eggs hatched in 34-55 h depending on water temperature. When 1-5 days old, larvae were removed from the holding aquaria and packed in oxygenated water-filled plastic bags placed inside styrofoam-lined shipping cartons. Larvae to be reared for stocking were airshipped to rearing facilities designated through various agreements--Marine Protein Corporation in Florida, the State of Oklahoma, and the National Fish Hatcheries in Edenton, North Carolina, and Welaka ~~National Fish Hatchery~~, Florida. These agencies used extensive (pond) culture techniques that included production of natural zooplankton blooms for Phase I growth (25-51 mm in total length) and the addition of artificial food to enhance Phase II growth (> 51 ~~in~~ mm total length). A preliminary culture period (approximately 1 wk) during which larvae were fed brine shrimp nauplii was employed prior to Phase I production. Fingerlings fingerlings were graded by size before being restocked for Phase II production.

Portions of the fingerling crops produced by Marine Protein, the State of Oklahoma, and the National Fish ~~Hatcheries~~ Hatchery in Edenton were transported by aircraft or tank truck to the Hudson River and stocked between RM 24 (km 39) and RM 60 (km 97) during late summer and early fall. Before or after transport, fingerlings were marked with month-specific fin-clips and injected with small magnetic nose tags color-coded in 1975 to designate stocking region. Acclimation periods and chemical treatments were provided when necessary to reduce stress and the incidence of infection.

13.1.1.2 Results. During 1973-75, a total of ~~328~~ 329 adult striped bass were caught and examined for use as hatchery brood ~~stock~~ fish; of these, 153 (47%) were selected for induced spawning (Table 13.1-1) and the remaining utilized primarily for biological characteristic and relative contribution studies. Gill nets, although occasionally yielding severely stressed or dead fish, were satisfactory for capturing brood fish providing the nets were checked at least every hour. Commercial fishermen, on the other hand, checked their gill nets only twice a day, so fish available from them were generally in poor condition.

Due to improved holding facilities and handling techniques, the success of induced spawning increased each year. In addition, in subsequent years, hatchery personnel were more experienced at egg staging, accurate prediction of ovulation times, and selection of female brood fish closest to ovulation. In 1973, 57% of the females selected as brood fish lived to ovulate and 39% ovulated completely producing ripe eggs; this compared with 72% and 53% in 1974 and 100% and 75% in 1975 (Table 13.1-2). Only 3% of the total eggs stripped from the ovaries of female brood fish during both 1974 and 1975 were over-ripe (Table 13.1-2).

Table 13.1-1 Adult Hudson River Striped Bass Captured for Brood Fish Selection and Artificial Propagation during 1973, 1974, and 1975

	1973*	1974**	1975	Total
Total caught and examined	89	96	~~143~~ 144	~~328~~ 329
Brood fish selected				
Females	28	36	16	80
Males	19	35	19	73
Total	47	71	35	153
% of catch	53	74	24	47

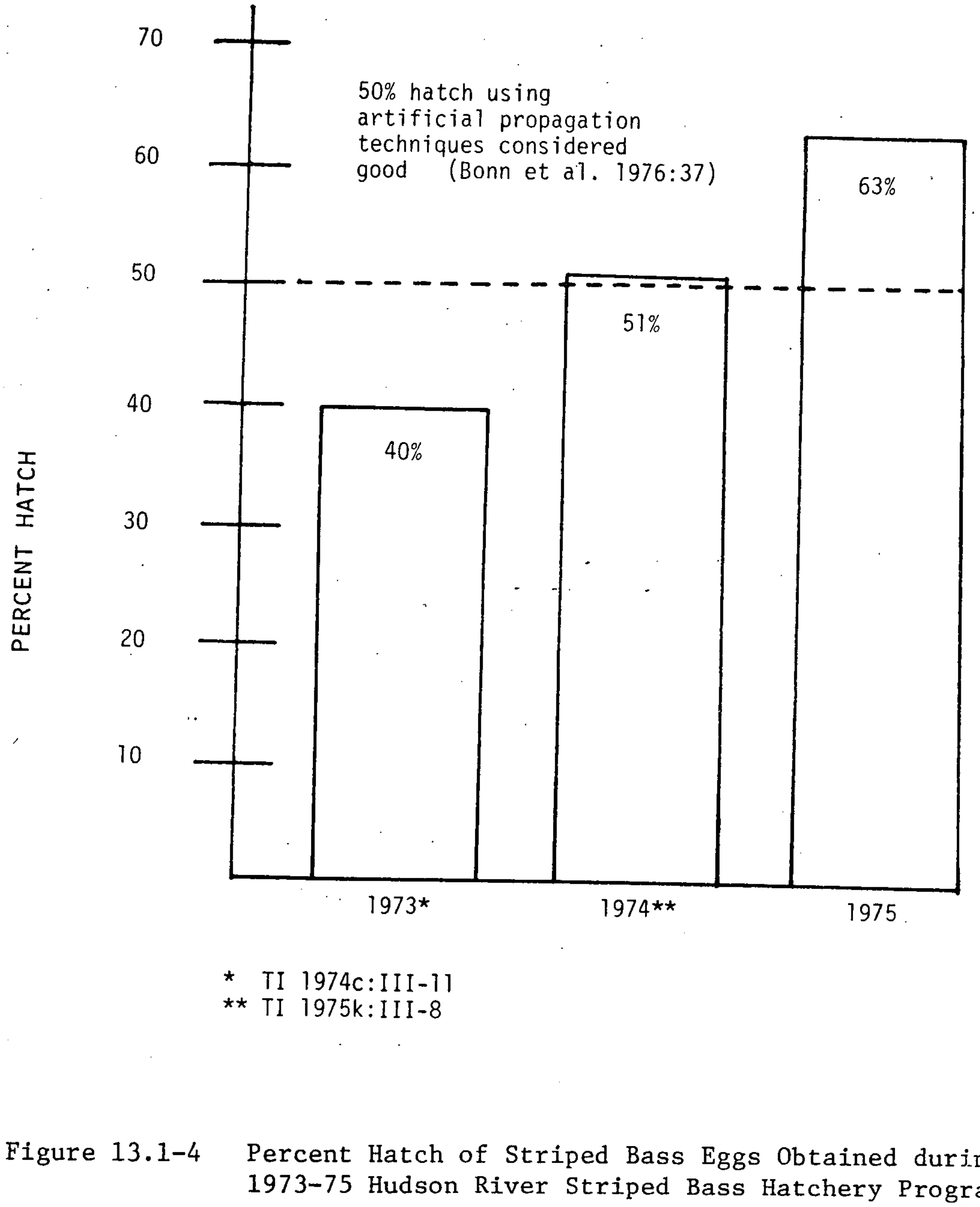
*TI 1974c:III-4
**TI 1975k:III-1

Table 13.1-2 ~~Summarized Survival Data for Exensive Culture of Hudson River Striped Bass, 1973-75~~
Results of the Induced Ovulation of Female Hudson River Striped Bass Used as Brood Fish, Verplanck, N.Y., 1973-1975.

	1973*	1974**	1975
No. selected	28	36	16
No. living to ovulate	16	26	16
of total	57	72	100
No. ovulate ≥ 90	11	19	12
of total	39	53	75
No. of stripped eggs (x 10^6)	26.7	31.328	22.845
% of total	-	92	~~85~~ 88
No. of unripe eggs (x 10^6)	-	2.621	~~3.056~~ 3.120
of total	-	8	12
Total eggs (x 10^6)	-	33.949	~~26.901~~ 25.965
No. of over-ripe or damaged (x 10^6)	-	.852	.765
of total	-	3	3

- No data
* TI 1974c: III-8 - III-9
** TI 1975k: III-5; Appendix A

The hatching percent of stripped eggs also increased from 1973 to 1975 (Figure 13.1-4) and exceeded 50% during all but the first year of the hatchery program; Bonn et al. (1976:37) stated that a 50% hatching rate is considered "good" for artificial propagation of striped bass. Approximately 10,640,000 larvae were produced in 1973 (TI 1974c:III-11), 16,027,000 in 1974 (TI 1975k:III-8), and 13,902,000 in 1975.



* TI 1974c:III-11
** TI 1975k:III-8

Figure 13.1-4 Percent Hatch of Striped Bass Eggs Obtained during 1973-75 Hudson River Striped Bass Hatchery Program

Larvae surviving shipment to rearing facilities and preliminary culture before being stocked in the rearing ponds ranged from 38 to 89% ~~41 to 90~~% (Table 13.1-3). Rearing success at these facilities, measured as percent survival of fish shipped, ranged from 0.5 to 27% through Phase II production. At Marine Protein (Florida) and in Oklahoma, rearing success was limited due to problems that included cannibalism, gas-bladder inflation failure, algae and vegetation control, and handling difficulties resulting from hot weather; the Edenton and Welaka hatcheries, however, obtained good to excellent results (Table 13.1-3).

Table 13.1-3 Summarized Survival Data for Extensive Culture of Hudson River Striped Bass, 1973-75

		Percent Survival Through		
Agency	Year	Shipping and Preliminary Culture	Phase I (25-51 mm)	Phase II (>51 mm)
Marine Protein, Florida	1973*	47	15	6
State of Oklahoma	1973**	38	4	1
	1974†	41	12	0.5
Welaka National Fish Hatchery, Florida	1974†	42	17	NA‡
	1975	89	20	NA
Edenton National Fish Hatchery, North Carolina	1974†	71	21	17
	1975	88	33	27

* From Stevens (1973:3-23)
** TI 1974c:IV-1 to IV-7
† TI 1975k:IV-1 to IV-10; Appendix A
‡ NA - not applicable because fish did not undergo Phase II culture

Fingerling survival during shipment from the rearing facilities to New York for stocking in the Hudson River was consistently high. All fingerlings in 1973 were shipped to New York via airfreight, with 91% survival (TI 1974c:V-3); again in 1974, most fingerlings were air-freighted to New York, although one trial shipment in a specially equipped fish-hauling truck was successful. Total survival for air and truck/shipping was 97% (TI 1975k:V-1 - V-6). A fish-hauling truck was used exclusively for transporting fingerlings in 1975, with shipping survival of 98%. Shipping by truck in addition to yielding better survival than airfreight proved to be considerably more efficient because of reduced handling, as well as more economical. Striped bass fingerlings stocked in the Hudson River totaled 28,674 in 1973 (TI 1974c:V-3), 101,524 in 1974 (TI 1975k:V-1 - V-3), and ~~188,397~~ 188,387 in 1975.

13.1.1.3 Discussion. During 1973-75, the hatchery program demonstrated that culture of Hudson River striped bass is feasible on a scale sufficient to support a mitigative stocking program. Based on 1975 results, an average female brood fish contains about ~~1,6000,000~~ 1,600,000 eggs; of these 1,400,000 (85%) can be stripped (Table 13.1-2). At a hatching rate of 63%, approximately 882,000 eggs hatch into larvae; of these, roughly 194,000 (22%*) survive extensive culture through Phase II (early September when they become stockable size [76 to 152 mm] fingerlings). Practically all of these fingerlings would be expected to survive transport to New York for stocking in the Hudson River in early fall. Thus, an average female brood fish may be expected to yield approximately 1,400,000 eggs and with artificial propagation, approximately 194,000 fingerlings of stockable size, an overall mortality of 86%. On the other hand, total mortality estimates for wild Hudson River striped bass S (section 7.7) indicate that 88 billion eggs deposited annually will yield

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*Average of percent survival through Phase II production during 1974 and 1975 by Edenton National Fish Hatchery, North Carolina, the primary culturing facility for the Hudson River striped bass hatchery program (Table 13.1-3).

5,000,000 fingerlings by 1 September and 4,300,000 fingerlings by 1 October (~~Fig.~~ Section 7.7-4), or total mortality from eggs to fingerlings through 1 September and 1 October of 99.9943% and 99.9951% respectively. If a female striped bass spawned naturally in the river and deposited 1,400,000 eggs, only 80 fingerlings would be expected to survive to 1 September and 69 fingerlings to 1 October. Thus, each naturally spawning female would produce only about 0.40% as many fingerlings as would a female used in hatchery propagation.

Artificial propagation of Hudson River striped bass greatly increases survival through the early months of life when highest natural mortality occurs. The production of large numbers of fingerlings for a mitigative stocking program would not require that a large number of wild adult striped bass be removed from the spawning population; rather five healthy female brood fish should supply approximately 1,000,000 stockable fingerlings. However, not every adult striped bass captured for a hatchery program is suitable for artificial spawning. For each female brood fish selected delete in 1975, for example, eight additional striped bass were caught and examined; these fish generally included one ripe, serviceable male (which usually died due to stress imposed during repeated extraction of milt), three fish that died before they could be utilized because of severe stress or injury imposed by capture and handling, and four fish in good condition but rejected as brood fish because they were not in the proper stage of sexual maturation. Although adult striped bass captured and examined by hatchery personnel but rejected for artificial spawning were generally utilized in other studies, it is estimated that four out of every nine fish could be released in good condition. Thus, removal of adult striped bass from the natural spawning population for artificial propagation (using gill net capture and the hand-stripping spawning method) would amount to five adults per 194,000 fingerlings produced, or approximately 25 adults for every 1,000,000 fingerlings produced. Based on the average weight of hatchery brood fish (approximately 7 kg), this removal level is < 1% of the average annual landings of adult striped bass in the Hudson River commercial fishery (1965-75) (~~s~~Section 5.4).

Alternative capture and spawning techniques, if tested and found to be satisfactory for Hudson River striped bass, have the potential of reducing brood fish fatalities and increasing production efficiency. Electrofishing or electrofishing within pound nets are techniques that have been used successfully to capture adult striped bass in other rivers and reservoirs with minimal stress to the fish (Bayless 1972:9-12; Bishop 1974:6-7; Bonn et al. 1976:13-14). Tank spawning, which utilizes hormone injection to induce natural spawning, has been used successfully since 1973 (Bishop 1974); this method requires considerably less handling and imposes less stress on brood fish than does the conventional hand-stripping spawning technique and enables spent brood fish to be released in good condition.

13.1.2 SURVIVAL OF HATCHERY-REARED STRIPED BASS. The success of stocking hatchery-reared striped bass in the Hudson River was evaluated by comparing the survival of hatchery fish to that of wild striped bass of the same year class following the 1973, 1974, and 1975 stocking efforts. Survival analyses were based on data obtained from an extensive mark/recapture program. For external identification, wild fish were marked with various fin-clip combinations to indicate time and area of release and hatchery fingerlings were marked with fin-clips (different from those applied to wild fish) to indicate time of stocking. In addition, small magnetic nose tags (~~colored-coded~~ color-coded during the 1975 stocking program to designate stocking regions so that information on movement patterns could be obtained) were inserted into the nose cartilage of hatchery fish to provide an additional means of recapture verification. In conjunction with estimating relative survival of stocked and wild striped bass in the river, 14-day holding experiments were conducted to evaluate and compare initial mortality of marked and unmarked (control) hatchery fish.

13.1.2.1 Marking Mortality. Initial mortality of hatchery-reared striped bass due to marking procedures was evaluated by holding samples of marked and unmarked fish in circular tanks for 14 days (TI 1974c:VI-1-VI-3; 1975k:VI-1-VI-7). During the 1973 holding experiments, fish were fed by an automatic device; separate samples of fish were tested in tanks containing quarry water and tanks containing Hudson River water. Fish held during 1974 and 1975 were not fed and were tested only in tanks containing river water.

Initial (14-day) mortality of fingerlings held in tanks containing Hudson River water was generally low and, in all tests except one*, mortality was not significantly different between marked and unmarked (control) groups. Fish receiving both a nose tag and fin-clip were usually subject to mortality rates of < 10% (Table 13.1-4). Most mortalities occurred within the first week of testing, indicating that the tests were of sufficient duration to assess mortality directly associated with handling and marking. These mortality rates can be applied to the total number of fish stocked to estimate the effective size of the stocked population.

13.1.2.2 Relative Survival. Survival of hatchery-reared striped bass relative to their wild counterparts of the same year class was assessed for a period of up to 9 mo of concurrent residence in the river (TI 1974c: VI-4-VI-7; 1975k:VI-8-VI-12). Relative survival (Paulik and Robson 1969), expressed as the ratio S_h/S_w, was computed as follows:

$$\frac{S_h}{S_w} = \frac{R_{h_2}}{R_{h_1}} \Bigg/ \frac{R_{w_2}}{R_{w_1}}$$

---

*During one of four holding experiments conducted in 1975, mortality of marked fish was significantly ($\alpha = 0.05$) higher than that of control fish; however, interpretation of the results of this test was confounded by fungal infections within the holding tanks.

where

S_h = fraction of hatchery fish surviving from time interval 1 to time interval 2

S_w = fraction of wild fish surviving from time interval 1 to time interval 2

R_{h_1} = number of hatchery fish recaptured during time interval 1

R_{h_2} = number of hatchery fish recaptured during time interval 2

R_{w_1} = number of wild fish recaptured during time interval 1

R_{w_2} = number of wild fish recaptured during time interval 2

If the S_h/S_w value is greater than unity, survival is better for hatchery-reared fish than for wild fish; conversely, if the value is less than unity, survival is better for wild fish.

Table 13.1-4 Mortality of Nose-Tagged and Fin-Clipped Hatchery-Reared Striped Bass during 14-Day Holding Experiments* 1973-75

		Marked Fish			Unmarked Fish (Control)		
Year	Month(s)	No. Tested	No. Dead	% Mortality	No. Tested	No. Dead	% Mortality
1973**	Sep	108	4	3.7	101	1	1.0
	Oct	100	2	2.0	100	7	7.0
1974†	Sep-Oct	200	9	4.5	~~200~~ 199	1	0.5
	Nov	50	3	~~6.8~~ 6.0	63	0	0
1975	Sep	~~100~~ 100	5	5.0	100	3	3.0
	Sep-Oct	~~100~~ 99	4	4.0	100	1	1.0
	Oct	100	9	9.0	100	15	15.0
	Nov	100	34	34.0‡	100	2	2.0

* Fish held in circular tanks supplied with constant flow of river water.

** TI 1974c:VI-3

† TI 1975k:VI-3 - VI-6

‡ Only test for which there was a significant difference in mortality between marked and unmarked fish.

Relative survival estimates for hatchery-reared vs wild striped bass recaptured within 3 mo following release in 1973-75 were consistently close to or greater than 1 (Table 13.1-5), indicating that the short-term survival of hatchery fish after being stocked in the river was comparable to that of wild fish. Similarly, winter-spring 1975 recaptures of fish released in fall 1974 indicated comparable survival of hatchery and wild striped bass after 8-9 mo of concurrent residence in the river (Table 13.1-5).

Table 13.1-5 Relative Survival Estimates for Hatchery-Reared and Wild Striped Bass Fingerlings in Hudson River Estuary, 1973-75

Time of Release		Survival Period		
Year	Month+	Interval 1	Interval 2	S_h/S_w
1973*	Sep-Oct	12-18 Nov 1973	26 Nov-2 Dec 1973	1.29
		12-18 Nov 1973	3-9 Dec 1973	2.00
		26 Nov-2 Dec 1973	3-9 Dec 1973	~~1.55~~ 1,56
1974	AUG ~~Sep~~-Oct	27 Oct-2 Nov 1974**	3-9 Nov 1974	1.90
		27 Oct-2 Nov 1974**	17-23 Nov 1974	2.80
		3-9 Nov 1974**	17-23 Nov 1974	1.47
		Jan 1975	May 1975	3.14
		May 1975	Jun 1975	0.82
1975	Aug-Sep	12-18 Oct 1975	19-25 Oct 1975	~~1.65~~ 1,59
		19-25 Oct 1975	26 Oct-1 Nov 1975	~~1.98~~ 2,05
		26 Oct-1 Nov 1975	2-8 Nov 1975	~~1.13~~ 0,80
		2-8 Nov 1975	9-15 Nov 1975	~~1.00~~ 1.41
		9-15 Nov 1975	16-22 Nov 1975	~~4.27~~ 4,11
	Oct	9-15 Nov 1975	16-22 Nov 1975	~~2.20~~ 2,03
		16-22 Nov 1975	23-29 Nov 1975	~~0.90~~ 1.24

* TI 1974c:VI-7

** TI 1975k:VI-10

\+ Releases of marked hatchery and wild fish were not always concurrent during the specified period.

Valid estimates of relative survival using this change-in-ratio technique require certain conditions. If a change in recapture ratio is to be utilized as an estimate of relative survival, it must be assumed that probabilities of capture of hatchery-reared and wild striped bass are equal or that they change at the same rate. An assumption of equal probabilities of capture may not be justifiable in this instance because hatchery-reared fish are generally larger than wild fish when released (Table 13.1-6), possibly allowing them to better avoid sampling gear. However, an assumption of an equal change in recapture rates for the two groups is reasonable because time intervals between recapture periods are usually short. In addition, most recapture comparisons are made during the colder months (Table 13.1-5) when growth is characteristically slow and capture rates would not be expected to change appreciably for either group because of size changes.

Table 13.1-6 Mean Total Lengths of Hatchery-Reared and Wild Striped Bass Fingerlings, 1973-75

Date		Type	Mean Total Length (mm)
1973*	26-29 Sep	Hatchery-reared	98-100
	9-19 Oct	Hatchery-reared	112-143
	23 Sep-6 Oct	Wild	85
1974**	4-10 Aug	Hatchery-reared	58
	4-10 Aug	Wild	59
	22-28 Sep	Hatchery-reared	115
	22-28 Sep	Wild	80
	13-19 Oct	Hatchery-reared	106
	13-19 Oct	Wild	83
1975	22 Sep – 10 Oct	Hatchery-reared	113
	Sep	Wild	86
	20 Oct – 2 Nov	Hatchery-reared	117
	Oct	Wild	107
	4-17 Nov	Hatchery-reared	~~131~~ 132
	Nov	Wild	108

* TI 1974c:VI-5
** TI 1975k:VI-11

The catchability of marked hatchery-reared and wild striped bass and the validity of relative survival estimates depend also on dispersal after release. If the probability of capture changes at different rates for the two groups of marked fish due to different degrees of dispersal, a bias in the relative survival estimate results in favor of the group with less dispersal. In comparing movements of hatchery-reared and wild striped bass based on fish released and recaptured during fall 1975, wild fish were found to disperse less than hatchery fish after release (Fig. 13.1-5): most wild fish were recaptured in the area of initial release, whereas hatchery fish were more frequently recaptured outside their release areas. Relative survival estimates require that equal effort be applied to capturing wild and hatchery fish; random dispersion of both groups facilitates the application of equal capture effort. Because dispersion is more likely to be random after a longer time has elapsed, estimates utilizing later recaptures would not so greatly reflect differences in capture effort due to variation in dispersal rates for the two groups. If wild fish do disperse more slowly, the relative survival applying to the early months following stocking would be underestimated; i.e., under such circumstances, hatchery fish probably would have survived even better than indicated.

Dispersal and subsequent longer-range movements also are of interest as indicators of the adaptability of hatchery-reared fish in a natural environment. As an anadromous species, the striped bass undergoes a cycle of movement from fresh water or brackish water as a juvenile to salt water as an adult, returning again to spawn in fresh water. Hatchery-reared fish must complete this cycle if they are to replace the segment of the natural population lost to entrainment or impingement at power plant intakes.

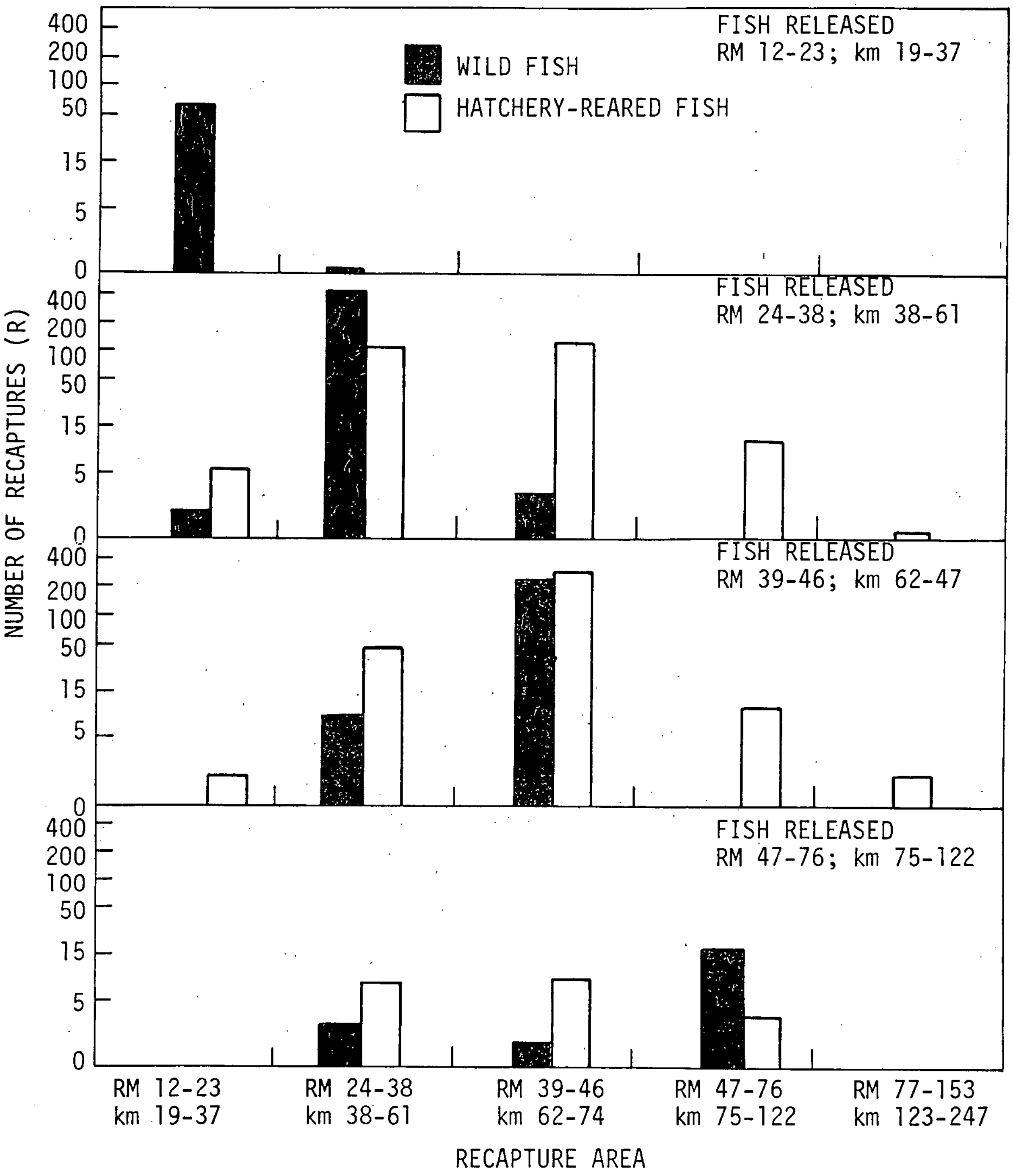

Figure 13.1-5 Recapture Distribution of Hatchery-Reared and Wild Striped Bass Released during Fall 1975

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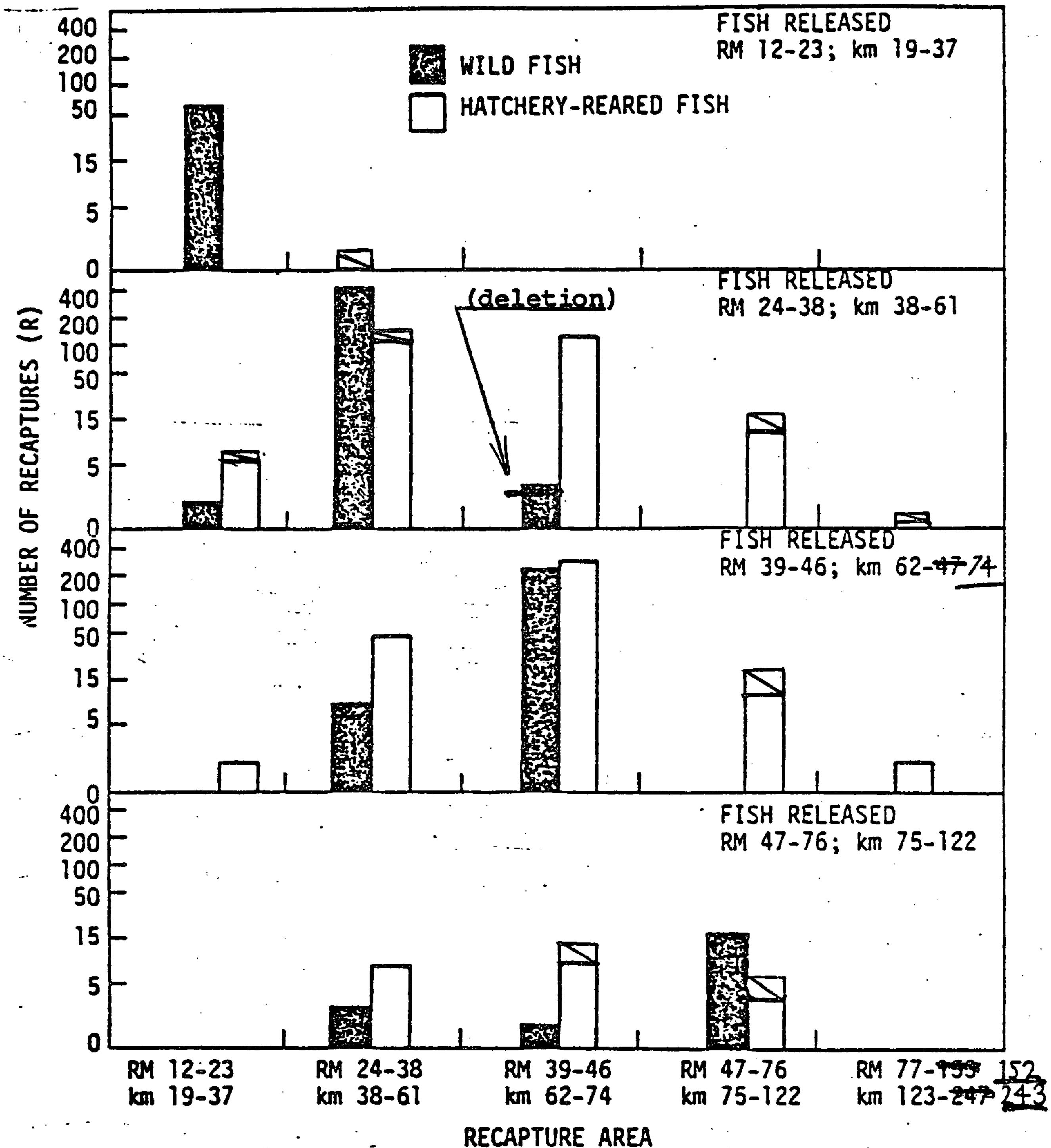

⧅ (indicates an addition)

Figure 13.1-5 Distribution of Hatchery-Reared and Wild Striped Bass Released and Recaptured during Fall 1975

Description of Headings

Table	(Pg.)	Column	Row	Change From	Change To
		1975	No. of unripe eggs ($x10^6$)	3.056	3.120
			Total eggs ($x10^6$)	25.901	25.965
13.1-4	(13.14)	Marked Fish - No. Tested	1975 Sep-Oct	100	99
		% Mortality	1974 Nov	6.8	6.0
		Unmarked Fish - No. Tested	1974 Sep-Oct	200	199
13.1-5	(13.15)	Column heading		Month	Month$^+$
		Month$^+$	1974	Sep-Oct	Aug-Oct
		S_h/S_w	1973* Sep-Oct		
			26 Nov-2 Dec 1973	1.55	1.56
			1975 Aug-Sep		
			12-18 Oct 1975	1.65	1.59
			19-25 Oct 1975	1.98	2.05
			26 Oct-1 Nov 1975	1.13	0.80
			2-8 Nov 1975	1.00	1.41
			9-15 Nov 1975	4.27	4.11
			1975 Oct		
			9-15 Nov 1975	2.20	2.03
			16-22 Nov 1975	0.90	1.24

Footnotes - add "$^+$Releases of marked hatchery and wild fish were not always concurrent during the specified period."

13.1-6	(13.16)	Date	1975 Sep		
			Hatchery-reared	Sep	22 Sep - 10 Oct
			1975 Oct		
			Hatchery-reared	Oct	20 Oct - 2 Nov
			1975 Nov		
			Hatchery-reared	Nov	4-17 Nov
		Mean Total Length	1975 4-17 Nov	131	132
13.1-7	(13.20)	No. Recaptures 1975	October 1975	519	518
			1975 Total	926	925
			April 1976	101	100
			June 1976	39	38
			1976 Total	238	236
			3-1/2 Year Grand Total	1164	1161

Within a few months following the 1975 stocking, hatchery- reared striped bass dispersed widely from the areas of release (Fig. 13.1-5), from the George Washington Bridge (RM 12; km 19) to Albany (RM 141; km 227). Wild fish of the same year class also were found over this range. Within 7 mo, some of the stocked hatchery fish left the river proper and entered the more saline bays, rivers, and inlets of the lower Hudson River estuary, as did wild fish, but no data comparing rates of emigration of wild and hatchery fish are available. Recaptures of hatchery-reared striped bass up to 22 mo following stocking further indicated their long-term adaptation and survival in the natural environment (Table 13.1-7).

13.2 FISH DIVERSION DEVICES

In 1974, an experimental program was designed to evaluate the effectiveness of various fish diversion devices and determine their efficiency and applicability with respect to fish protection at Indian Point and other Hudson River sites. Stone and Webster Engineering Corporation (S&W) was contracted by Con Edison to conduct the biological testing associated with the study program in an experimental flume constructed by the Alden Research Laboratories (ARL). A preliminary review, including an evaluation of prototype design considerations, gave angled screens and louvers top ranking for potential application at Indian Point (RM 42; km 69) and Cornwall (RM 56; km 90) (S&W 1975). Consequently, the testing of these devices received primary attention in the flume study program.

In the flume, a rectangular channel 80 ft (24 m) long and 7 ft (2 m) deep, the potential for various fish diversion systems to successfully guide and bypass fish can be evaluated. In general, a specific fish diversion system and bypass are installed in the flume and a controlled uniform flow of water maintained through the system. Test fish are introduced into the flume flow and are monitored with respect to their behavior and movement upon approaching the diversion system. Fish that are successfully guided by the system are bypassed to a collection area and removed for survivability studies.

Table 13.1-7 Summary of Stocking and Recapture Data for Hatchery-Reared Hudson River Striped Bass Based on Stocking of 28,674 fish in 1973; 101,524 fish in 1974; and 188,387 fish in 1975.

Recapture Date	No. Recaptures by Year Stocked			Total Recaptured
	1973	1974	1975	
October 1973	20			20
November	23			23
December	3			3
1973 Total	46			46
March 1974	3			3
August		9		9
September		1		1
October		65		65
November		69		69
December		20		20
1974 Total	3	164		167
January 1975		11		11
February		63		63
March		42		42
April		219		219
May		49		49
June		31		31
July		10		10
August		8		8
September		1	75	76
October		9	~~519~~ 518	~~528~~ 527
November			274	274
December		1	58	59
1975 Total		444	~~926~~ 925	~~1370~~ 1369
January 1976			35	35
February		2	8	10
March			21	21
April		1	~~101~~ 100	~~75~~ 101
May			34	34
June		2	~~39~~ 38	~~41~~ 40
1976 Total		5	~~238~~ 236	~~243~~ 241
3-½ Year Grand Total	49	613	~~1164~~ 1161	~~1826~~ 1823

Testing to determine the diversion efficiency of angled screens and louvers begin in May 1975 and concluded in January 1976. Fish species examined included white perch, Atlantic tomcod, and hatchery-reared and native Hudson River striped bass. Since the efficiency of each device depended on its ability to guide fish along the structure, similar test parameters were used for both devices. The environmental test parameters included test species, lighting condition (light or dark), water temperature, salinity, and conductivity. Hydraulic considerations included approach and bypass velocities, test device angle (screen only), and the presence or absence of an air bubble curtain upstream of the device. All test parameters were recorded at the beginning and end of each test. In addition, at the end of each angled screen trial, test, control, and nonbypassed fish were held for 1-wk fish mortality studies. Table 13.2-1 indicates the range of vaules tested for each parameter.

Table 13.2-1 Parameter Values Used in Diversion Efficiency Tests

Parameter	Angled Screen Test*	Louver test**
Screen angle (^{o})	25 or 45	-
Mean water temperature (^{o}F)	34.7-77.8	34.3-63.9
Mean dissolved oxygen (ppm)	8.3-12.8	9.4-13.6
Salinity (^{o}/oo)	0-3	0-3
Mean conductivity (mS cm^{-1})	74-3865	78-4000
Lighting condition	Light or dark	Light or dark
Air curtain	Present or absent	Present or absent
Approach velocity (ft s^{-1})^{2}	0.50-3.02	0.94-2.89
Bypass velocity (ft s^{-1})	0.60-3.24	1.15-4.54
Duration of test (h)	0.50-91.5	0.5-61.0

* 39 tests, 28 June 1975-29 January 1976

** 21 tests, 30 September 1975-6 January 1976

† Micromho

Concurrent with biological testing was hydraulic testing by ARL to obtain information on the hydraulic characteristics of the flow approaching the screens and louvers and along the face of the devices. The hydraulic test results are reported in detail in an appendix to the Stone and Webster final flume study report (S&W 1976c: Appendix A).

In evaluating the test results, both angled screens and louvers were found to be effective in diverting fish to a bypass system. The criterion for successful diversion was called total efficiency (TE), a combination of diversion efficiency of the device and mortality attributable to the diversion system. The TE of the angled screens and louvers was evaluated in conjunction with the interacting environmental and hydraulic variables listed in Tables 13.2-2 through 13.2-4. The test results have already been reported in detail (S&W 1976c).

Angled screens were tested at 25° and 45° angles to the flume flow. Variant test angles had no apparent effect on the total efficiency of the device; however, fish diverted at the 45° angle seemed to experience more physical damage. The louver system was tested only at a 25° angle to the flume flow, with louver slot spacings of 1 in (2.5 cm) clear opening.

Results of the tests conducted with the angled screens and louvers were subjected to statistical analyses to determine the diversion efficiency of the devices and the effect of the independent variables on the total efficiency of the systems. These analyses found that angled screens yielded higher degrees of efficiency when operated under dark conditions and when tested in conjunction with fish tested only once and not physiologically stressed. Angled screen TE was found also to be nondependent on the species tested. Louver efficiency, on the other hand, increased when the system was operated under light conditions and when the fish being tested had previously experienced the device. Species was found to be a significant factor in evaluating the system's effectiveness; however, the physiological condition of the fish had no apparent effect

Table 13.2-2 Results of Analysis of Covariance for Angled Screen Tests, Indian Point Flume Study*

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-Ratio	Probability
Species	3	0.0001	0.0000	0.369	0.7757
Previous Use	1	0.0000	0.0000	0.298	0.5898
Light/Dark	1	0.0000	0.0000	0.768	0.3887
Conductivity	1	0.0000	0.0000	0.455	0.5057
Mean Condition Factor	1	0.0000	0.0000	0.489	0.4902
Temperature Change, °F	1	0.0000	0.0000	0.392	0.5365
Residual	27	0.0013	0.0000		
Total	35	0.0017			
System Differential Mortality (m)					
Species	3	0.02882	0.0094	2.413	0.0886
Previous Use	1	0.0143	0.0143	3.684	0.0655
Light/Dark	1	0.0245	0.0245	6.284	0.0185
Conductivity	1	0.0170	0.0170	4.363	0.0463
Mean Condition Factor	1	0.0124	0.0124	3.174	0.0861
Temperature Change, °F	1	0.0005	0.0005	0.132	0.7193
Residual	27	0.1051	0.0039		
Total	35	0.1913			
Total Efficiency					
Species	3	0.0271	0.0090	2.308	0.0990
Previous Use	1	0.0135	0.0135	3.440	0.0746
Light/Dark	1	0.0262	0.0262	6.675	0.0155
Conductivity	1	0.0180	0.0180	4.602	0.0411
Mean Condition Factor	1	0.0115	0.0115	2.927	0.0986
Temperature Change, °F	1	0.0004	0.0004	0.092	0.7644
Residual	27	0.1058			
Total	35	0.1973			

*S+W 1976c

Table 13.2-3 Results of Analysis of Covariance for Louver Tests, Indian Point Flume Study*

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-Ratio	Probability
Species	3	0.2393	0.0798	9.165	0.0005
Previous Use	1	0.0686	0.0686	7.880	0.0109
Light/Dark	1	0.0303	0.0303	3.481	0.0768
Conductivity	1	0.0274	0.0274	3.152	0.0910
Temperature Change, ^oF	1	0.0339	0.0339	3.898	0.0623
Mean Condition Factor	1	0.0051	0.0051	0.583	0.4542
Residual	20	0.1741	0.0087		
Total	28	0.5700			

*S+W 1976c

Table 13.2-4 Results of Combined Analysis of Covariance for Louver and Angled Screen Tests, Indian Point Flume Study*

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-Ratio	Probability
Device	1	0.0603	0.0603	7.417	0.0088
Species	3	0.0709	0.0236	2.907	0.0433
Light/Dark	1	0.0141	0.0141	1.733	0.1938
Device x Species	3	0.0726	0.0242	2.977	0.0398
Device x Light/Dark	1	0.0364	0.0364	4.475	0.0392
Approach Velocity	1	0.0013	0.0013	0.161	0.6895
Conductivity	1	0.0257	0.0257	3.155	0.0815
Mean Temperature, ^oF	1	0.0079	0.0079	0.966	0.3303
Residual	52	0.4228	0.0081		
Total	64	1.0244			

*S+W 1976c

on the device's efficiency. Both angled screen and louver efficiency appeared to be negatively influenced by salinity; approach and bypass velocities, temperature, and the presence of an air-bubble curtain had no effect on the TE of either device.

Based on the data obtained from the study program, both devices were found to exhibit high rates of efficiency in diverting and bypassing fish (96% for angled screens and 85% for louvers); however, TE varied for the different fish species tested. Test species diverted in decreasing order of efficiency were Atlantic tomcod, hatchery-reared striped bass, native Hudson River striped bass, and white perch. Results to date indicate the potential effectiveness of using angled screens and louvers for alleviating problems of fish impingement at Indian Point and other Hudson River sites.

13.3 PLANT OPERATIONAL PATTERNS

Striped bass losses have and will continue to be mitigated through prudent operation of the Indian Point Unit 2 hydraulic intake system and the thermal, chemical, and radioactive discharge systems. On 1 January 1974, Con Edison submitted a report to the U.S. Atomic Energy Commission describing operating procedures and the design of facility systems to reduce plant impact to a practicable minimum in the interim period prior to any decision to install a closed-cycle cooling system (Con Edison 1974a). The mitigation measures described in the report complement the "Limiting Conditions for Operation, Monitoring Requirements and Environmental Surveillance Programs" contained in Appendix B of <u>Environmental Technical Specification Requirements to the Facility Operating License</u>. Con Edison will continue to operate Indian Point Unit 2 in accordance with the requirements of the <u>Environmental Technical Specification Requirements</u> and the "Plan of Action".

13.4 RELATIONSHIP OF IMPINGEMENT TO ~~EVNIRONMENTAL~~ ENVIRONMENTAL VARIABLES

13.4.1 INTRODUCTION. Monitoring physiochemical characteristics of intake water and daily fish impingement at Indian Point has demonstrated a relationship between major peaks in impingement, temperature, and conductivity. From these data, mathematical models of changes in temperature and conductivity can now be developed to predict the time of occurrence of impingement peaks.

Striped bass account for <2% of impingement collections at Indian Point and have never been impinged in sufficient numbers to permit development of impingement prediction as just described. The companion species, white perch, does occur frequently in impingement collections and has been used to develop a procedure for predicting the time of occurrence of impingement peaks. The pattern of impingement of striped bass follows that of white perch, so the predictions apply to some unquantified degree to both species.

13.4.2 SEASONAL IMPINGEMENT AND MOVEMENT OF SALT FRONT. Impingement of white perch has accounted for 42% of total impingement at Indian Point since 1972 and has been closely related to the movement of the salt front (freshwater-saltwater interface area defined as 0.3 mS cm^{-1} conductivity) through the Indian Point region. During winter and spring, white perch impingement peaks occur subsequent to conductivity peaks as the salt front is diluted and recedes downstream (Fig. 13.4-1).

This relationship disappears from early May through late fall when water temperatures are >12-15°C. Studies of white perch distribution indicate movement from overwintering habitats in the deeper channel to shoals and beaches at approximately this temperature. This migration removes white perch from the direct influence of an intruding salt front, which will generally follow the channel. This movement also removes white perch from the area of influence of the intake structures.

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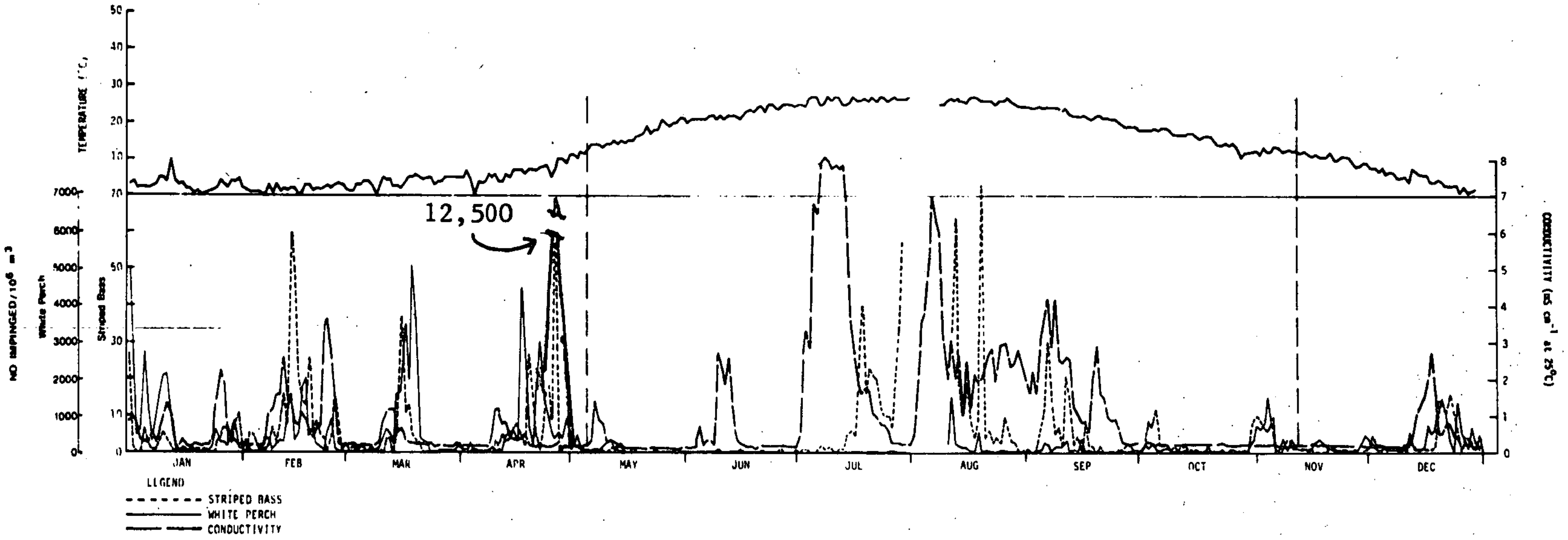

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Figure 13.4-1 White Perch and Striped Bass Impingement at Indian Point Unit 2 during 1975 Graphed with Conductivity and Temperature Measured Daily at Unit 2 Intake. Vertical dashed lines indicate 12°C water temperature discussed in text in relationship to fish movement. White perch and striped bass plotted on different abundance scales.

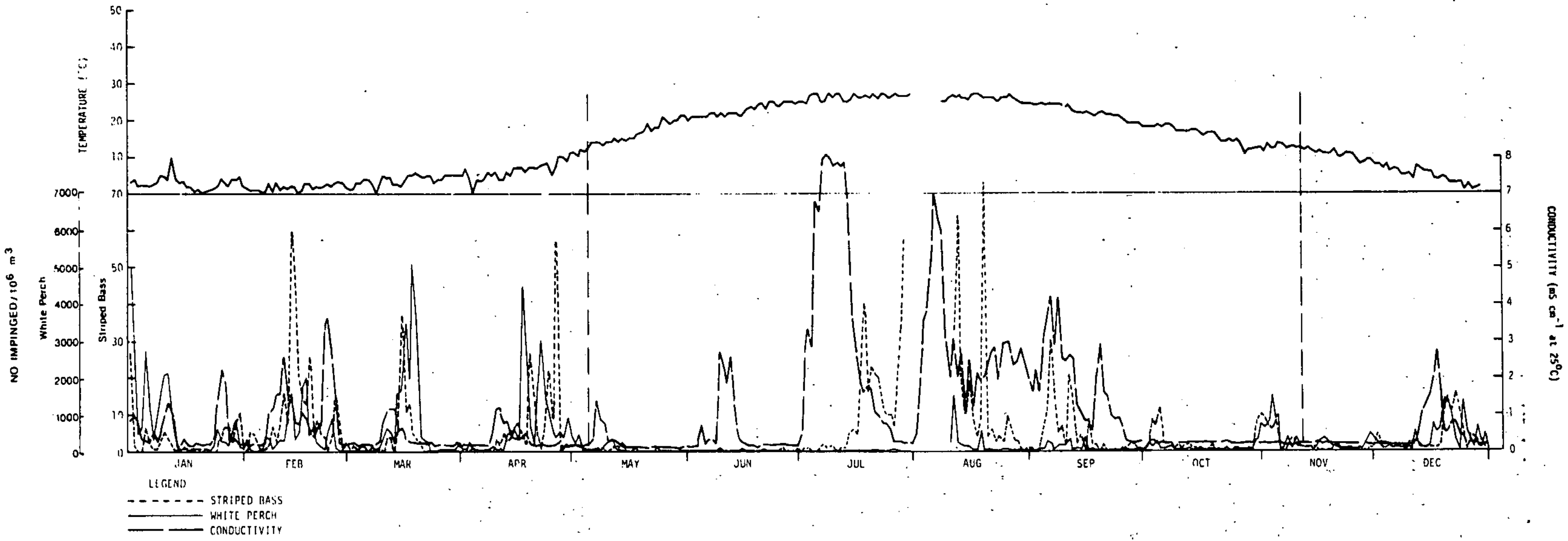

Figure 13.4-1 White Perch and Striped Bass Impingement at Indian Point Unit 2 during 1975 Graphed with Conductivity and Temperature Measured Daily at Unit 2 Intake. Vertical dashed lines indicate 12°C water temperature discussed in text in relationship to fish movement. White perch and striped bass plotted on different abundance scales.

The conductivity distribution near Indian Point follows a general seasonal pattern (Fig. 13.4-1). During the first half of the year, short-lived (2 to 15-day) salt intrusions into the Indian Point region occur regularly. A more extensive intrusion follows during summer, when relatively high conductivity conditions predominate; however, maximum salinity values rarely exceed 5 o/oo (8.7 mS cm^{-1} at $25^{o}C$). The extended summer intrusion ends in early fall when freshwater release into the estuary increases above the minimal summer levels. Salt water briefly surges into the region again during late fall.

The relationship between impingement and movement of the salt front parallels the longitudinal distribution of white perch collections in epibenthic sled and bottom trawl samples (Fig. 13.4-2 and 13.4-3). Peak catches of white perch occur at conductivities between 0.3 and 2.5 mS cm^{-1} (at $25^{o}C$). The river mile location of peak collections is displaced up or down river as the salt front moves up or down river. Whether changes in impingement and fisheries gear collections reflect changes in density or vulnerability to the respective gear has not yet been demonstrated.

13.4.3 PREDICTIVE MODELS FOR PHYSICAL VARIABLES. Based on the inference that impingement is in some way related to movement of the salt front and to seasonal temperature trends, the first step toward predicting Indian Point impingement is to develop accurate predictive models of these two factors.

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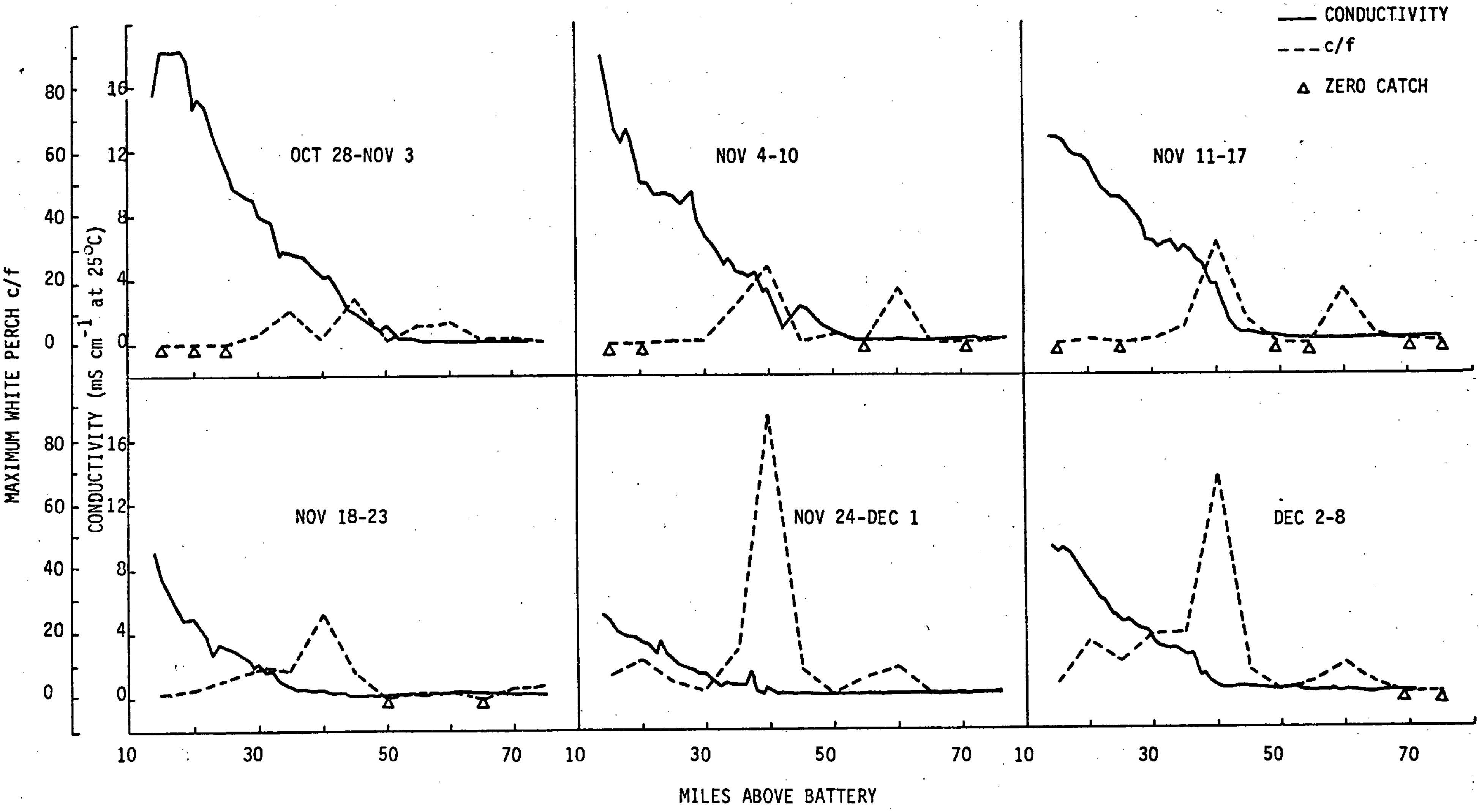

Figure 13.4-2 Longitudinal Distributions of White Perch Young-of-the-Year and Conductivity during Weekly Ichthyoplankton Sampling in 1974. (Catch values are maximum for indicated 5-RM [8-km] interval)

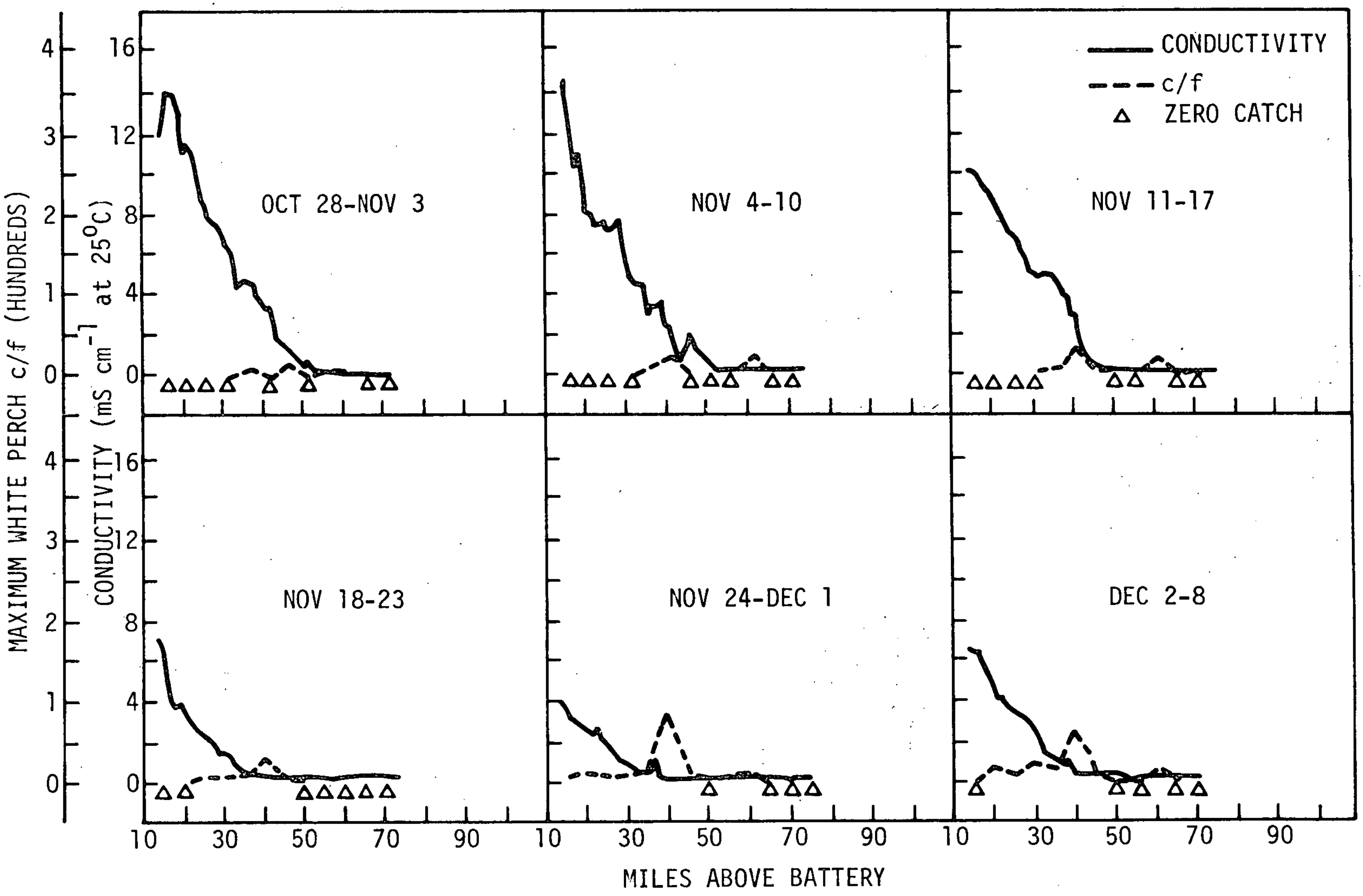

Figure 13.4-2 Longitudinal Distributions of White Perch Young-of-the-Year and Conductivity during Weekly Ichthyoplankton Sampling in 1974. (Catch values are maximum for indicated 5-RM [8-km] interval)

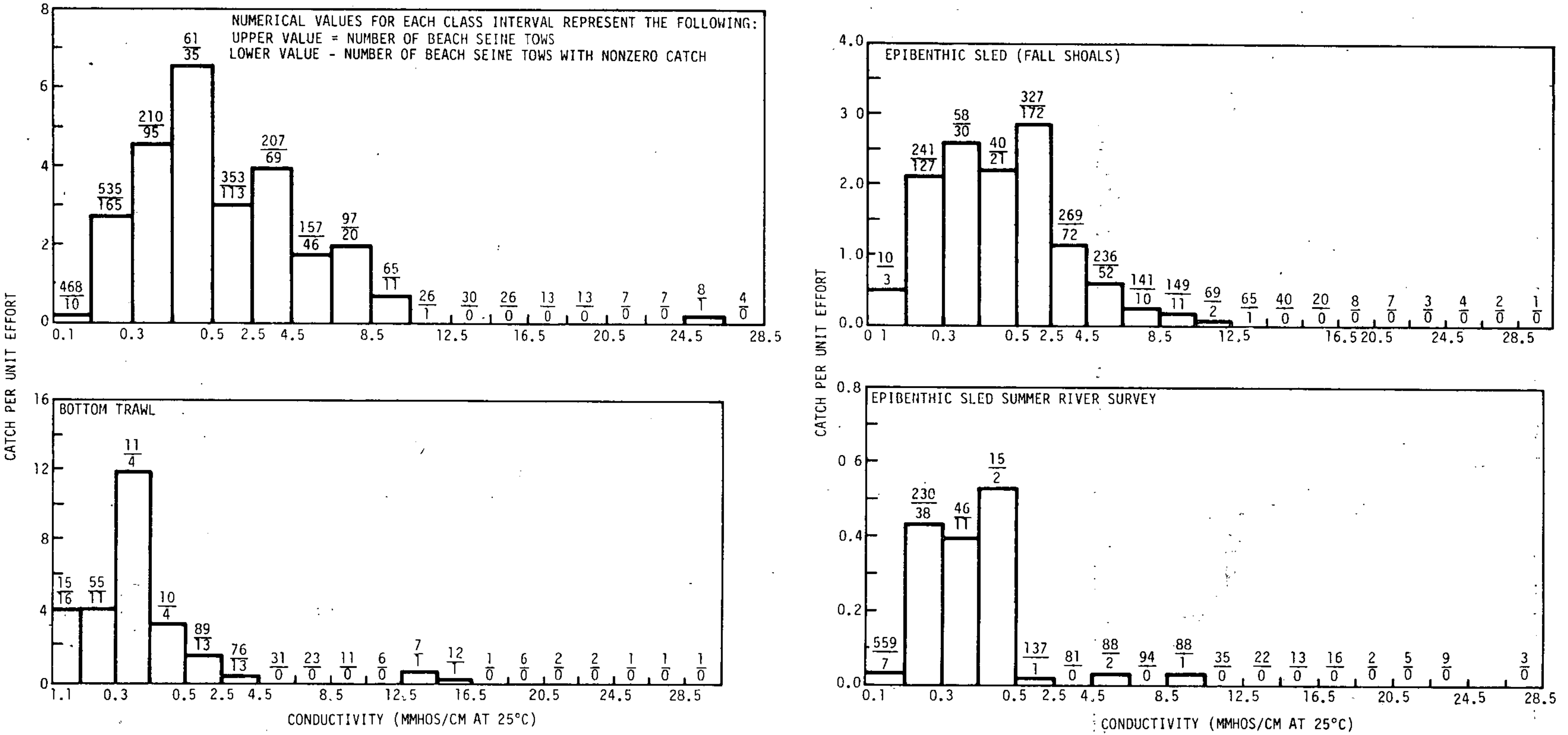

Figure 13.4-3 Relationship of Conductivity and Abundance of White Perch Juveniles Collected in Hudson River Estuary (RM 12-152; km 19-246) by Beach Seine (Top Left), Bottom Trawl (Bottom Left), and Epibenthic Sled (Right) during 1974

73
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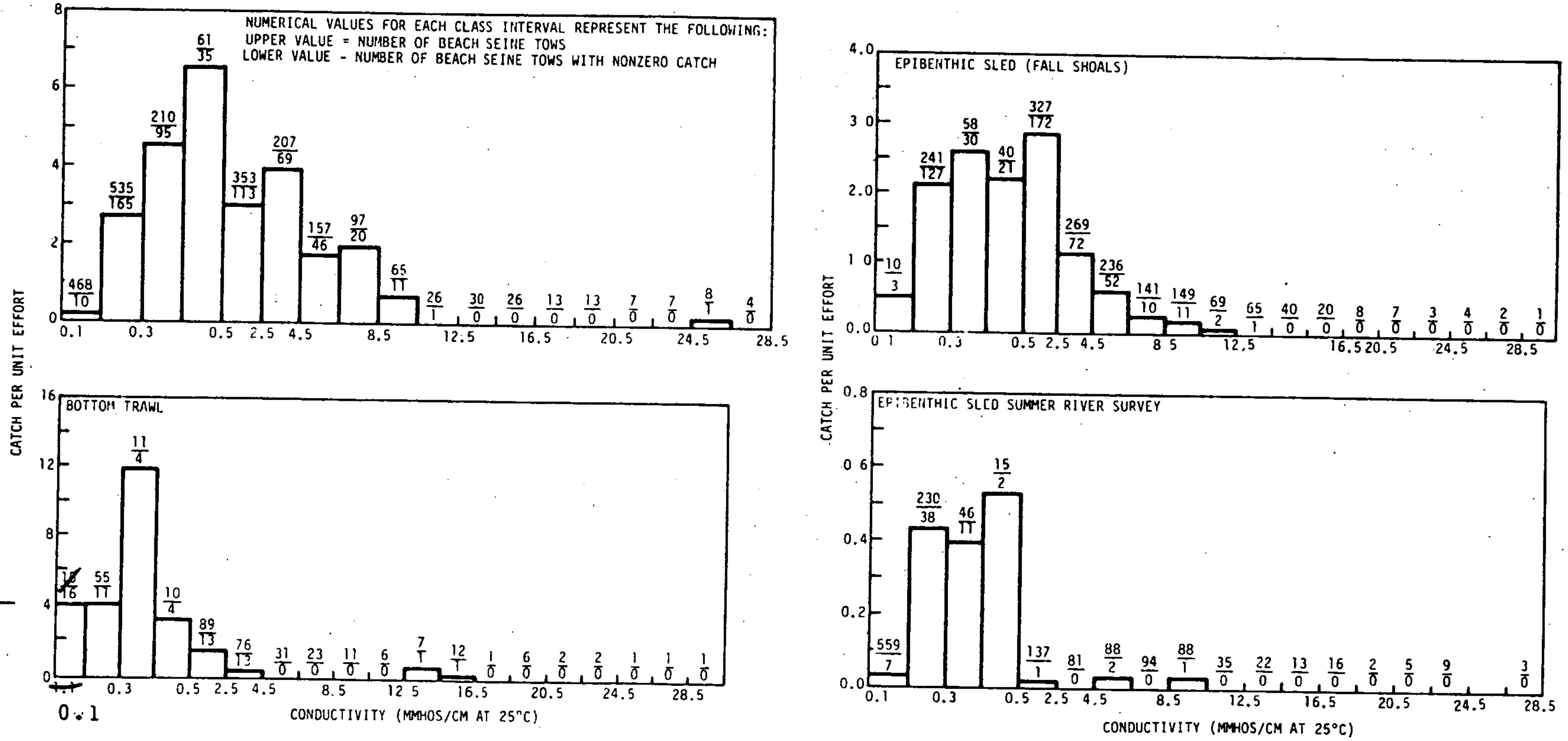

Figure 13.4-3 Relationship of Conductivity and Abundance of White Perch Juveniles Collected in Hudson River Estuary (RM 12-152; km 19-246) by Beach Seine (Top Left), Bottom Trawl (Bottom Left), and Epibenthic Sled (Right) during 1974

Of the physicochemical parameters routinely monitored in the vicinity of Indian Point, conductivity is the most variable on a daily and seasonal basis. Saltwater intrusion into the Indian Point region is controlled primarily by turbulent mixing in the estuary, a function of the interaction between freshwater flow and tidal movement. Between Battery Park (RM 0; km 0) and Albany (RM 140; km 224), there is a relatively constant bottom level, a condition conducive to gravitational influxes of denser seawater along the bottom of the estuary. Consequently, upstream salt migration is limited primarily by freshwater dilution, which is accentuated by tidal mixing.

Using freshwater flow, tidal amplitudes and observed salt front positions, a nonlinear equation was derived to estimate the distance of the salinity intrusion north of the Battery and to predict daily positions of the salt front. The mathematical relationships were examined by multiple regression, producing the equation:

$$M_s = -27.90 (\log_e U_5) + 12.56/A_4 + 219.04$$

where

M_s = intrusion distance of salt front (km above Battery Park) as position of 0.3 $\mathrm{mS/cm^{-1}}$ isopleth at midchannel

U_5 = freshwater discharge ($\mathrm{m^3\ s^{-1}}$) at Green Island 5 days before determination of salt front

A_4 = tidal amplitude (m) at Indian Point 4 days before determination of salt front; (mean difference between high and low tide for a specific day)

The observed values yielded a multiple regression coefficient of 0.9403. The 95% confidence interval for the estimated value of M_s at a tidal amplitude A_4 of 2.9 ft (88 cm) and a freshwater flow U_5 of 12,000 $\mathrm{ft^3 s^{-1}}$ (340 $\mathrm{m^3\ s^{-1}}$) was ±1.4 mi (2.2 km), which became ± 3.5 mi (5.6 km) when freshwater flow was increased to 50,000 $\mathrm{ft^3 s^{-1}}$ (1420 $\mathrm{m^3\ s^{-1}}$) and ± 5.7 mi (9.2 km) when flow was decreased to 1000 $\mathrm{ft^3 s^{-1}}$ (28 $\mathrm{m^3 s^{-1}}$).

During the 10 yr from 1965 through 1974, 80% of the observed salt front locations were within 5 mi (8 km) or 3 days of the calculated values using this equation. The majority of the observed deviations from calcualted values represented the influence of elevated bottom structure across the channel (sills) near Verplanck Point (RM 41; km 66) and Storm King Mountain (RM 56; km 90), which serve to delay salt intrusion until tidal amplitude decreases to a level that allows the saltwater-freshwater interface to pass the areas of high turbulence created by these sills.

Lag times incorporated in the equation were determined by comparing correlation coefficients of observed vs predicted values for 3-, 4- and 5-day tidal amplitude lags and 4- and 5-day flow lags. These lags reflect the fact that an observed salt front position is the result of conditions occurring during some previous time interval. The 5-day lag applied to Green Island (RM 152; km 243) discharge and the 4-day lag applied to tidal amplitude provided the best fit to the observed data.

Temporal variation in temperature was described mathematically using midwater temperature data collected from 1972 through 1974 near Indian Point in areas outside the influence of the thermal plume. The data suggest that two primary factors are related to changes in temperature through time. The annual cycle of river temperature is closely related to seasonal changes in air temperature and can be defined by a simple harmonic curve. Also, sudden fluctuations from such a pattern appear to be due to changes in freshwater flow. Freshwater surges in the watershed from rainfall or snowmelt depress temperatures downriver from the water source.

Using multiple linear regression that incorporated terms for freshwater release at Green Island and cosine-transformed time, the temporal change in temperature near Indian Point was described by

$$T_c = 11.89971 \cos \left(\frac{2\pi}{365.25} t_i\right) - 0.04625\ \bar{U}_5 + 13.29842$$

T_c = river temperature (^{o}C) at Indian Point

$\bar{U}$ = 5-day mean freshwater discharge (10^3 $ft^3 s^{-1}$)
at Green Island centered 5 days prior to t_i

t_i = time (days) of projected temperature measured from
t (August 6 of any year)

The multiple regression coefficient for observed values was 0.9885. Daily temperatures for 1966 through 1973 were calculated with this equation and the results compared with USGS data collected for those years near Jones Point (RM 44; km 71). Points were similar at temperatures above $5^{o}C$; below $5^{o}C$, however, the near-surface water temperatures provided by the USGS tended to be lower than the calculated values, apparently in response to the influence of lower air temperature and decreased density of water colder than $4^{o}C$.

These two equations provide very close predictions of actual variation in conductivity and temperature; however, unusual meteorological occurrences can cause significant deviation from predicted values. During 1975, the characteristic summer intrusion period began in late June but was abruptly terminated in mid-July by high levels of local rainfall not reflected in freshwater flow data at Green Island. After local high flows dissipated, there was a rapid reinvasion of saline water into the area and a second extended intrusion period that was unique compared to those of prior years because it lasted only until late September; heavy local rainfall and high freshwater releases at Green Island during late September caused the early retreat of the saline water from the Indian Point region.

13.4.4 FISH DISTRIBUTION FUNCTION. The third variable required for the capability of predicting impingement magnitude is probability function that defines fish distribution in relationship to the salt front and vertical and lateral movement in relation to seasonal temperature (Sections 7.5 and 7.6). It may be necessary for this function to account for seasonal abundance and distribution of white perch in and around the salt front and vulnerability of white perch to capture or impingement near the salt front. An appropriate term to proceed from sample catch per effort to a probability distribution based on abundance has not been developed at this time. Some potential terms that can be investigated are "regional" maximum catch per sample, percent of non-zero catches, and percent of the combined catch for the total series of river samples.

13.4.5 CONCLUSION. By using the two mathematical models described in this section, the time of major white perch impingement peaks can be predicted to within a few days of their occurrence. This capability is based on patterns of white perch impingement but might be applied also to striped bass impingement; the distribution of striped bass impingement at Indian Point is similar to that of white perch (Fig. 13.4-1), although two orders of magnitude lower.

During late fall, winter, and spring, the salt front moves through the Indian Point region with predictable regularity. Major peaks in white perch and striped bass impingement also occur during this period. Because movement of the salt front past Indian Point and fish location are the key variables, the ability to predict the movement of the salt front and associated impingement is limited to that period.

While the timing of impingement peaks can be predicted, their magnitude cannot--and the prospect of developing this latter capability is remote at this time because of weekly, seasonal, and annual variations in abundance and distribution of fish. For rapid short-term (on the order of days) monitoring of microdistribution of fish, there is no available or foreseeable system as there is for such physical factors as conductivity, freshwater flow, temperature, and tidal amplitude.

SECTION 14

EVALUATION OF POWER PLANT IMPACT ON OTHER FISH SPECIES

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SECTION 14

EVALUATION OF POWER PLANT IMPACT ON OTHER FISH SPECIES

14.1 INTRODUCTION

In addition to striped bass, several other fish species in the Hudson River estuary may be affected by power plant operations via entrainment and impingement. This group includes estuarine and anadromous species (see section 5.2). The following species are considered: white perch (*Morone americana*), Atlantic tomcod (*Microgadus tomcod*), American shad (*Alosa sapidissima*), other members of the herring group such as Blueback herring (*Alosa aestivalis*), and the shortnose sturgeon (*Acipenser brevirostrum*).

The available data sets for each species are somewhat different, so the level of treatment varies from species to species; however, the overall objective is to determine whether any substantial impact due to operation of power plants is likely to accrue to these populations. Impact is investigated by examining what is known about the population dynamics of these species and the levels of plant-induced mortality to which they are subjected.

14.2 POPULATION STATISTICS OF IMPACT ESTIMATION

Estimating plant impact on the above species followed the same procedures outlined for striped bass (section 11.2) with one exception: the values for α in these less studied species were not determined empirically but were chosen from among the curves presented by Ricker (1975:286) based on what is known about related species. Conservative (i.e., lower) values for α were chosen to avoid overestimating the capacity of the fish stocks to absorb impact without serious decline. Thus, the α value for tomcod is 4.482, when gadoids are known to be strongly regulated by density-dependent factors (Cushing and Harris 1973;

Lett and Doubleday 1976; Garrod 1967), and the α value for white perch is 3.490, which is less than the estimated compensatory capacity of the congeneric species, striped bass (section 10.6). For the clupeids such as shad, which generally are less regulated by density-dependent processes (Cushing and Harris 1973), the α value is set at a very low 1.948.

14.3 WHITE PERCH

14.3.1 POPULATION DYNAMICS. The white perch (*Morone americana*), a close relative of the anadromous striped bass (*Morone saxatilis*), is an abundant life-long resident of the Hudson River estuary. Adult populations of several million individuals exist throughout the year, spawning billions of eggs in the spring. Peak standing crop estimates per river run during 1974 were 1.2×10^8 eggs, 8.5×10^7 yolk-sac larvae, and 3.8×10^8 post yolk-sac larvae; during 1975, 4.8×10^8 eggs, 1.9×10^8 yolk-sac larvae, and 1.4×10^9 post yolk-sac larvae. The high peak in post yolk-sac larvae standing crop reflects the longer duration of this life stage compared with eggs and yolk-sac larvae. Since these are only weekly standing crop estimates, not estimates of the number passing through a life stage during a season, they give a more or less instantaneous look at the number of animals existing in a given life stage at a particular time.

A Petersen estimate of the 1975 population of juveniles present in August and September was 111×10^6, with a 95% confidence interval of 72×10^6 to 180×10^6. Based on the yearly variations in relative abundance measured by beach-seine catch per unit effort, equivalent population sizes would have been 27×10^6 in 1974 and 154×10^6 in 1973.

Some of the variation in year-class strength is reflected in yearly changes in age composition. Most of the population comprises young-of-the-year fish during the fall (Fig. 14.3-1); this is true for any

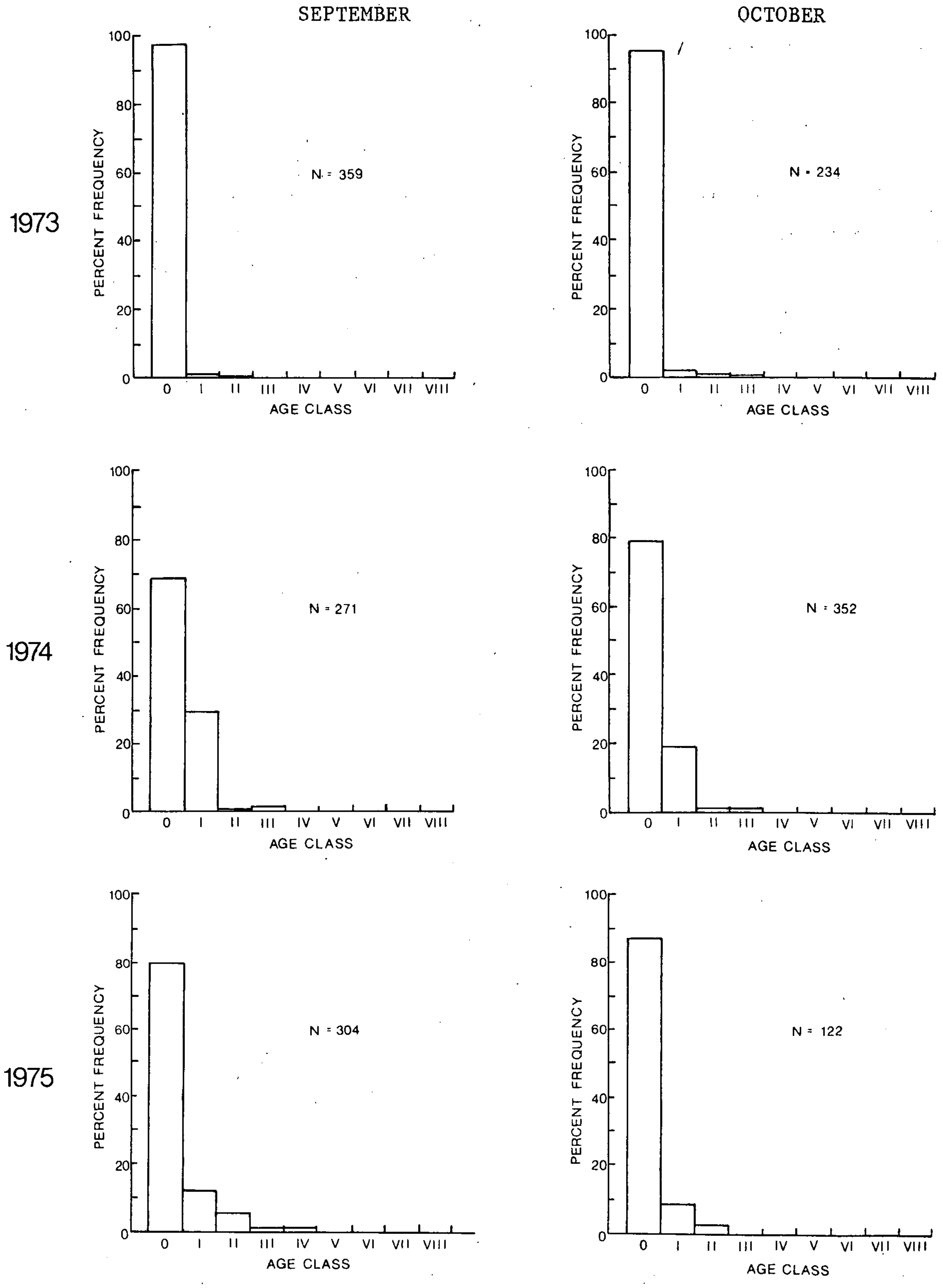

Figure 14.3-1 Age Composition of White Perch Sampled by Beach Seine in Indian Point Area. (N refers to number aged by annulus method)

month after spawning takes place. From 1965 through 1975 (excluding 1971), strong year classes were produced in 1965, 1967, 1969, 1973, and 1975 and weak year classes in 1972 and 1974.

Mortality causes the staircase appearance of the age-composition histrograms in Figure 14.3-1. To assess mortality, the age composition in October 1973 was analyzed (TI 1974a) yielding an estimated annual mortality of 0.65 between ages I and IV (Fig. 14.3-2). White perch mortality during the first year of life is likely to be similar to striped bass mortality (section 7.7), i.e., 0.999 for eggs and larvae and ≥ 0.80 for juveniles and yearlings.

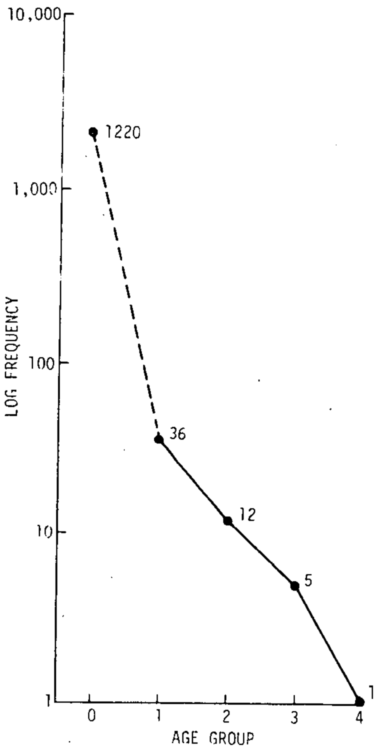

Figure 14.3-2 Catch Curve of White Perch Based on Frequency of Occurrence of 1969 Year Classes in October 1973 Beach Seine Samples

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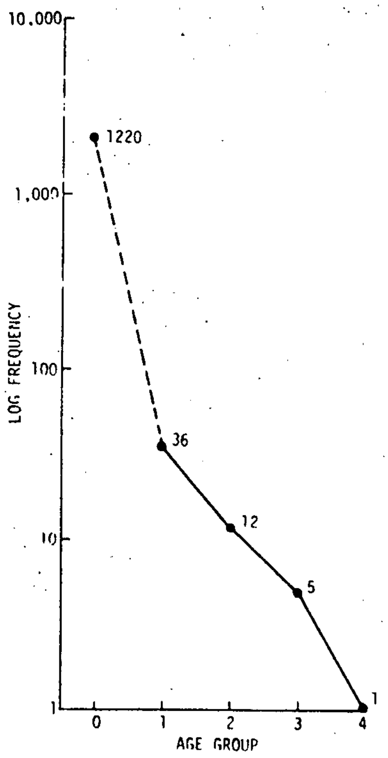

Figure 14.3-2 Catch Curve of White Perch Based on Frequency of Occurrence of 1969-1973 Year Classes in October 1973 Beach Seine Samples in Indian Point Area of the Hudson River Estuary

Examination of nine cohorts (year classes) of white perch revealed seasonal growth patterns (Fig. 14.3-3). Growth occurs in spring, summer, and autumn, with growth generally being most rapid between June and September. In late autumn and in winter, there is little or no growth, a condition typical of most temperate fish species. The result of these seasonal growth patterns is the appearance of distinct annual periods of slow and rapid growth on scales (annuli), which can be used to determine age. The maximum age observed in Hudson River white perch is 11 yr.

Compared with striped bass, white perch mature earlier and produce fewer eggs per individual. Both males and females first mature at age II; 100% of 4-yr-old males and 5-yr-old females are mature. The average number of eggs per female ranges from 19,000 for 2-yr olds to 54,000 for 6-yr-olds. The eggs themselves adhere to the bottom in the shoal areas where they are deposited and thus are not very vulnerable to most sampling gear. Hence, entrainment of large numbers of white perch eggs is not likely.

The white perch has been an abundant member of the fish community at least since the early years of this century and has always been of some commercial value; now, however, it is primarily a panfish serving the interests of some of the sport fishermen in the Hudson. Some commercial fishermen have even made an attempt in recent years to avoid white perch (personal communication with Bob Gabrielson, commercial fisherman), since it is of little commercial value and is considered a nuisance in the operation of commercial gill nets.

14.3.2 IMPACT ASSESSMENT. Entrainment mortality rates estimated for the 1974 and 1975 year classes of white perch generally indicated little susceptibility of white perch eggs and larvae to entrainment at Hudson River power plants. Conditional mortality rates due to entrainment in 1974 were .0355 at Indian Point Unit 2, and .0551 for the multiplant case.

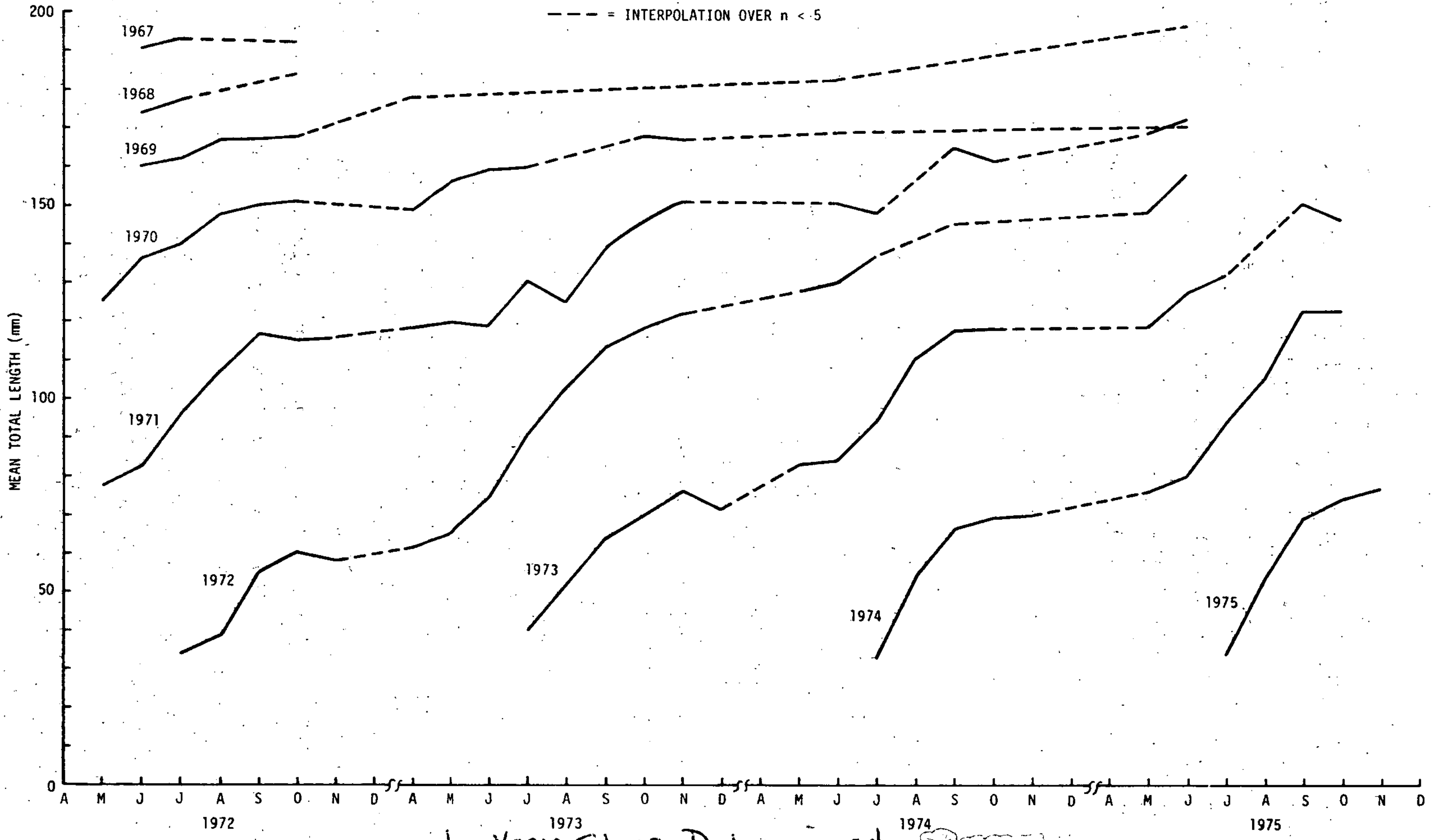

Figure 14.3-3 Growth of White Perch by Year Class, Determined ~~1972-75, Determined~~ from Beach-Seine Samples Collected in Indian Point Region, 1972-75

The 1975 rates were .0301 at Indian Point Unit 2 and .0632 for the multiplant case. Using a natural mortality of 0.999 and an α value of 3.49, these rates reduce equilibrium stock size as follows:

Year Class	Indian Point Unit 2	Multiplant
1974	0.4%	0.7%
1975	0.4%	0.8%

Impingement impact for the 1974 year class was estimated assuming that 90% of the July 1974-June 1975 impingement consisted of the 1974 year class. Exploitation of this year class was calculated to be 5.1% at Indian Point Unit 2 and 6.8% for the multiplant case. Equivalent levels of reduction in equilibrium stock size based on $\alpha = 3.49$ were 4.2% due to Indian Point Unit 2 and 5.6% for multiplant. The expected reduction in equilibrium stock size due to the combined operation of entrainment and impingement on the 1974 year class was higher than for any other species studied but nevertheless, not very great: estimates were 4.6% for Indian Point Unit 2 and 6.3% for multiplant.

14.4 ATLANTIC TOMCOD

14.4.1 POPULATION DYNAMICS. The Atlantic tomcod (*Microgadus tomcod*) is an abundant estuarine species that utilizes the Hudson River as a spawning and nursery area. The winter spawning population consists of several million individuals (Table 14.4-1), which produce approximately 10 billion eggs. The 1974 standing crop estimates of juveniles ranged from 1.2×10^9 in early May to 2.47×10^6 in December. Almost the entire spawning population (>99%) comprises fish in their first year of life; this is evident from the unimodal length frequency diagrams (Fig. 14.4-1) of the December 1973, 1974, and 1975 populations. This age composition was verified by examining either scales or otoliths. Such an age composition is indicative of a very high mortality rate in the second year of life, which is not surprising considering that the

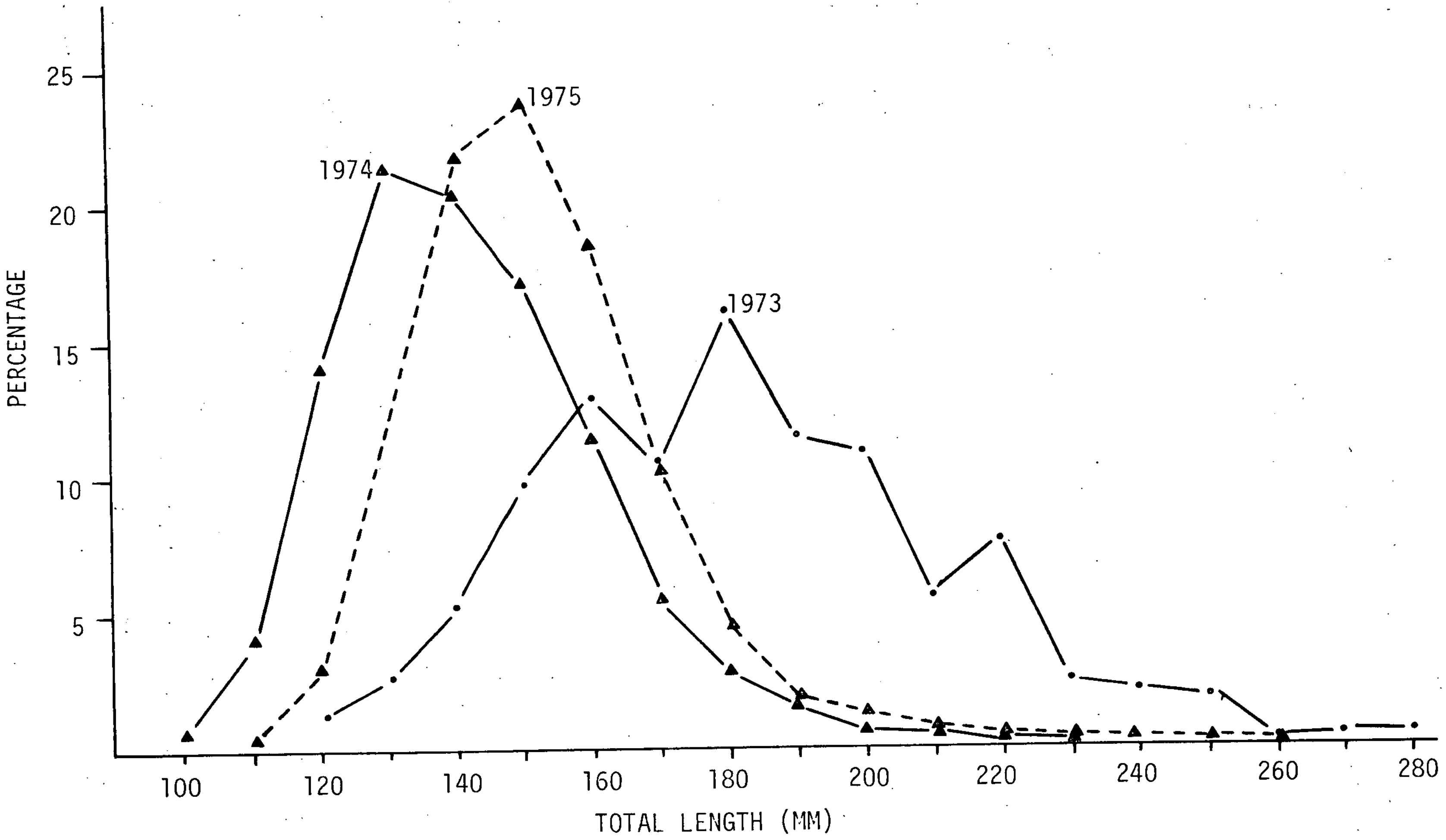

Figure 14.4-1 Length Frequency of December 1973, 1974, and 1975 Atlantic Tomcod in Hudson River

Table 14.4-1 Petersen Population Estimates of Atlantic Tomcod Spawning Populations in Hudson River

Year	Population Size	95% Confidence Interval
1973-74	~~2.234×10^6~~ 2.100×10^6	~~1.284×10^6~~ - ~~8.588×10^6~~ 1.207×10^6 - 8.074×10^6
1974-75	2.470×10^6	1.690×10^6 - 4.587×10^6

estimated annual mortality rate for the first year of life is 99.98% (Fig. 14.4-2).

Seasonal growth patterns for the 1974 and 1975 year classes (Fig. 14.4-3) indicated a completely different picture from that seen for white perch and striped bass. Atlantic tomcod grow most rapidly during the colder months, considerably slower during summer. The period of slow growth produces distinct annual marks on both scales and otoliths. The maximum age observed in Hudson River Atlantic tomcod is 2 yr.

Annual production of young-of-the-year Atlantic tomcod (Fig. 14.4-4) was estimated with the Allen curve method to be 1200 metric tons (approximately 40 kg ha^{-1}). Productivity (defined here as the rate of accumulation of fish flesh in the population through growth of individuals and including the production by those fish which die during the year) was highest during early spring.

Atlantic tomcod males and females mature during the first year of life, with gonad development beginning at an age of about 9 mo. Average fecundity has varied from 20,000 in the 1973-74 spawning season to 12,000 in the 1974-75 spawning season. The reasons for this variation are changes in both the relationship between length and fecundity (Fig. 14.4-5) and changes in length frequency (Fig. 14.4-1) between years.

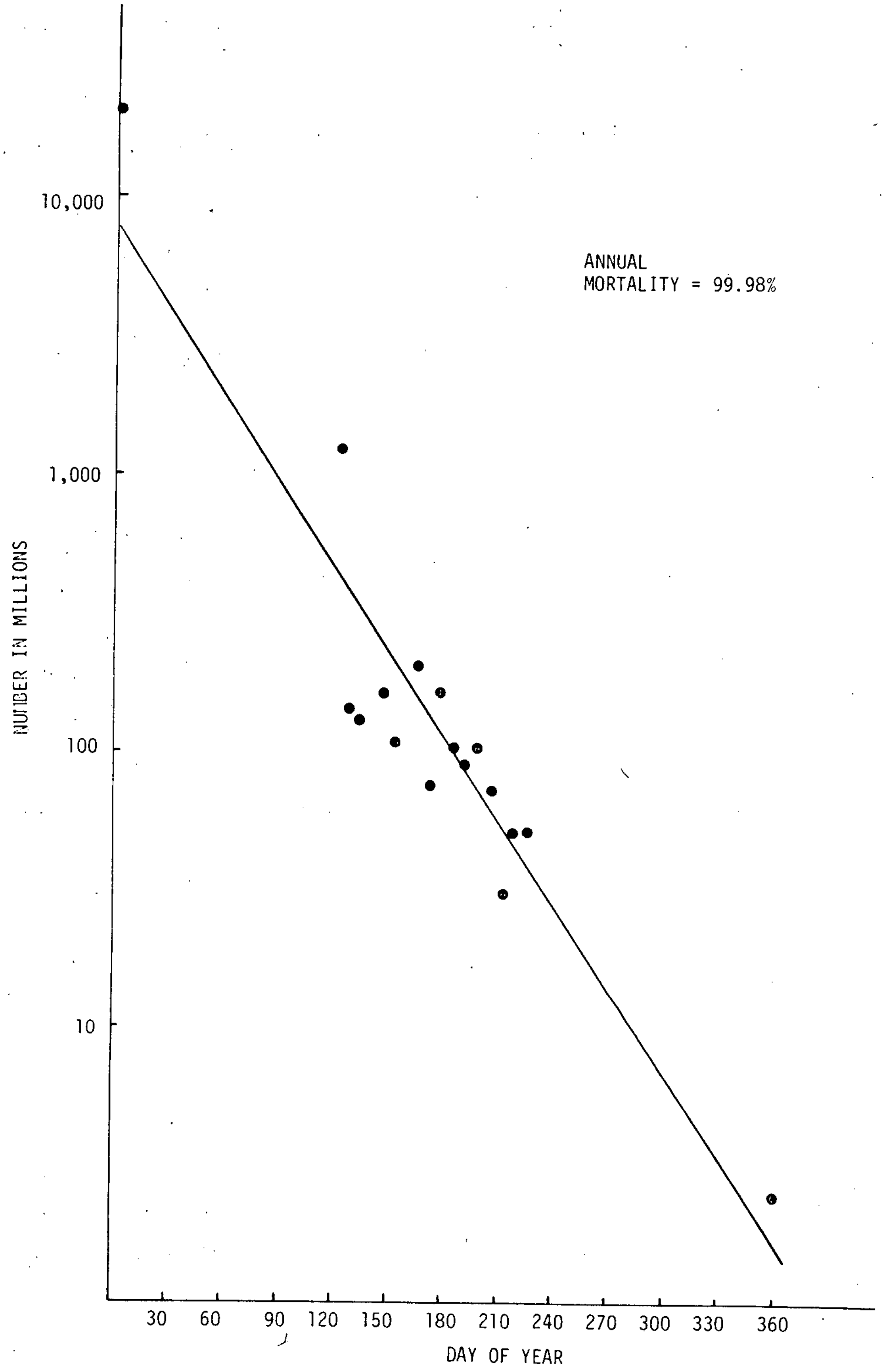

Figure 14.4-2 Survivorship Curve for Atlantic Tomcod in Hudson River, 1974. Data Points Were Derived from Mark-Recapture Estimates, Sex Ratio, Fecundity and Ichthyoplankton Densities.

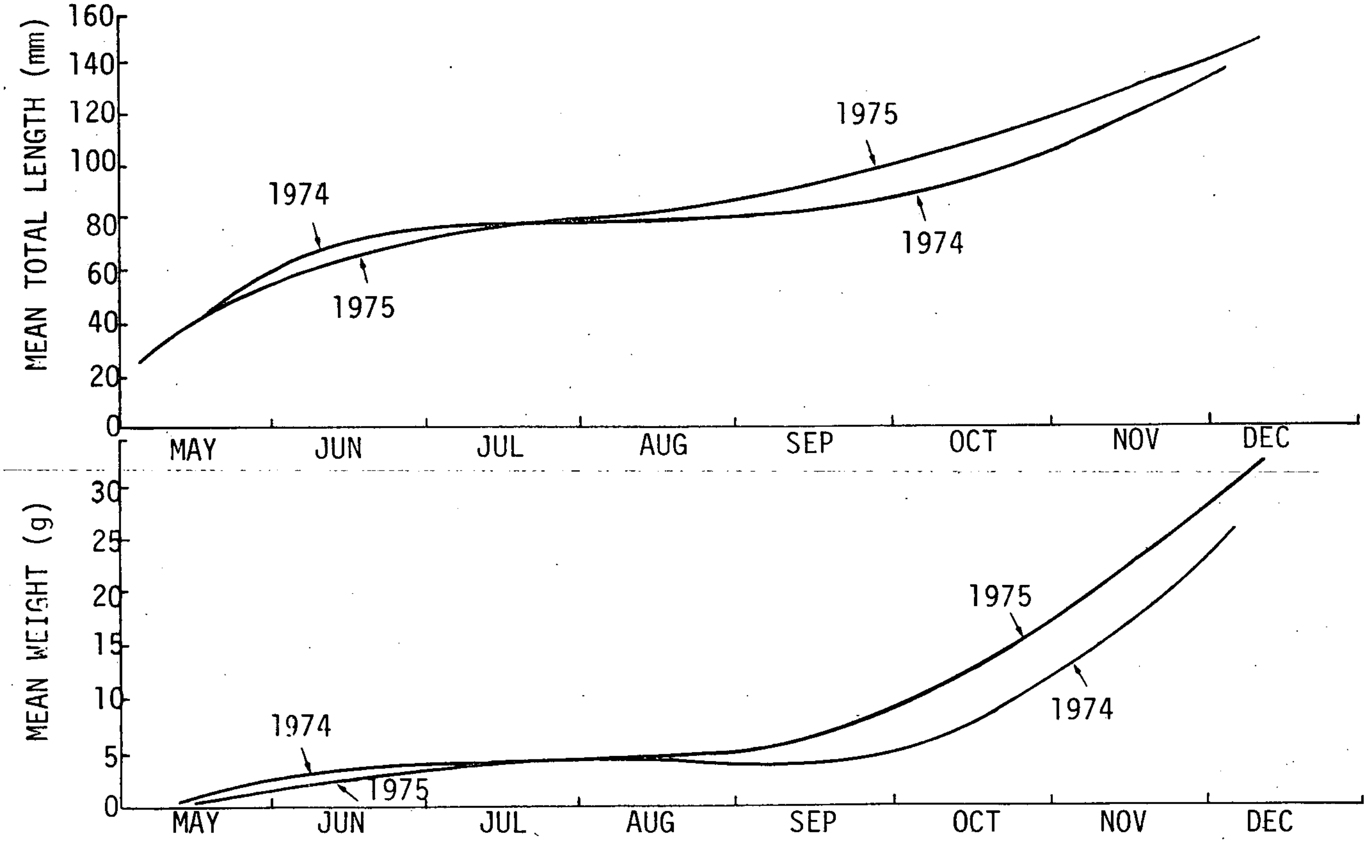

Figure 14.4-3 Growth of Atlantic Tomcod in Hudson River

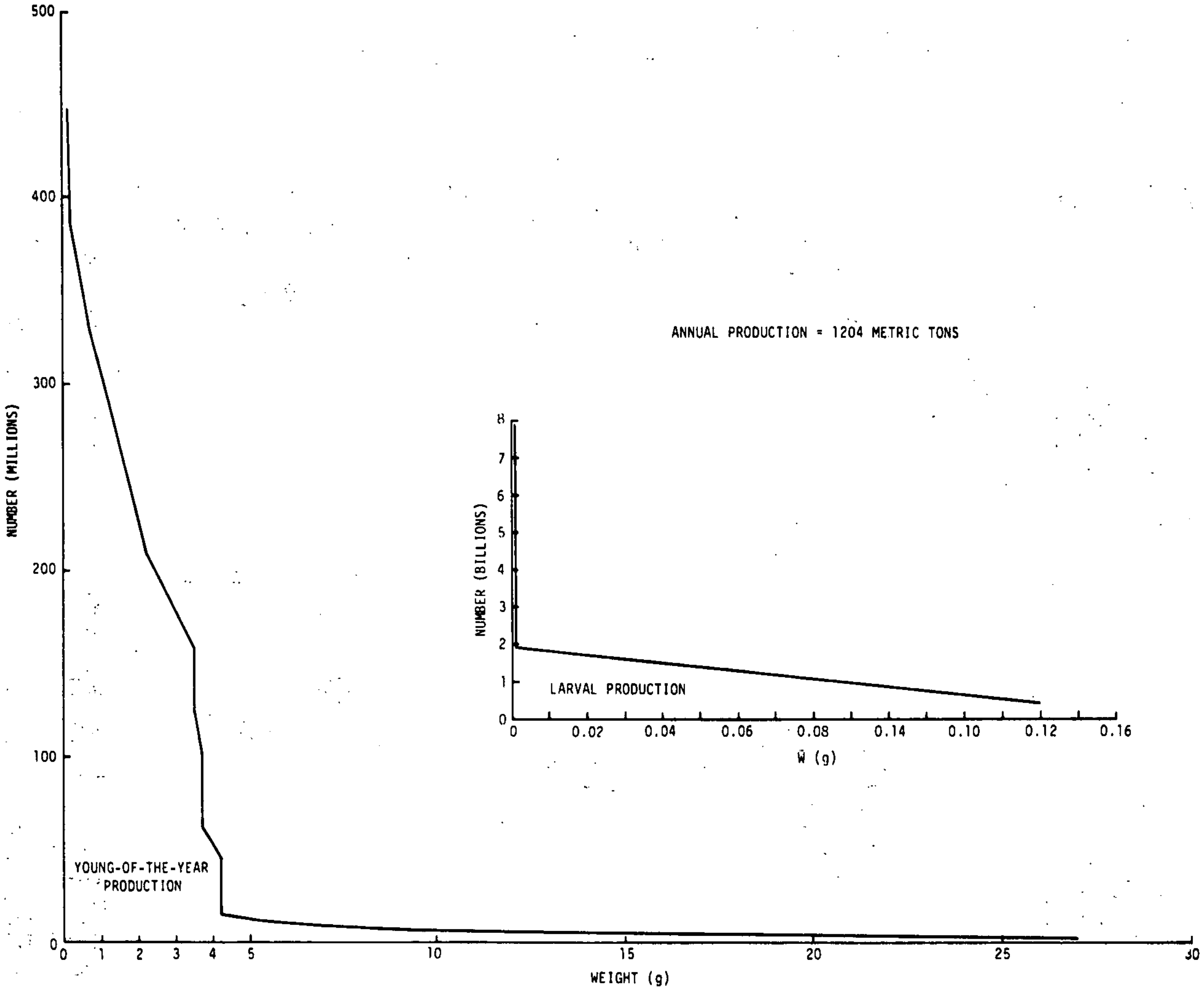

Figure 14.4-4 1974 Production of Hudson River Atlantic Tomcod Estimated with Allen Curve

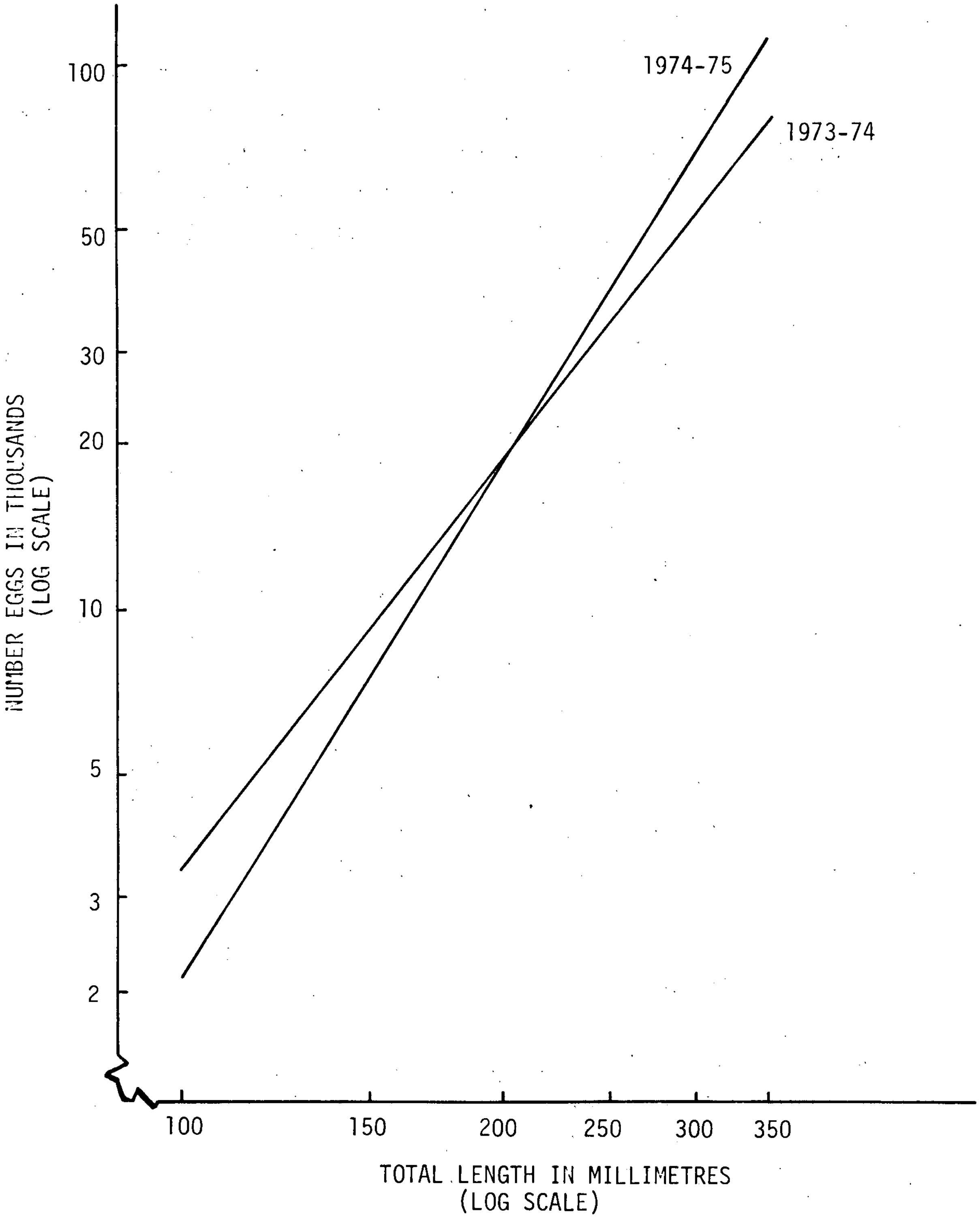

Figure 14.4-5 Hudson River Atlantic Tomcod Fecundity Related to Length

The history of the Atlantic tomcod stock in the Hudson River is not well-known since there are few records on this fishery. Both the sport and commercial fisheries are winter fisheries conducted when ice floe is generally heavy. The fish taken are usually small (almost always < 305 mm). Changes in the vital statistics of this stock over the years have not been documented.

14.4.2 IMPACT ASSESSMENT. Because poor weather and water conditions preclude sampling during and after the Atlantic tomcod spawning season, there are no adequate estimates of egg or larval densities with which to estimate entrainment impact for 1974. However, it is unlikely that the egg stage, which lasts 30 to 40 days, would be susceptible to entrainment since the eggs are adhesive and demersal. Yolk-sac and post-yolk sac larvae may be subjected somewhat to entrainment as they move toward lower river areas such as Tappan Zee, but assessment of Atlantic tomcod entrainment is not possible for 1974.

In 1975, Atlantic tomcod entrainment was estimated for the period of March 9-May 17. Conditional mortality rates due to entrainment in this time interval were estimated to be 0.0079 for Indian Point Unit 2 and 0.0403 for the multiplant case. Applying the equilibrium displacement equation (Equation 11.4) to these estimates yielded a reduction in stock size of 0.59% for the multiplant case assuming a natural mortality rate of 0.99.

At the beginning of the juvenile stage in early May, Atlantic tomcod become increasingly susceptible to impingement. Since concurrent estimates of impingement and population size are available, it is possible to estimate the effects of impingement on the tomcod population. Based on the regression in Figure 14.4-2, the population size on 1 May 1974 was 4.7×10^8. Atlantic tomcod impingement estimates for the multiplant case and Indian Point Unit 2 were 1.996×10^6 and 1.939×10^6 respectively. Thus, the exploitation rate for Indian Point Unit 2 was 0.42%, and the rate for the multiplant case was 0.43%. Applying the equilibrium displacement equation to these rates of exploitation yielded negligible reduction in equilibrium stock size, i.e., 0.28% for Indian Point Unit 2 and 0.29% for the multiplant case.

Data compilation for estimating the 1975 impingement impact on Atlantic tomcod has not been completed; therefore, the combined impact of entrainment and impingement on the 1975 year class cannot be estimated. However, by using the 1975 entrainment impact (0.6%), one can see that the combined reduction in stock size as a result of entrainment and impingement should be on the order of 1%.

14.5 AMERICAN SHAD

14.5.1 POPULATION DYNAMICS. The American shad (*Alosa sapidissima*) is an important anadromous fish that utilizes the Hudson as a spawning and nursery area. Spawning occurs over an extended period (April-June) in areas upriver from most power plants. Standing crops of eggs peak in late May. Residence time in the estuary is relatively brief, with most young shad leaving the river during November or December of their first year of life. Peak standing crop estimates in 1974 were 8.5×10^7 eggs, 6.5×10^6 yolk-sac larvae, and 8.3×10^7 post yolk-sac larvae. Again, these are only weekly standing crop estimates, not estimates of the number passing through a life stage throughout a season; thus, they give a more or less instantaneous look at the number of animals existing in a given life stage at a particular time.

During 1965-75 (excluding 1971), beach seine catch data indicated exceptionally large American shad year classes in 1973, 1974, and 1975. At least since the early years of this century, American shad spawner abundance in the Hudson River has shown rather large fluctuations; both Talbot (1954) and Burdick (1954) have attributed much of this variation to the amount of escapement allowed by fishery regulations, i.e., the

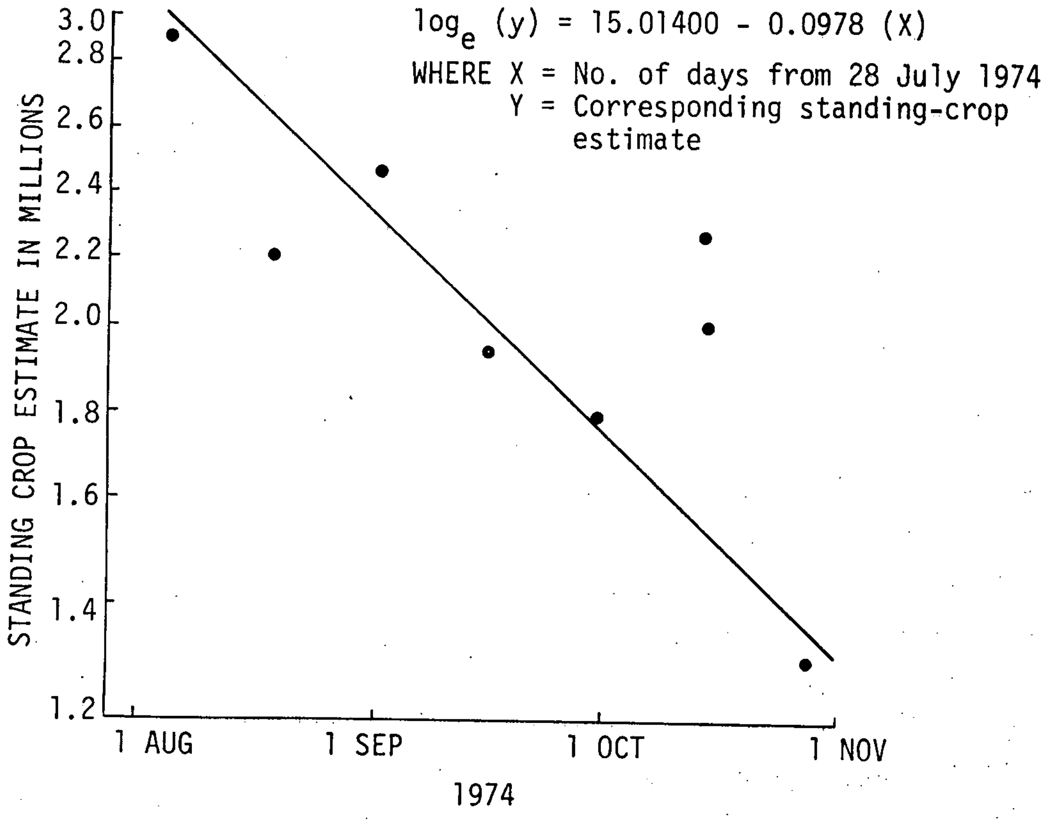

Figure 14.5-1 Juvenile American Shad Standing Crop Estimates Based on Daytime Beach Seine Catch per Unit Area Vs Time from July 28 through November 2, 1974

amount of time in which fishermen may not set their nets (net lift periods). How this relates to the strong year classes in recent years is not clear since the net lift periods have not changed and, from 1973 through 1975, fishing effort actually increased.

Based on beach seine catches, annual mortality of American shad juveniles was estimated to be 0.835 (Fig. 14.5-1). These same data were used to estimate minimum initial population size for assessing impingement impact: these estimates, which represented only the portion of the population in the shore zone, were 4.7×10^6 in 1973 and 1.8×10^6 in 1974. These minimal estimates tend to cause an overestimate of exploitation due to impingement but, as will be seen later, this is of little consequence since impingement of shad produces very low estimates of exploitation, even using these underestimates of population size. American shad are simply not very vulnerable to the existing power plants in the Hudson River.

14.5.2 IMPACT ASSESSMENT. Conditional entrainment mortality rates estimated for the 1974 year class of American shad using the methods described in Section 14.2 were 0.0117 for Indian Point Unit 2 and 0.0160 for multiplant. Applying the equilibrium displacement equation (Equation 11.4) using a natural mortality rate of 0.99 and a conservative α value of 1.948 yielded reductions in equilibrium stock size of <1% for all cases: reduction levels were 0.4% for Indian Point Unit 2 and 0.5% for multiplant.

Exploitation rates due to impingement impact were calculated from impingement sampling data at the major power plant complexes on the river for the 1973 and 1974 year classes of American shad and found to be respectively 0.002% and 0.29% for Indian Point Unit 2 and 0.015% and 0.58% for the multiplant case. Reductions in equilibrium stock size based on 1974 impingement were 0.4% at Indian Point Unit 2 and 0.9% for Multiplant. By summing the reductions caused by entrainment and impingement, the combined impact on equilibrium stock size from 1974 entrainment and impingement was estimated to be 0.8% for Indian Point Unit 2 and 1.4% for multiplant.

Such inconsequential reduction in the American shad stock size due to power plant operation should be expected since American shad are not very vulnerable to the power plants in the Hudson River (section 6.3).

14.6 BLUEBACK HERRING.

14.6.1 POPULATION DYNAMICS. The life history of blueback herring is similar to that of American shad: adults return from the sea to spawn during May in the upper estuary above the power plants; the young tend to remain in that region (section 6.3.4) through early August when downstream movement begins and, after mid-July are found primarily in the shorezone where there is little vulnerability to power plants; migration to the ocean is evident by late October or early November.

The population dynamics of blueback herring (*Alosa aestivalis*) have not been studied in detail for the Hudson River population. However, the blueback herring is known to be an extremely abundant species in the Hudson River. Since separation of blueback herring from the congeneric alewife (*Alosa pseudoharengus*) is extremely difficult during early life stages (Dovel 1971:4), actual estimates of mortality for these species during the first complete year of life are not possible at this time. However, since the life histories of the American shad and blueback herring are so similar, it is likely that the mortality rate for juvenile blueback herring is similar to that estimated for American shad.

14.6.2 IMPACT ASSESSMENT. Entrainment of blueback herring is not likely to cause any substantial impact on the blueback herring population because of the upriver location of most eggs, larvae, and early juveniles. Impingement occurs primarily in the fall during the juveniles' seaward migration. Following the vulnerability analogy with American shad (section 6.3), impingement impact on blueback herring can also be expected to be very low. At this time, not all data necessary for estimating impact on blueback herring have been compiled but, through vulnerability analysis and comparison with American shad (sections 6.3 and 14.5), entrainment impact almost certainly is nonexistent and impingement impact very low.

14.7 SHORTNOSE STURGEON

14.7.1 POPULATION DYNAMICS. The shortnose sturgeon (*Acipenser brevirostrum*) has been classified as endangered by the Endangered Species Act of 1973, P.L. 93-205, but it is an uncommon resident of the Hudson River estuary so knowledge of its population dynamics is relatively limited. Currently, the Boyce Thompson Institute is studying the Atlantic sturgeon and shortnose sturgeon; however, at the time of this writing, data on the vital statistics of these two populations are not available (personal communication with William Dovel, Boyce Thompson Institute).

14.7.2 IMPACT ASSESSMENT. Without estimates of population size, mortality, etc., numerical estimates of power plant impact on the shortnose sturgeon cannot be made. Further hampering estimation of entrainment impact on shortnose sturgeon is the inability to distinguish the eggs and larvae of the two sturgeon species.

While impingement impact cannot be estimated directly because of a lack of information on population size, some idea of the magnitude of the impingement is available from counts of shortnose sturgeon impinged.

Total counts are available for 1972, 1973, 1974, and 1975 at Indian Point (at all other plants, counts are not made daily) and were as follows:

Year	No. Impinged
1972	4
1973	2
1974	4
1975	1

These low numbers reflect either the low abundance of shortnose sturgeon in the river or a low vulnerability to impingement. Currently, ~~although~~ there is no adequate data base on which to construct any estimates of power plant impact,however, their exposure is expected to be low because of the demersal character of the species.

14.8 SUMMARY

Important fish species occurring in the Hudson River other than striped bass were studied to ascertain levels of impact that may accrue from power plant operations. White perch, Atlantic tomcod, American shad, blueback herring, and shortnose sturgeon were considered, but the level of treatment varied from species to species, depending on the availability of appropriate data for making an assessment.

Among the species that could be treated quantitatively, white perch exhibited the greatest reduction in equilibrium stock size: based on the combined effects of entrainment and impingement on the 1974 year class, reductions in equilibrium stock size would be expected to be approximately 4.6% for Indian Point Unit 2, and 6.3% for the multiplant case. Atlantic tomcod and American shad were less affected by the existing power plants: in 1974, the expected reduction in equilibrium stock size was about 1% from the effect of multiplant impact on Atlantic tomcod and about 1.4% for multiplant impact on American shad.

The reduction of American shad equilibrium stock size by Indian Point Unit 2 in 1974 was estimated to be 0.8%.

The quantitative impact of power plants on blueback herring was not estimated, but their distribution in the river and life history are very similar to those of American shad; thus, power plant impact is expected to be similar.

The population dynamics of the shortnose sturgeon are essentially unknown in the Hudson River at this time, but a study of this species is currently in progress at the Boyce Thompson Institute. Based on current knowledge of this species, it is impossible to estimate whether power plant impacts in the Hudson River are having any serious effect on the shortnose sturgeon population, however, their exposure is expected to be low because of the demersal character of the species.

SECTION 15

SUMMARY OF RESEARCH PROGRAM FINDINGS ON ECOLOGICAL IMPACT OF ONCE-THROUGH COOLING SYSTEM

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SECTION 15

SUMMARY OF RESEARCH PROGRAM FINDINGS ON ECOLOGICAL IMPACT OF ONCE-THROUGH COOLING SYSTEM

15.1 RESEARCH PROGRAM (SECTION 1)

The Con Edison research program focused on the following:

- The effects of entrainment and impingement by Indian Point Unit 2 and other Hudson River power plants on the populations of striped bass and other important fish species
- The compensatory reserve of the Hudson River striped bass population
- The relative contribution of the Hudson River striped bass population to the Atlantic coastal fishery
- Striped bass ichthyoplankton survival during entrainment
- In-depth study of the physical environment of the Hudson River
- The potential effectiveness of a striped bass hatchery and fish diversion devices as possible mitigation measures for losses due to power-plant operation

Various organizations retained by Consolidated Edison independently obtained their data, which were made available to state and federal agencies and to other involved contractors for evaluation, analysis, and synthesis. This report has integrated the research efforts performed primarily by:

- Texas Instruments Incorporated
- Lawler, Matusky and Skelly Engineers
- New York University Medical Center

Other contributing contractors were Stone and Webster Engineers, Inc.; Ecological Analysts, Inc.; the University of Rhode Island; Alden Research Laboratories, Inc; and the La Salle Hydrological Laboratories, Ltd.

The conclusions contained in this report are based on one of the most intensive analyses of fish populations ever undertaken with respect to a single body of water. The main study area covered the 154-mi stretch of river from the Battery in Manhattan (RM 0) to the Troy Dam (RM 154).

15.2 THE HUDSON RIVER (SECTION 2)

The Hudson River as a resource system is described in detail in Section 2. The distinctive elevation, slope, and relief characteristics of each physiographic region of the Hudson River Valley are described. From 57 yr of flow data recorded at the USGS gauging station at Green Island, freshwater flow at Green Island has been estimated to average 13,268 ft^3s^{-1} (376 m^3s^{-1}), accounting for approximately 80% (under normal summer conditions) of the freshwater flow entering the estuary.

15.3 GENERAL EFFECTS OF POWER PLANTS (SECTIONS 2,3)

The seven power plants which presently utilize the flows of the Hudson River for once-through cooling purposes are the Albany steam generating station, Roseton, Danskammer Point, Indian Point, Lovett, Bowline Point, and the 59th Street generating station (RM 152-12; km 243-19).

Several components of the aquatic biota have been studied to determine the effects, if any, that may be imposed on them by operation of the Hudson River power plants. Small portions of the phytoplankton, microzooplankton, macrozooplankton, and ichthyoplankton communities of the Hudson River are entrained within the cooling water of the above power plants; also, small portions of the young-of-the-year and adult fish populations are impinged on the fixed or traveling screens at the intake structures of the plants. Discharges of certain chemical effluents from these power plants, however, are reported to be within New York State effluent limitations and therefore would have little effect on the biota of the Hudson River. In general, the effects of operation of the Hudson River power plants are limited to the removal (cropping) of small portions of the populations of plankton and fish.

The total energy input into the Hudson River ecosystem has been estimated to be approximately ~~2760~~ 81,960 x 10^9 kcal yr^{-1}. During 1974, some ~~0.026 x 10^9~~ 0.55 x 10^9 kcal of viable organisms that would not have died otherwise ~~fish was~~ transformed into detritus by entrainment and impingement at Indian Point. From the transformation-of-energy viewpoint, it can be seen that operation of Indian Point Unit 2 has an insignificant effect on the total energy budget of the Hudson River. The same is true for the multiplant set.

15.4 INVERTEBRATES (SECTION 4)

Abundance of several major invertebrate species in the Hudson River estuary was studied and their vulnerability to power plant impact was assessed. The major invertebrate groups (benthic infauna, epibenthos, and zooplankton) are herbivores and detritivores which obtain energy from primary producers and detritus. These invertebrate groups in turn, are, consumed by small fish, predatory fish, and large detritivores. The invertebrate studies summarized in Section 4 of this report show that the Hudson River estuary is productive and supports healthy standing crops of a diverse assemblage of invertebrates.

Benthic community studies compared relative abundances within the Indian Point thermal plume with those in a similar area beyond the thermal plume. The relative abundance of benthic organisms did not differ significantly between the thermal plume and control areas. Planktonic invertebrates are occasionally vulnerable to plant entrainment. However, operation of the Hudson River power plants has had little or no effect on the relative abundance or distribution of the major invertebrate species.

Invertebrate species such as *Gammarus*, *Neomysis*, *Monoculodes*, copepods, and chironomid larvae are important food sources for striped bass young-of-the-year (YOY); white perch YOY; yearling, and older white perch; Atlantic tomcod YOY; blueback herring YOY; and American shad YOY. These fishes, in turn, may be consumed by larger predators. The feeding habits depend largely on the fishes' life stages, sizes, and distribution and on the availability of food organisms. The complex nature of the fish community of the Hudson River estuary is reflected in the following summary of the life histories, trophic relationships, and species associations of six important fish species: striped bass, white perch, Atlantic tomcod, American shad, blueback herring, and shortnose sturgeon.

15.5 STRIPED BASS BIOLOGY (SECTION 5)

The anadromous striped bass spawns in freshwater rivers, usually from April to June, and then returns to the ocean. Fecundity data indicate that a single female may lay 150,000 to several million semibuoyant eggs. Approximately 50% of all fertilized eggs hatch, usually within 38-74 hours after fertilization. In early July, the motile post yolk-sac larvae move from the main channel to the shoal areas where they develop into the juvenile stage in late July. The juveniles then begin to move downstream toward areas of higher salinity. During September and October, many juveniles migrate from the river; some overwinter in the lower estuary and bays before migrating to the ocean, while others are found in Long Island Sound or off the south shore of Long Island.

Striped bass larvae and early juveniles feed principally on copepods and *Gammarus*; larger juveniles feed on insect larvae, annelid worms, mysids, crabs, and small fish. There are more fish in yearling diets, and individuals age II and older feed almost exclusively on fish. Although striped bass trophic relationships change with life stage and the availability of prey, the species is apparently an opportunistic predator. Juveniles are probably subject to both interspecific and intraspecific competition for food within the estuary and appear to grow more slowly at high density; the influence of competition on the growth of adults, however, is unknown.

Atlantic tomcod, Atlantic cod, bluefish, silver hake, and larger striped bass may prey on small striped bass. Cluster analysis of species associations has shown that young-of-the-year striped bass are most closely associated with young-of-the-year shad and adult white perch during the summer; during other seasons, however, young-of-the-year striped bass are more closely associated with young-of-the-year alewives and blueback herring. Striped bass yearlings are closely associated with bluefish young-of-the-year and bay anchovy.

15.6 WHITE PERCH BIOLOGY (SECTION 5)

White perch are primarily an estuarine species but occurs also in coastal marine areas and in fresh water. Hudson River white perch spawn in May and June in shallow areas, primarily north of Croton Bay (RM 34; km 54). Fecundity data indicate that a female white perch may lay 10,000-70,000 adhesive eggs. Hatching occurs 1.5-6 days after fertilization. Juvenile white perch occur in shoal and beach areas during their first summer, then move gradually downriver to Tappan Zee and Croton-Haverstraw Bays to overwinter in deep water.

Hudson river white perch feed primarily on copepods, midge larvae, and *Gammarus*. Cladocerans are also important prey of juveniles, and amphipods and polychaetes are common prey of adults. Apparently, fish are not important prey of Hudson River white perch.

Juvenile white perch occupy a position in the food web similar to that of striped bass, which suggests that competition may exist between these species. Juvenile white perch are the prey of larger predators, especially yearling and older striped bass. Evidence of decreased growth at higher densities has been reported for juvenile white perch in other estuaries, but there is no such evidence in the Hudson.

Adult white perch are closely associated with young-of-the-year striped bass and American shad during the summer but young-of-the-year white perch are associated with pumpkinseed and banded killifish.

15.7 ATLANTIC TOMCOD BIOLOGY (SECTION 5)

Tomcod are an inshore marine and estuarine species occurring in salt, brackish, and fresh water, but it is usually anadromous, entering coastal estuaries for midwinter spawning runs. Spawning occurs in shallow areas of the Hudson River, primarily between Indian Point and Cornwall (RM 39-56; km 62-89). The 1973-74 fecundity estimates for Hudson River Atlantic tomcod ranged from 3,860 to 55,700 adhesive eggs per female. Hatching may occur up to 30 days following fertilization. The juveniles, once developed, move downriver and spend their first summer in the lower regions of the estuary.

Adult Hudson River Atlantic tomcod feed primarily on *Gammarus* and *Neomysis*, but other food items include polychaetes, isopods, other amphipods, shrimp, midge larvae, fish, and tomcod eggs. Copepods and *Gammarus* are the most frequent prey of the juvenile tomcod. The juveniles, in turn, are probably consumed by striped bass and juvenile bluefish.

Beach-seine catches have indicated that young tomcod are closely associated with the hogchoker, an estuarine resident. Bottom trawl catches have shown young tomcod to be associated with hogchoker and yearling and older white perch; and yearling tomcod to be associated with striped bass yearlings.

15.8 AMERICAN SHAD BIOLOGY (SECTION 5)

The adults of American shad, an anadromous species, occur in the Hudson River estuary only during early spring when they return to spawn. Most of their spawning occurs between Hyde Park and Catskill (RM 77-107;

km 123-171). The semibuoyant, nonadhesive eggs hatch within 4 to 7 days. Juvenile American shad utilize the estuary as a nursery area during their first summer, then migrate to the ocean in the fall. While in the estuarine nurseries, juvenile shad first feed on small zooplankton and later on aquatic insects, ostracods, and amphipods. Young shad in the Hudson River estuary are consumed by young-of-the-year bluefish and probably by striped bass.

Beach seine data show juvenile American shad to be associated with striped bass young-of-the-year and with white perch yearlings. Bottom trawl data show young-of-the-year American shad to be associated with young-of-the-year alewives.

15.9 BLUEBACK HERRING BIOLOGY (SECTION 5)

The anadromous blueback herring is closely related to the American shad but is much smaller when an adult. Blueback herring spawn in the Hudson River estuary during late spring and early summer, primarily north of the Beacon-Newburgh bridge (RM 61; km 99). The adhesive eggs are found near the bottom and hatch in 2-3 days when the water temperature range is 22-24°C. Juvenile blueback herring utilize the Hudson River estuary as a nursery area in the summer before migrating to the ocean in the fall.

Blueback herring are primarily plankton feeders consuming copepods, shrimp, larval and early juvenile fish, and fish eggs. As juveniles, they provide forage for larger predators.

Bottom trawl data show young-of-the-year blueback herring to be weakly associated with young-of-the-year striped bass; yearling and older blueback herring are weakly associated with banded killifish. Beach seine data show stronger associations between blueback herring and alewives when both are in the young-of-the-year, yearling, and older stages.

15.10 SHORTNOSE STURGEON BIOLOGY (SECTION 5)

This species inhabits fresh, brackish, and salt water but is most common in the lower reaches of large tidal rivers. Few details of its life history are known except that it lives in deep water near the bottom throughout its life cycle and feeds on bottom-dwelling organisms.

Adult shortnose sturgeon have no known predators except man; the young are probably vulnerable to predation by larger fishes. The shortnose sturgeon competes little with other important fish species in the estuary because it is a bottom feeder. It is not presently exploited commercially or for sport.

15.11 VULNERABILITY TO POWER PLANTS (SECTION 6)

The degree of vulnerability during the first year of life of striped bass, white perch, Atlantic tomcod, American shad, and blueback herring differs among power plants, life history stages, and species. Vulnerability assessment was based on longitudinal distributions of the fish during 1974 and 1975, and on the respective life-stage characteristics. The vulnerability of shortnose sturgeon could not be adequately assessed using the methods of Section 6 because of insufficient catches of this species. However, the demersal nature of the shortnose sturgeon greatly reduces its exposure to power plants.

Striped bass eggs and larvae are most vulnerable to entrainment during May and June with the eggs being less vulnerable because they are always concentrated near the bottom. Yolk-sac and post yolk-sac larvae are also concentrated near the bottom during the day but migrate vertically in the water column at night, with the result that densities are more uniform from bottom to surface. This behavior is strongest for yolk-sac larvae. The vulnerability of the larvae, then, varies on a day-night basis; during the day, they may be more vulnerable to plants withdrawing water from the bottom strata; at night, they are vulnerable to plants withdrawing water from midwater and surface strata. Striped bass juveniles exhibit high vulnerability to entrainment through July although their increased swimming ability may partially enable them to avoid entrainment. They reach impingeable size in early August. During August and September, the population begins to move downstream and shoreward. By early October, striped bass juveniles exhibit negligible vulnerability at Roseton and Danskammer (RM 65.4-66; km 105.6-106) but are still vulnerable to impingement at the other plants, especially Bowline (RM 37.5; km 60), until mid-November when most of the population has moved offshore and has migrated downstream. A small portion of the juvenile population overwinters in the lower and middle estuary. Vulnerability to impingement is low to moderate from December through April.

The vulnerability of white perch eggs, larvae and early juveniles to entrainment is moderate during May and June and low during July. Eggs and yolk-sac larvae are more vulnerable at Roseton and Danskammer than at Bowline, Lovett, and Indian Point. Post yolk-sac larvae are also moderately vulnerable, but their vulnerability may exhibit day-night differences: during the daytime, they may be more vulnerable to any plant withdrawing water from the bottom strata; at night, however, they disperse upward through the water column and become more vulnerable to any plant withdrawing from midwater and surface strata. The vulnerability of juveniles to impingement is moderate from August through October but increases during winter. As the white perch population moves downstream through the shorezone during August and September, vulnerability to any plant withdrawing cooling water from the shoals increases. Vulnerability increases during late fall and winter (November-March) when the juveniles concentrate and overwinter in the deeper areas of the lower and middle estuary in the vicinity of Indian Point and Lovett (RM 42-41; km 67-66).

The vulnerability of Atlantic tomcod eggs, larvae, and early juveniles to entrainment is relatively low. The eggs are essentially invulnerable because they are demersal and adhesive. Yolk-sac larvae and early juveniles (through May) are moderately vulnerable to entrainment only at Bowline, Lovett, and Indian Point (RM 37.5-42; km 60-69). Since the post yolk-sac larvae are concentrated in the lower estuary, their vulnerability is negligible. Juvenile vulnerability is high during summer and early fall and moderate during the winter spawning period; their overall vulnerability is greatest at Indian Point and Lovett. Vulnerability at Roseton and Danskammer (RM 65.4-66; km 105.6-106) increases during December-February when the spawning tomcod move into the shoals and shorezone near these plants.

The vulnerability of American shad eggs, larvae, and juveniles is low, with eggs and yolk-sac larvae being restricted to the upper estuary far upstream from the power plants. Some post yolk-sac larvae and early juveniles are collected in the middle estuary near Roseton and Danskammer (RM 65.4-66; km 105.6-106), but exposure to Lovett, Indian Point, and Bowline (RM 42-37.5; km 69-60) is negligible. Prior to October, the vulnerability of juvenile shad is low at Bowline, Lovett, and Indian Point and moderate at Roseton and Danskammer; then, during a brief period in October and November when they are moving downriver into deeper water past Indian Point, Lovett, and Bowline, vulnerability is high. By December, most juveniles have left the estuary.

The vulnerability of blueback herring eggs, larvae, and early juveniles is negligible since they are concentrated in the upper estuary. The vulnerability of juveniles also is very low through September but increases in late September-early October as they migrate seaward. This period of increased vulnerability continues only through November.

15.12 DETAILED DESCRIPTION OF HUDSON RIVER STRIPED BASS POPULATION (SECTION 7)

Almost all spawning by striped bass in the Hudson River is in fresh water. In 1974, spawning peaked at water temperatures of 14-18°C; in 1975, at 16-20°C.

To analyze egg and larval distribution in relation to time of day (day or night), relative depth, and area of the river, the Cornwall (RM 56; km 90) and Indian Point (RM 42; km 67) areas were intensively studied. The Cornwall study showed that eggs generally were concentrated in the middle and bottom strata, with densities being highest during the day. Lateral distribution and depth of striped bass eggs strongly depended on the longitudinal zone. The Indian Point study also showed that striped bass eggs were concentrated in bottom waters. This depth distribution did not change with time-of-day, sampling period, or area of the river.

When striped bass eggs hatch, the larvae are 2.0-3.7 mm long and have a large yolk-sac with a well-defined oil globule. Yolk-sac larvae, which are capable of limited movement, were caught in greatest numbers in areas ~~when~~ where temperatures ranged between 17 and 20°C. Yolk-sac larvae were concentrated near the bottom during the day but were generally dispersed upward through the water column at night.

The post yolk-sac larval stage begins when the fish are about 5-6 mm long and have a complete digestive tract. They are active swimmers and are able to oppose currents, capture prey, and avoid predators. During 1974 and 1975, Hudson River post yolk-sac larvae were collected in waters ranging from 16 to 24°C; they were most abundant during June. Overall distribution among river regions is similar to that of yolk-sac larvae. Post yolk-sac larvae were oriented toward the bottom during both day and night, with nighttime migrations being similar to those of yolk-sac larvae.

The juvenile stage begins when fish reach a total length ranging from 14-31 mm. Juvenile striped bass are strong swimmers capable of lengthy migration. They move from deep water to the shore and shoal areas during July and are widely distributed; these movements occur during the period of maximum summer water temperatures and the rapid growth phase of young juveniles. Shorezone density is greater at night, especially at beaches adjacent to deep water. During fall when juveniles range from 80 to 100 mm in total length, they move out of shallow water and apparently begin emigrating from the river. Since the theoretical maximum entrainable size is 65 mm and the minimum impingeable size is 46 mm, probably few fish larger than 40 mm are actually entrained. During the fall, the mean total length ranges from 80 to 100 mm so that juveniles are vulnerable only to impingement during this time of year.

In early spring, yearlings are found in deep water in the lower regions of the Hudson River estuary where they have overwintered as juveniles. By mid-June, the yearlings are distributed throughout the estuary and lower bays from Albany to the western end of Long Island. By November, those in the estuary have moved into deeper water and downstream and those in the lower bays appear to have moved eastward to the north shore of Long Island and possibly west to Staten Island. Smaller yearling striped bass remain for a time in the lower bays while larger yearlings emigrate from the river. Mark/recapture efforts suggest that yearlings present in the lower bays of the Hudson River estuary do not move into the river but continue their emigration to the ocean. This emigration to lower estuary areas beyond the mouth of the river is essentially complete by the end of the yearling stage.

For older Hudson River striped bass, females are larger than males after age III. There is no significant difference in growth rates between Hudson River striped bass and other anadromous striped bass populations. Females in the Hudson River striped bass population begin to mature at age IV and all are mature by age VIII, which is 1-2 yr later than striped bass in the Chesapeake and Connecticut waters (the latter being predominantly of Chesapeake origin).

Total annual mortality rates for Hudson River striped bass after the first year of life are not known but may be approximately 0.4. A total mortality rate of 0.8 applied to the estimated 6 x 10^6 age 0 striped bass yields

1.2×10^6 as the mean number of age I striped bass. Assuming a mortality rate of 0.6 for yearlings, there would be approximately 480,000 two-year old fish. If the sex ratio is 1:1, there would be approximately 240,000 age II females. The average spawning population has 85,652 females, which produces 87.9 billion eggs. The critical age (the point at which the growth rate equals the natural mortality rate) for the striped bass fishery is 3.25-7 yr for males and 3.75-6.5 yr for females, depending on the natural mortality rate. Harvesting at these average ages would produce the greatest biomass yield.

Based on the 1974 and 1975 year classes, striped bass year-class strength in late August is at least 5,000,000 or 6,000,000. The very large 1973 year class was almost 20,000,000. This fourfold variation in year-class strength is not unusual for fish populations. The late-summer population estimate of 5,000,000 or 6,000,000 is used as a base for impingement impact assessment.

Of the seven environmental factors tested, the following three accounted for for about 70% of the year-to-year variation in juvenile striped bass abundance: a predation index ($p<0.10$), an egg production index ($p<0.05$), and the rate of water temperature rise during the first summer of life ($p<0.05$). This analysis showed no significant relationship between striped bass abundance and power plant operation.

The large bluefish population probably contributes to the reduction of juvenile striped bass abundance through predation. Over certain ranges of population density, a large spawning stock and greater egg production may increase the absolute number of larvae surviving to the juvenile stage or may help to synchronize young-of-the-year with a food-organism cycle through an expanded spawning season. A rapid increase in temperature from 16 to 20°C increases larval growth rates, shortens sac fry duration and probably shortens exposure time to certain types of predation.

15.13 CONTRIBUTION OF HUDSON RIVER STRIPED BASS POPULATION TO ATLANTIC COASTAL FISHERY (SECTION 7.10)

To estimate precisely the relative contribution of striped bass stocks from various estuaries to the Atlantic coastal fishery, the striped bass were segregated into their natal stocks by discriminant analysis of meristic, morphometric, and enzyme characters. Approximately 75% accuracy was obtained in classifying representative samples from each spawning stock. Also, the additional discriminative potential of enzyme characters was investigated.

Striped bass were collected from the Atlantic coastal fishery from Cape Hatteras, North Carolina to Maine. The collected fish were subjected to meristic, morphometric, and enzyme analyses and the resulting data entered into discriminant functions obtained from the spawning stock collections. Atlantic fishery specimens then were classified on the basis of the spawning river from which they originated. The result indicated that the Chesapeake stock was the major contributor to the Atlantic coastal striped bass fishery (90%) with minor contributions from the Hudson and Roanoke stocks (7% and 3% respectively).

15.14 ENTRAINMENT (SECTION 8)

Numbers of striped bass eggs and larvae entrained and killed by power plants were estimated both from direct measurements of plant intakes and discharges and from simulation model calculations (Table 8.11-1). Direct estimates of the total numbers of striped bass entrained and killed at Indian Point Unit 2 were 3.19 million eggs and 5.92 million larvae during 1974, and 3.52 million eggs and 16.14 million larvae during 1975. The higher entrainment estimates for 1975 were due to higher abundances of striped bass ichthyoplankton and slightly higher plant flow rates. Neither year exhibited a consistent diurnal pattern of larval entrainment.

Indian Point Unit 3 was not operational until February 1976, when limited operation of the circulating water pumps was begun; consequently, no striped bass ichthyoplankton were entrained at Unit 3 during either 1974 or 1975. The design and pumping rates of Unit 3 are identical to those of Unit 2, and the intakes of both units are approximately 700 ft apart; therefore, if both units were operated at the same levels of cooling-water withdrawal, the entrainment of striped bass ichthyoplankton at Unit 3 probably would not differ significantly from that at Unit 2.

At Roseton, 10,000 eggs and 190,000 larvae were entrained and killed during 1974, and 70,000 eggs and 4,600,000 larvae during 1975. At Bowline, eggs were not enumerated in 1974 samples, but 240,000 larvae were entrained and killed. In 1975, no eggs but 780,000 larvae were entrained and killed.

Entrainment was calculated also for Indian Point Unit 1, Lovett, and Danskammer, but these plants have been operating long enough that their effects are already reflected in the fish population, so they are not included in the multiplant impact assessment.

Simulation model calculations of numbers of entrained striped bass larvae were generally higher (more conservative) than the entrainment calculations based on direct sampling at the power plants. Model calculations of entrainment extensively employ parameters called f factors and W ratios. Values for these are summarized in Section 8 by life-history stage. One f factor (f_c), represented the fraction of the entrained ichthyoplankton cropped due to the entrainment process. The f_3 factor used in model calculations represents both the long-term population drawdown effects and recirculation; for Indian Point and Roseton, it was based on hydraulic and mathematical model studies. The f_q factor represented the approximate fraction of intake water from the upper layer (f_{qU}) and lower layer (f_{qL}) of the water column. Based on the results of the LaSalle (1976) studies, values of 0.53 (f_{qU}) and 0.47 (f_{qL}) were calculated for Indian Point.

Withdrawal factors (w ratios) were calculated for Indian Point, Bowline, and Roseton, w_u and w_L were equivalent to the ratio of plant entrainment concentrations to upper and lower-layer river concentrations respectively and to the product of the f_1 and f_2 factors previously described by Lawler, Matusky and Skelly. In the real-time model calculations (described in Section 12), river ichthyoplankton concentrations were multiplied by plant flow and the product $w \cdot f_3 \cdot f_c \cdot f_q$ in order to obtain an estimate of the number of organisms cropped by entrainment.

15.15 IMPINGEMENT (SECTION 9)

Indian Point Unit 2 was monitored daily for impingement of striped bass. The number impinged varied with conductivity, temperature, and water circulation as well as with abundance and distribution. Usually, striped bass were <2% of the total impingement collections. Also collection efficiency at Indian Point Unit 2 was found to vary with operation of the air curtain. Actual numbers of striped bass impinged may have been 6.5 times greater than numbers collected. Since some survival during impingement was likely, the total number of striped bass cropped was probably less than the approximate numbers reported. Based on 1973-75 data, approximately 24,000 striped bass are impinged each year at Indian Point Unit 2.

Impingement of striped bass at Indian Point Unit 3 for the limited period monitored during 1974 was estimated to be 221 fish at a rate of 5.5 fish $m^{-3} \times 10^6$ of water circulated. The absence of fixed screens may have accounted for the comparatively higher collection efficiency of 80%.

Impingement at Indian Point Unit 1 has been monitored since mid-1972. Collection methods are identical to those at Unit 2. Corrections for collection efficiency at Unit 1 are not available. During 1973-74, only 1,374 striped bass were impinged. As at Unit 2, striped bass are usually <2% of all fishes impinged.

The frequency of impingement sampling at the other Hudson River power plants varied between weekly and biweekly. The estimated total annual impingement of striped bass was:

	Roseton	Bowline	Lovett	Danskammer	Albany
1973	--	9,050	3,808	18,091	
1974	520	81,904	9,158	6,434	19,628
1975	1,820	82,947	5,726	2,779	6,586

These estimates did not include adjustments for known but unquantified losses, nor for factors which could have inflated them. Reliable quantitative estimates for inoperative traveling screens, and for recirculation and survival during impingement do not exist for each plant.

15.16 COMPENSATION (SECTION 10)

When fish populations are reduced in numbers by a commercial fishery, sport fishery, or power plant entrainment and impingement, the survival rate or the reproductive rate among the surviving population tends to increase. This is known as a compensatory response to the factors that crop the population. The striped bass population~~,~~ has a measurable and impressive natural capacity to persist in the face of exploitation by man.

An explanation of model representation of compensation and summary of empirical evidence of compensatory mechanisms in fish populations are presented. The examples were extracted from existing literature sources and provide an understanding of the resilience of fish populations that encounter increases in mortality. Modern fishery management concepts recognize that the maximum sustained yield of fish populations will be obtained under exploitation rates of 25-75% and at average equilibrium levels less than one-half the virgin stock level. Power plant impacts occur only during the first year of life, when young fish may be entrained or impinged. By contrast, sport and commercial fisheries impact each year class repeatedly on an annual basis.

Two major striped bass stocks--Chesapeake Bay and San Francisco Bay--have been shown empirically to be regulated by compensatory processes. Observations for both indicate that the stock recruitment curves are somewhat convex rather than flat-domed. This is consistent with the substantial fecundity of the species. Cushing (1975) postulates that the more fecund species (such as striped bass) generally have greater compensatory reserve.

Compensatory processes which occur in the Hudson River are: intraspecific competition leading to density-dependent growth of juveniles; cannibalism of yearlings on juveniles; and predation by several other companion species on juvenile striped bass. There is also evidence that Hudson River striped bass respond to the combined commercial and sport fishery in a compensatory manner. This density-dependent (compensatory) regulation of the striped bass population of the Hudson River has been represented mathematically by a Ricker stock recruitment curve, from which estimates of compensatory reserve have been calculated.

On the basis of the estimate of compensatory reserve, it is shown that reductions in young striped bass due to entrainment and impingement can be compensated by small changes in natural mortality. Also, the ultimate reductions in equilibrium spawning stock caused by entrainment and impingement impact will necessarily be small. This is so because to attain a 50% or greater reduction in the equilibrium spawning stock size would require very large plant-caused conditional mortality rates for young striped bass of more than 80 or 90%. A given exploitation rate due to impingement has more effect than the same rate due to entrainment in reducing the equilibrium spawning stock. This is so because the natural mortality rate is lower during the impingement period than during the entrainment period.

15.17 IMPACT ESTIMATED FROM EQUILIBRIUM REDUCTION EQUATION (SECTION 11)

The definition of impact used in this report is the percentage by which the pre-impact equilibrium level of the fish population is ultimately reduced as a result of plant operation. Mortality statistics that reflect plant operation are entered into an equation that predicts the average percentage by which the striped bass population will be reduced. The following parameters were used for the entrainment impact estimates derived by the equilibrium reduction equation method (Section 11): recirculation was estimated to be 10%; the actual volumes of river water pumped were used; the ratio of intake to river ichthyoplankton densities was estimated to be 0.5; and the fraction of the different life stages cropped during entrainment was estimated to be 80% for eggs, 60% for larvae, and 70% for juveniles. To calculate the impingement impact estimates, exploitation rate (u) was estimated directly from the population size at the beginning of impingement vulnerability and numbers impinged; and reduction in equilibrium stock size due to impingement was estimated using the equilibrium reduction equation based on the compensatory relationship between spawning stock and recruitment developed in Section 10.6. The sum of the entrainment and impingement impacts was used as an estimate of total impact.

Using the equilibrium reduction equation, the following was estimated to be the power plant impact on the striped bass population of the Hudson River:

For Indian Point Unit 2:

	1974	1975
Entrainment	.52%	.54%
Impingement	.24%	.43%
Total	.76%	.97%

For the multiplant case:

	1974	1975
Entrainment	.76%	1.13%
Impingement	1.34%	.71%
Total	2.10%	1.84%

15.18 IMPACT ESTIMATED FROM REAL-TIME LIFE-CYCLE MODEL (SECTION 12)

The 1974 and 1975 data bases are used to determine the impact of post-1972 plants: Indian Point Units 2 and 3, Roseton Units 1 and 2, and Bowline Units 1 and 2. In each case, the real-time model predicted impact during the year the data base was collected and then predicted 39 additional years of impact based on projected plant operating conditions (Section 12.2). The percentage cropping values after 40 yr were equivalent to the percentage reduction in the size of the equilibrium spawning stock used as the measure of impact in the equilibrium reduction equation method of Section 11. Multiplant predictions of impact on the Hudson River striped bass population after 40 yr of operating all plants on once-through cooling were 5.16% based on 1974 data and 3.97% based on 1975 data. Predictions of Indian Point Unit 2 impact on the Hudson River striped bass population after 40 yr of operation were 1.22% and 0.93%, based on the respective 1974 and 1975 data bases.

The two impact estimation methods used in this study are in good agreement. They use the same basic data but employ very different methods of calculation and assumptions. Multiplant impact on the Hudson River population will be manifested as a gradual decline in striped bass abundance over a period of some 20 yr and establishment of a new average equilibrium level at a density 4-5% lower than the density that would prevail in the absence of power plant impacts. The effect of Indian Point Unit 2 would be a decline of only about 1%. Expressed as a percentage, the reduction is small. It would not be expected to be irreversible; could be offset by mitigation measures if necessary; would not be ecologically damaging to the population; and would not significantly limit sport or commercial fisheries. In the case of the Atlantic coastal fishery, to which the Hudson contributes 7% of the stock, the reduction caused by multiplant impact is estimated to be about 0.35%, a change that would not even be discernible.

15.19 MITIGATION OF IMPACT (SECTION 13)

The research program has demonstrated that it is possible to artificially propagate striped bass in numbers sufficient to replace losses to the natural population resulting from power plant operation.

The applicability of fish diversion devices at the intake structures of Indian Point and other Hudson River power plants was evaluated. Extensive biological testing of both louvers and angled traveling screens indicates the potential effectiveness for alleviating the problems of fish impingement at these plants. Utilization of these fish diversion devices represents a potential economic alternative to cooling towers because the fish diversion devices are capable of greatly reducing impingement losses.

15.20 IMPACT ON SPECIES OTHER THAN STRIPED BASS (SECTION 14)

Power plant impacts on white perch, Atlantic tomcod, American shad, blueback herring, and shortnose sturgeon were evaluated. The level of treatment varied among species, depending on availability of appropriate data.

Based on 1974 data, the combined effects of entrainment and impingement on white perch result in reductions in equilibrium stock size of 4.6% for Indian Point Unit 2, and 6.3% for the multiplant case.

Atlantic tomcod and American shad are less affected by power plant operation. Expected reduction in equilibrium stock of Atlantic tomcod is approximately 1% for the multiplant case. American shad equilibrium stock is reduced by about 1.4% by multiplant impact and by 0.8% for Indian Point Unit 2 alone based on 1974 data.

The impact of power plants on blueback herring was not quantitatively estimated but would be expected to be similar to that for American shad since their distribution in the river and their life histories are very similar.

The population dynamics of the shortnose sturgeon in the Hudson River are not known. At this time, available data do not permit estimation of power plant impacts on the shortnose sturgeon population, but such impacts would not be expected to be severe because of the demersal character of the species.

The data and analyses indicate that power plant impact on the above species will be small and will not cause serious ecological damage or economic loss.

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ERRATA

Section 1	Change From	Change To
Page 1.10	(7 AEC at 772)	(6 AEC at 772)
Page 1.13	line 3, impingement	Impingement season
Section 2		
Page 2.24	LMS 1975	(LMS 1974a)
Page 2.62	LMS 1975	LMS 1975a
Section 4		
Page 4.6	Footnote to Table 4.2-3, LMS (1975)	(LMS 1975c)
Section 8		
Page 8.9	LMS 1975	LMS 1975f
Page 8.60	Ecological Analysts, Inc (1976)	Ecological Analysts, Inc (1976c)
Page 8.61	(JPL 1972; IP 1975 Environmental Report)	(Lawler, 1972; Con Edison 1975)
Page 8.82	(LMS 1976)	(LMS, personal communication)
Page 8.91	(LMS 1976)	(LMS, personal communication
Section 9		
Page 9.13	Table 9.13	Striped Bass
Section 12		
Page 12.26	Table 13.2-1	Add † by Mean Conductivity (mS)
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APPENDIX A

PHYSICAL PARAMETERS

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PHYSICAL PARAMETERS

A. SILTATION

Because siltation is one of the processes that may influence physical and chemical properties of the benthic environment, it may affect the growth and distribution of bottom organisms, which represent a vital link in the food chains of Hudson River fishes. In addition, siltation may directly affect the behavior of river fish populations.

Although the process of siltation in the Hudson River estuary has been studied extensively in connection with the dredging of the navigation channels, the effects of siltation on river-bottom organisms are still not well understood.

In general, the sediments supplied by the Hudson River watershed are primarily fine lightweight particles that remain in suspension in the freshwater reach of the river and can be transported by weak currents. Since the freshwater reach experiences a net unidirectional flow seaward throughout the entire water column, only a small portion of the suspended sediments settles out.

As the sediments approach the ocean-derived salt front, the transition from a 1-layer to a 2-layer system (a seaward-moving upper layer and a landward-moving lower layer) begins to play a major role. This transition results in a very weak net velocity near the bottom, characterized by a change in direction from downstream to upstream. Heavy shoaling usually occurs in this vicinity, with heavier particles being deposited just downstream. The presence of ocean-derived salt enhances a flocculation process among the remaining suspended sediments. This process continues, mainly in the seaward-moving upper layer, as the sediments move downstream. After flocculation, the sediments settle to the landward-moving lower layer. The rate of settling is controlled primarily by salinity and other environmental factors such as temperature, pH, type and concentration of sediments, and water turbulence.

Siltation has long been a serious navigation problem in the lower Hudson River. The Corps of Engineers dredges about 1.6×10^6 yd^3 (1.45×10^6 m^3) of sediment annually from the navigation channel. The single main source of shoaling material (40%) is the watershed of the Hudson River and its tributaries; secondary sources are the solids discharged via sanitary and storm sewers, industrial plants, and other waste-disposal facilities. Other potential sources are dredge spoils, the solids that are carried into the Hudson River via the Harlem River and upper New York Bay.

B. COLOR, TURBIDITY, AND SUSPENDED SOLIDS

These three parameters are discussed together because they have similar effects on the biological environment. All are important in determining the light transmission in natural waters; consequently, they regulate light-dependent biological processes. Mean values and ranges of these three parameters in the Hudson River for 1970 through 1972 are presented in Figure A-1.

Color in water may be of mineral or organic origin. In particular, color may be imparted to water by the prescence of metallic ions (e.g., the blue color of cupric salts dissolved in water), humus, peat, tannins, algae, and some protozoa. Industrial effluents can impart additional color to water. In practice, the true color of water is considered to be only that which is attributable to substances in solution after suspended matter has been removed. The term "apparent color" is used to describe an observed color that includes suspended matter.

Turbidity results from the presence of colloidal and suspended substances in water. It is measured by passing a beam of light through a column of the water sample and determining the extent of light reduction that occurs. Factors contributing to turbidity in natural waters are detritus,

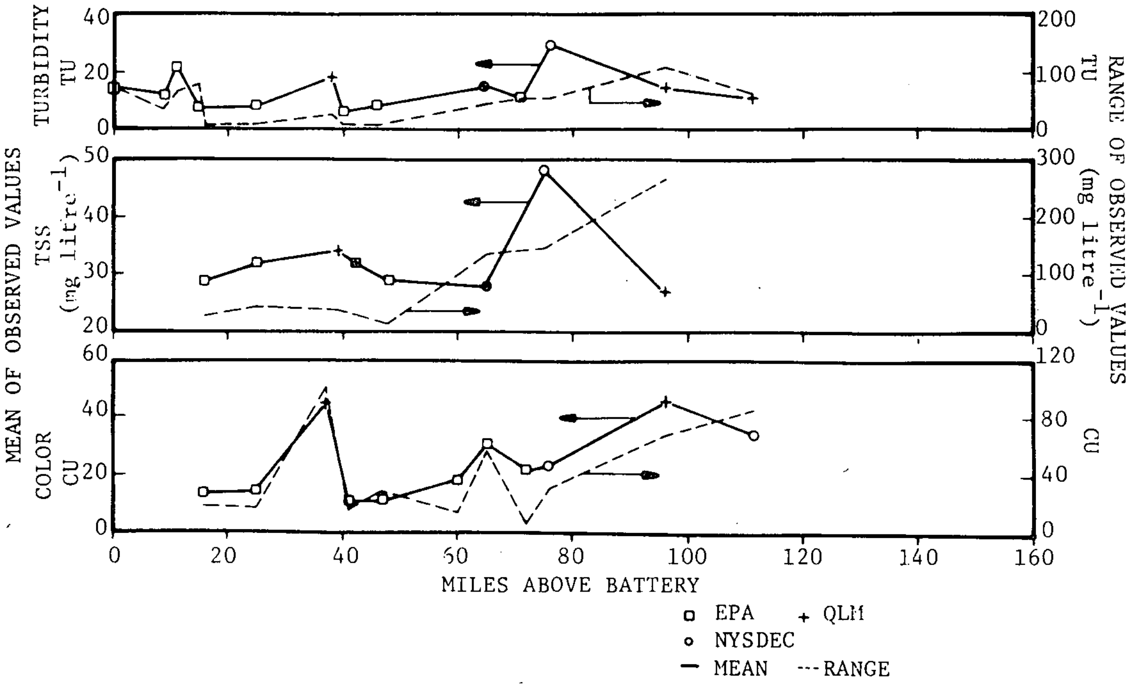


Figure A-1 Turbidity, Total Suspended Solids, and Color in Lower Hudson River, 1970-72

microorganisms, chemical substances (silica, iron, zinc, and manganese compounds), and eroded clay or silt. Domestic and industrial effluents also can increase the turbidity of a water body. The amount of suspended solids in a sample is determined by gravimetric analysis and is usually correlated with the turbidity of the sample.

APPENDIX B

WATER CHEMISTRY

APPENDIX B

WATER CHEMISTRY

A. DISSOLVED SOLIDS

In natural waters, dissolved solids consist mainly of carbonates, bicarbonates, chlorides, sulfates, phosphates, and nitrates. Calcium, magnesium, sodium, and potassium are also present, along with traces of iron, manganese, and other substances. The concentration of dissolved solids can be estimated by multiplying the measured specific conductance of most natural waters (in micromhos cm^{-1} at $25^{o}C$) by a factor between 0.55 and 0.7. For inland freshwater lakes and rivers, the value of specific conductance generally lies between 150 and 500 μmhos cm^{-1} at $25^{o}C$. (Fig. B-1).

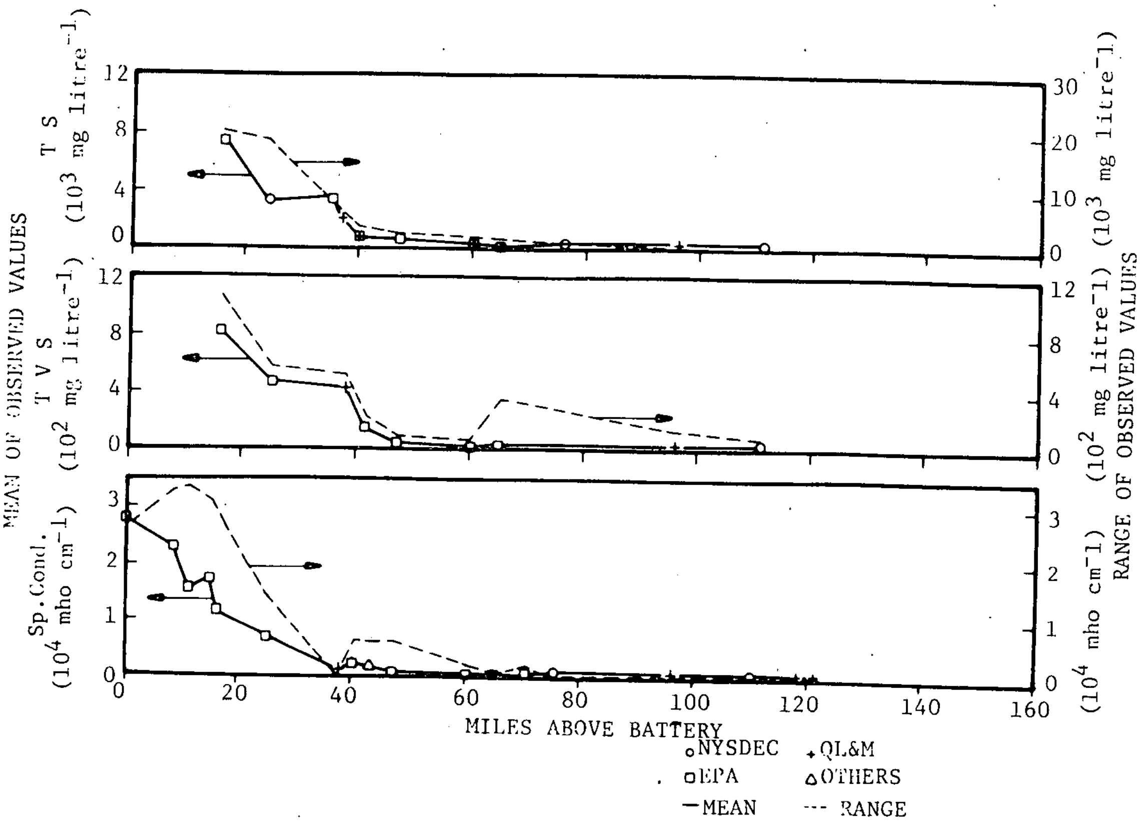


Figure B-1 Specific Conductance, Total Volatile Solids, and Total Solids in Lower Hudson River, 1970-1972

Natural sources of suspended solids include silt, organic detritus, and plankton. Man-induced sources are industrial and residential wastes and erosion (including wind-blown dust) from unforested and cultivated areas.

The most significant impact of these three parameters on aquatic systems is their influence on light penetration. As their values increase, the light intensity at each depth is reduced, which in turn reduces photosynthetic activity of aquatic plants. This reduction indirectly affects the organisms at higher trophic levels; for example, by limiting primary production and therefore available food, growth of fish populations is limited. Reduced light penetration also may directly influence fish and other predators by impairing their ability to find prey by visual cues.

In addition to their effects on light penetration, turbidity and suspended solids also may influence temperature stratification, particularly in still bodies of water. Because high concentrations of suspended solids may be lethal to some species (e.g., clog fish gills and cause suffocation) or inhibit biological processes of others, these substances should be accorded special consideration.

B. DISSOLVED OXYGEN

The types of organisms present and their pattern of distribution within an environment are determined in part by the concentration of dissolved gases within the water. The most important of these is oxygen, which decreases in solubility with rising temperature and decreasing barometric pressure.

Aquatic plants simultaneously produce oxygen during the process of photosynthesis and utilize it in respiration. In the illuminated nutrient-rich surface waters, plant photosynthesis produces more oxygen than is consumed by plant respiration.

Non-photosynthetic organisms derive energy for their life processes from oxidation of energy-rich molecules. In poorly lighted or unlighted portions of water bodies and at night, aquatic biological systems consume more oxygen than is produced by photosynthesis.

The organic materials contained in the estuary or deposited in its bottom are additional causes of oxygen demand. These materials originate from both natural and artificial sources. Aerobic decomposition of aquatic plants and organisms and surface runoff represent the natural sources, while industrial and municipal wastes discharged into the estuary are the artificially introduced sources of oxygen demand. The addition of municipal wastes to the lower Hudson is a major determinant of longitudinal variations in dissolved oxygen content. If the oxygen concentration of an area is not periodically renewed (i.e., by photosynthesis, currents), anaerobic conditions will be established and most aquatic organisms will die.

1. Observed Hudson River Dissolved Oxygen Concentrations

Many observations of Hudson River dissolved oxygen (DO) concentrations have been made at different locations and times by various governmental, state, and private institutions. These measurements provide the basic information on river DO levels. Three surveys conducted by Quirk, Lawler and Matusky Engineers in August, September, and October 1967 have yielded the most comprehensive DO concentration data available for the Hudson River estuary. The longitudinal DO profiles in Figure B-2 are based on the 1967 data, while Figure B-3 shows average values and ranges based on measurements performed by many different organization during 1970-72. Winter values generally range between 6.0 and 13.0 mg litre^{-1}, while summer concentrations range from approximately 1.0 mg litre^{-1} (Albany reach) to approximately 9.0 mg litre^{-1}.

All Hudson River estuary DO profiles have a typical shape. After the Troy dam, concentration steadily declines, sags in the Albany area, quickly recovers to reach a high in the vicinity of Saugerties, then varies little to remain at relatively high levels to Croton Point. Downstream of this site, the DO concentration begins to sag, reaches low values along Manhattan Island, and increases from the Battery to the ocean, where it finally reaches saturation.

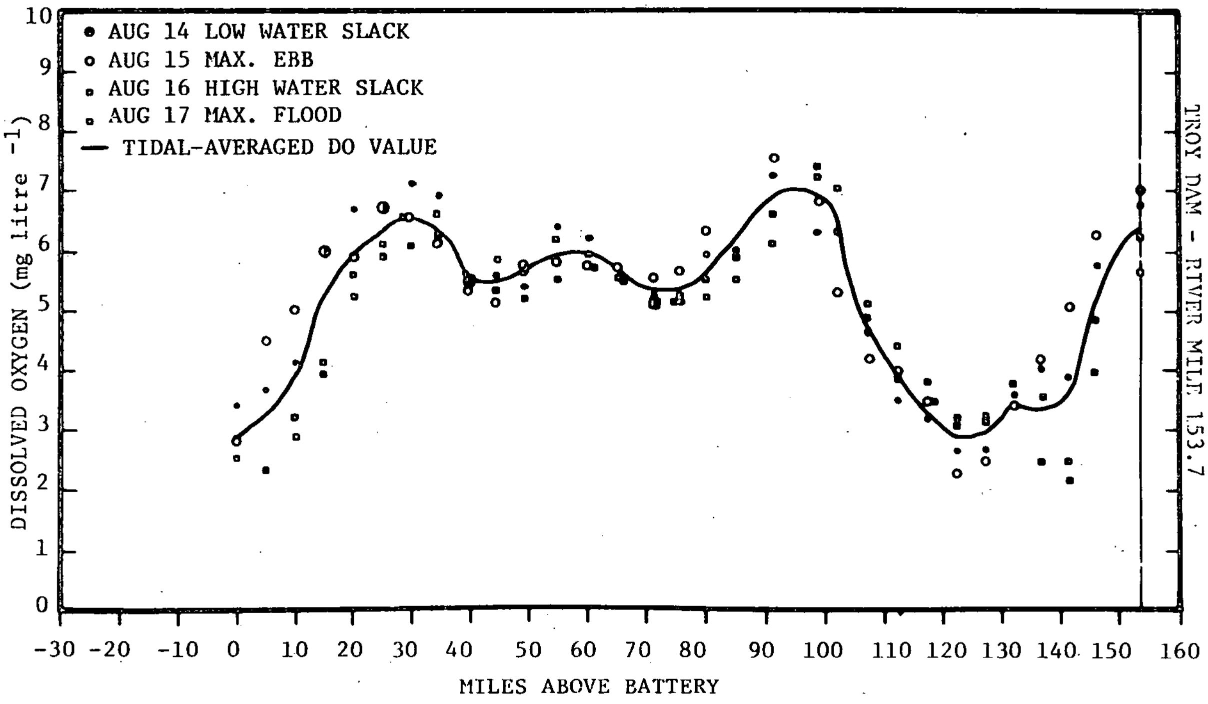
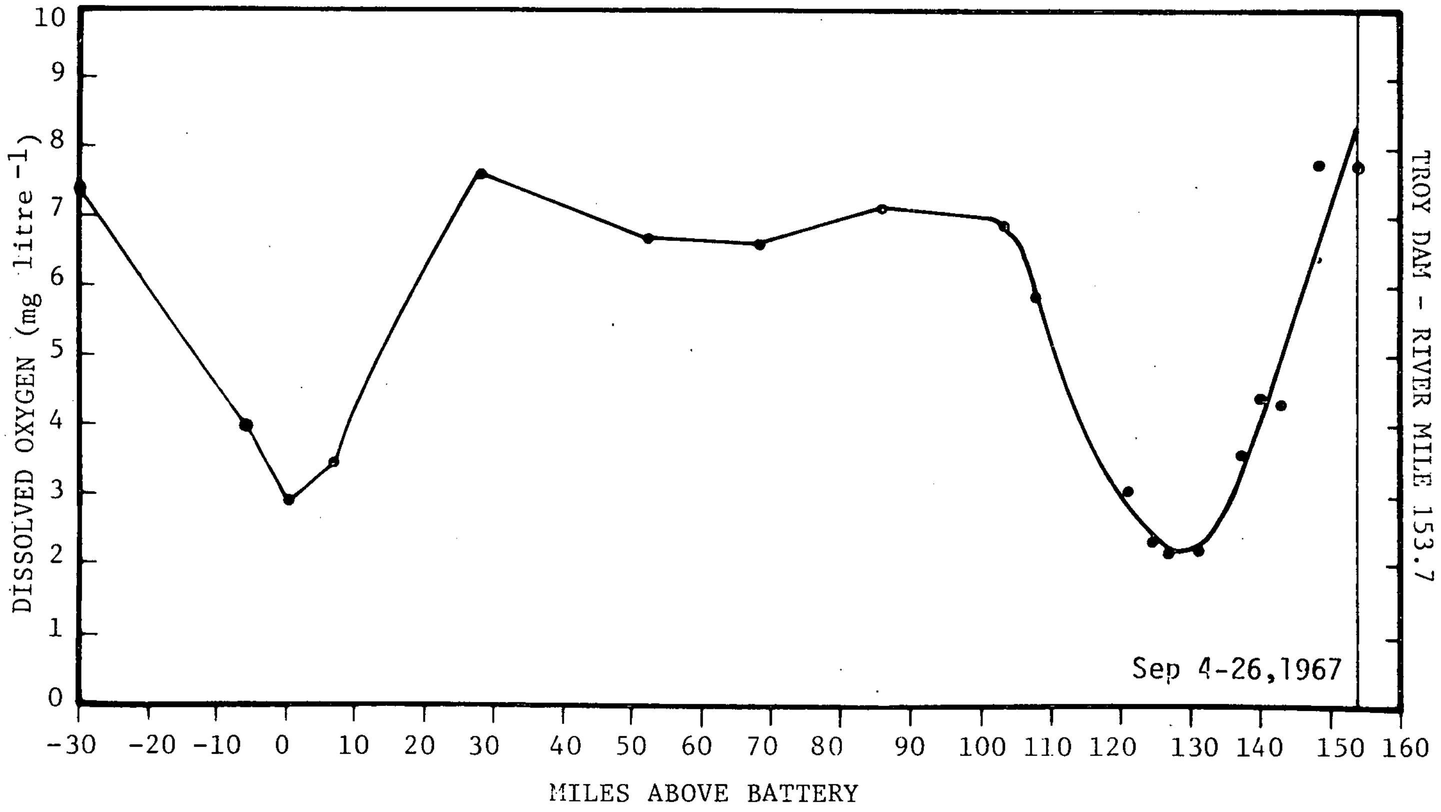


Figure B-2 Hudson River Estuary Dissolved Oxygen Profile, 1967 (LMS 1975a) (Page 1 of 3)



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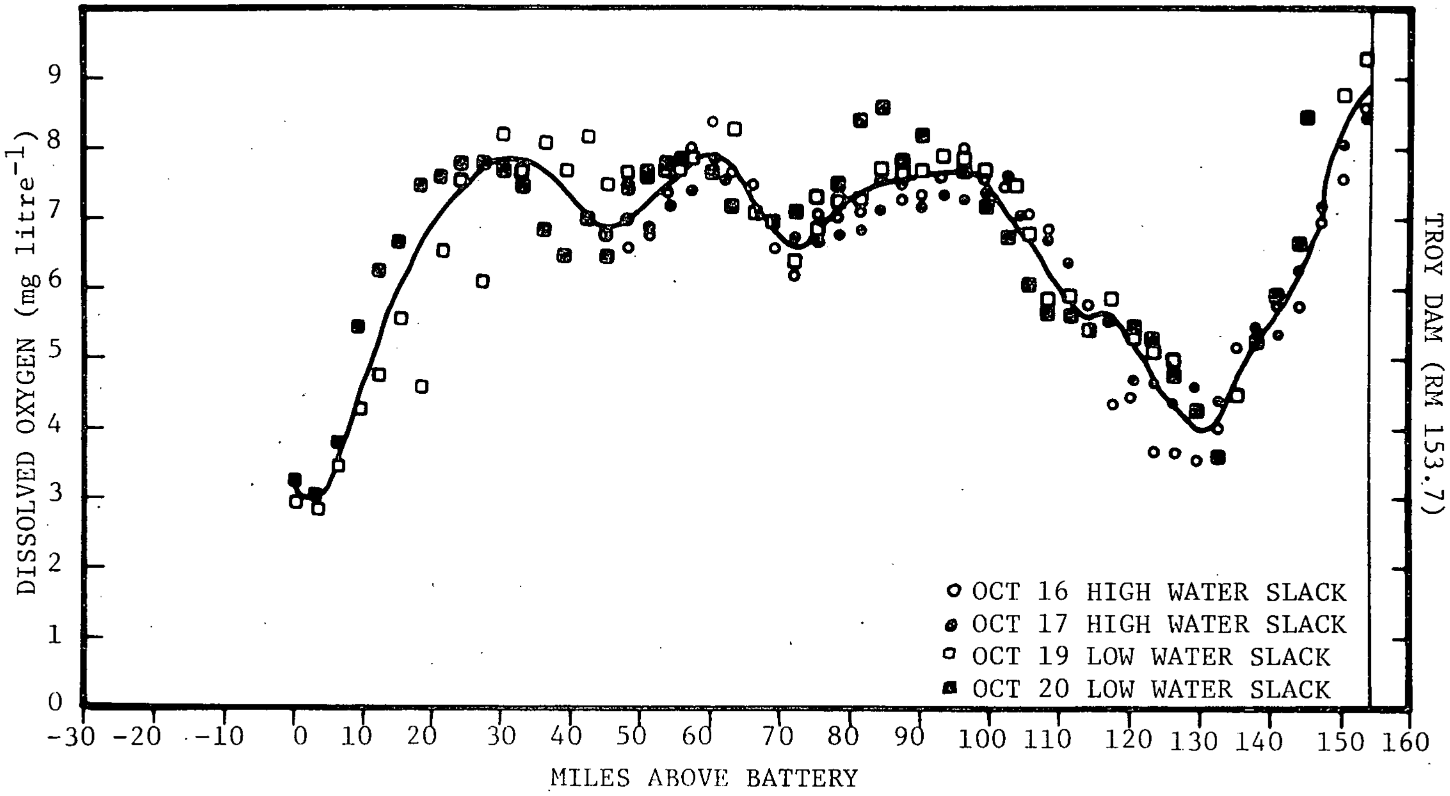

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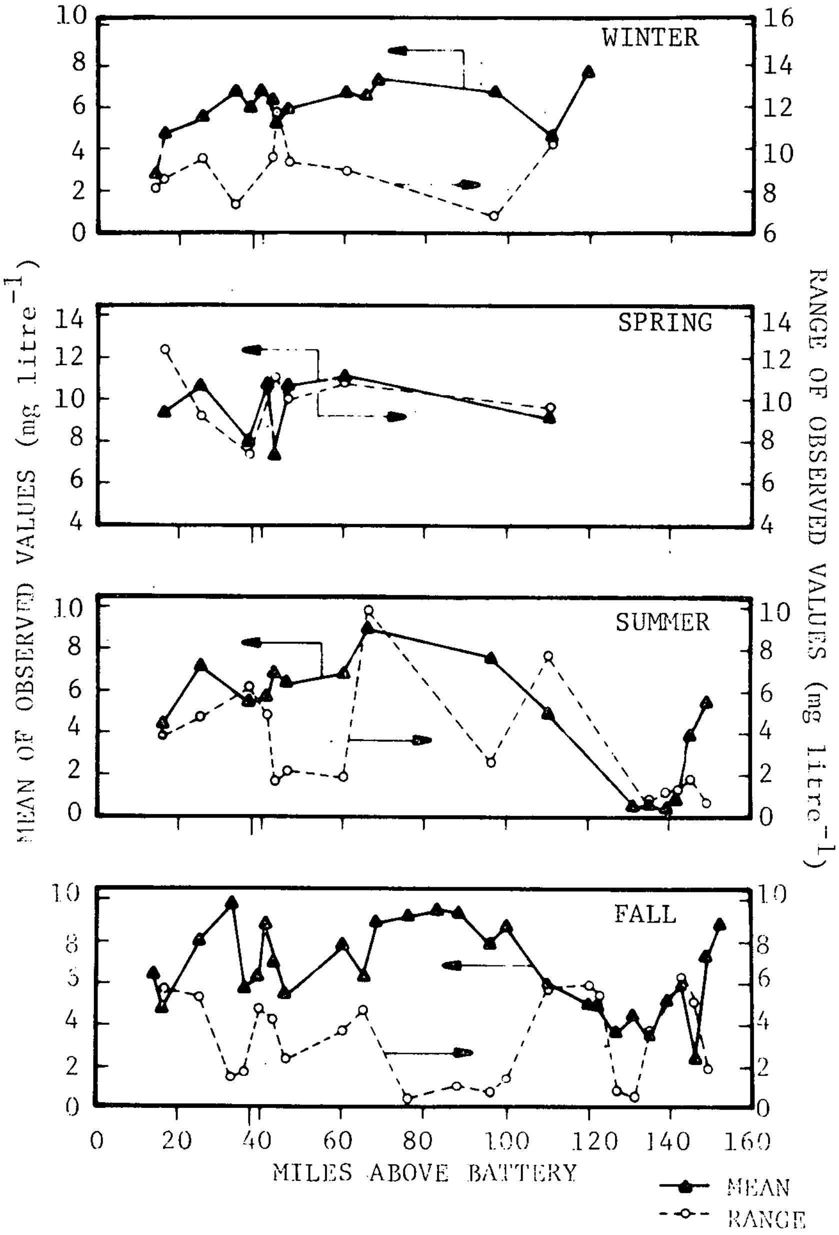

Figure B-3 Dissolved Oxygen in Lower Hudson River, 1970-72

APPENDIX C

GENERAL TEMPERATURE EFFECTS

APPENDIX C

GENERAL TEMPERATURE EFFECTS

A substantial body of literature has accumulated on the effects of temperature on aquatic organisms; annual reviews of this literature conducted by C.C. Coutant and others have appeared in the Journal of the Water Pollution Control Federation. Although the impact of a thermal discharge is site-dependent, a number of potential thermal effects have been identified (Table C-1).

The effects of a thermal discharge will depend on such site-specific characteristics as:

- The water's ambient (natural) temperature
- Magnitude of the temperature rise (ΔT) as water passes through the condenser cooling system
- Volume of water pumped to sustain a particular temperature rise
- The current patterns within the vicinity of the discharge
- Type of discharge structure
- Duration of exposure of the organism
- The kinds and physiological states of the organisms present

The "zone of tolerance" characterizes the high or low lethal temperatures for a species after acclimation. Within this temperature range, the organism can survive, but changes in temperature alter its physiological characteristics. When body temperatures of fish are raised, for example, the transport of oxygen by blood pigment is reduced, lipids change in state, and all membranes become increasingly permeable.

Table C-1 Potential Effects of Thermal Discharges on Aquatic Biota

Community	Effect	Reference
Phytoplankton	a. Shift in algal flora from diatoms to blue-greens resulting in obnoxious blooms.	Patrick (1969)
	b. Inhibition of photosynthesis at high and stimulation at low ambient and/or discharge temperatures.	Morgan and Stross (1969); Brooks et al. (1974)
Macrophytes	a. Possible shift in species composition due to difference in optimum temperature for growth and photosynthesis.	Anderson (1969) Stanley and Naylor (1972) Reed et al. (1974)
Benthos	a. Shift in species composition	Wurtz (1969)
	b. Increased incidence of disease in shellfish as a result of increased temperature.	Andrews (1965) Hargis and Warinner (1973)
	c. Lethal effects at high temperatures	Milhursky and Cronin (1967)
	d. Alteration of development and reproduction.	Aston (1973) Wurtz (1969)
Zooplankton	a. Increase of reproductive, development, and growth rates with increasing temperature up to some optimum level; then inhibition above that.	Edmondson (1965) Prosser (1973) Bhajan and Hynes (1972) Hutchinson (1967)
	b. Lethal effects at high temperatures	Lauer et al. (1974) Goss and Bunting (1976)
Fish	a. Alteration of behavior, manifested as attraction to or avoidance of elevated water temperatures; potential for blockage of fish migration due to avoidance.	Meldrim et al. (1974) Cherry et al. (1975) Nakatani (1969) Leggett and Whitney (1972)
	b. Lethal effects of decreasing temperature (cold shock)	American Nuclear Society (1974)
	c. Increased metabolic rate, resulting in poor condition, i.e., "skinny fish."	Merriman (1970)
	d. Increased incidence of parasitism and disease among fish residing in discharge plumes.	Baver (1959) Patrick (1968) Everest (1973)
	e. Lethal effects at high temperatures.	Hoff and Westman (1966)
	f. Synergistic detrimental effects with low dissolved oxygen and/or toxic substances.	FWPCA (1967)

Temperature effects can be modified by the past thermal history of the organisms. Temperature acclimation is a physiological adjustment to a given thermal level within a limited range of temperatures. Fry (1947) calls the maximum upper or lower acclimation point the "ultimate incipient lethal level." When there is a sufficiently large change in temperature (either high or low) to be of physiological significance but acclimation time is not sufficient, "thermal shock", characterized in fish by disorientation and cessation of directed activities, can occur. The critical thermal maximum (CTM) is the thermal point at which a fish's locomotory activity becomes disorganized and the fish loses its ability to escape from conditions that may cause death. During the winter, fish may be attracted to the warmer thermal discharge waters. If the plume is stable, fish may reside in it and become acclimated to the higher temperatures, setting up the potential for cold shock, a phenomenon caused by rapid decrease in water temperature when a power plant terminates the discharge of its heated effluent during the colder part of the year. The severity of cold shock, when it occurs, stems from the physiological fact that fish cannot acclimate to descending temperatures as quickly as they can to ascending temperatures (Brett 1944; Jones 1974).

The degree of potential impact presented by a thermal effluent depends on several factors of plant design, such as rate of dilution, ΔT, and amount of water discharged. A plant with a small discharge, a low ΔT, and efficient dilution would have low potential for fish kills caused by cold shock. The stability of the heated area is of prime importance when evaluating potential cold-shock problems.

The effects of temperature are influenced also by a variety of factors, e.g., the length, weight, sex, and age of the fish, as well as the photoperiod, light intensity, diet, water chemistry, and salinity (Halsband 1953; Sullivan and Fisher 1953; Hoar 1955; Fisher 1958; McCauley 1958; Hoar and Robertson 1959; Cragie 1963; Sprague 1963; Smironova 1967; Garside and Jordan 1968; Baker et al. 1970; Meldrim and Gift 1971; and Cherry et al. 1975).

APPENDIX D

BIOLOGICAL EFFECTS OF CHEMICAL EFFLUENTS

APPENDIX D

BIOLOGICAL EFFECTS OF CHEMICAL EFFLUENTS

The United States Atomic Energy Commission (1973) described the complexity of chemical composition in power plant effluents:

> The composition of the discharge is unique to each situation and depends upon such factors as intake water quality, additives used for neutralizing or passivating the water, additives used for pre-operational cleaning, additives used for preserving the structural strength of cooling tower wood, and additives used for control of corrosion, scaling, and biological growths. Compounding the situation in the effluents are chemical reactions that occur between various compounds, depending on whether one or more are present in the system at any given time, and between various chemicals and the cooling or receiving water.
>
> Certain groups of chemical additives are commonly encountered. Mixtures of chromate, zinc, phosphate, and silicates are frequently used for corrosion control. Chlorine, hypochlorites and non-oxidizing organics, such as chlorophenols, quaternary amines and organometallics, are used to control microbial growths. Acids and alkalis are used for pH control of the water, and such additives as hydrazine may be used to reduce the oxygen content. Silt deposition may be reduced by use of polymers such as lignin-tannin dispersives, polyacrylamides, polyacrylates, polyethylene amines and other polyelectrolytes. Organic phosphorus compounds such as organic phosphates, aminomethylene phosphonate, and polyesters are often used to control corrosion and scale formation and to act as dispersives.

Toxicity data on the most important chemical constituents of these effluents have been compiled by the USAEC (1973) and National Academy of Sciences and National Academy of Engineering (1973). In addition, there has been bioassay work on the effects of these chemicals on Hudson River organisms (Con Edison 1973). These data are summarized in the following paragraphs.

A. PHOSPHATE

Phosphate is an algal nutrient. Generally, if its addition to a system does not perturb the existing ratio of nitrogen to phosphorus, many species will have larger populations, predator pressure will increase, and the productivity of the ecosystem will increase; if the ratio is altered, the potential of excessive growth of species with low predator pressure increases. The interrelationships of the many physical and chemical factors included in such a shift in community are quite complex and still poorly understood.

Any one limiting factor (e.g., solar radiation, temperature, salinity, etc.) may prevent excessive growth of nuisance organisms even though most of the conditions are favorable. The most widely endorsed criteria for phosphate suggest that inorganic orthophosphate to total phosphate and NO_3- to PO_4-P ratios be maintained as they occur naturally.

Dowden and Bennett (1965) showed that *Daphnia magna* exhibited a 96-h TL_m of 126 mg $litre^{-1}$ of Na_3PO_4. Gift et al. (1971) conducted bioassays with phosphate and arrived at the following 96-h static median tolerance limits (TL_m) for two fish sepcies:

	96-h TL_m
Fundulus heteroclitus	28.32 mg $litre^{-1}$ (as PO_4)
Menidia menidia	9.62 mg $litre^{-1}$ (as PO_4)

Lauer et al. (1973) conducted static bioassays to determine the effects of trisodium phosphate on Hudson River fish:

	24-h TL_m	48-h TL_m
Morone americana	510 mg $litre^{-1}$	510 mg $litre^{-1}$
Morone saxatilis	388 mg $litre^{-1}$	385 mg $litre^{-1}$

B. CYCLOHEXYLAMINE

Gift et al. (1971) conducted bioassays with cyclohexylamine and arrived at the following 96-h static median tolerance limits (TL_m) for two fish species:

	96-h TL_m
Fundulus heteroclitus	2.36 mg litre^{-1}
Menidia menidia	0.80 mg litre^{-1}

Lauer (1973) conducted static bioassays to determine the effects of cyclohexylamine on Hudson River fish:

	4-h TL_m	48-h TL_m
Morone americana	40 mg litre^{-1}	40 mg litre^{-1}
Morone saxitilis	64 mg litre^{-1}	64 mg litre^{-1}

C. HYDRAZINE

Very little bioassay data are available to describe the toxicity of hydrazine to aquatic organisms. Certainly the addition of this compound in excess of the oxygen present in a natural body of water would kill any organism that depends on the available dissolved oxygen for its existence. Crestin et al. (cited in Con Edison 1974) reported behavioral differences in fish (*Morone americana* and *Morone saxatilis*) maintained at a 10 mg litre^{-1} hydrazine concentration but provided no information on dissolved oxygen. Gift et al. (1971) conducted bioassays with hydrazine and arrived at the following 96-h static median tolerance limits (TL_m) for two fish species:

	96-h TL_m
Fundulus heteroclitus	2.36 mg litre^{-1}
Menidia menidia	0.80 mg litre^{-1}

However, in a separate 48-h test of hydrazine in conjunction with ammonia, the TL_m was as follows:

	48-h TL_m
Fundulus heteroclitus	13.3 mg $litre^{-1}$
Menidia menidia	7.4 mg $litre^{-1}$

Once again, the relevant dissolved oxygen effects were not discussed.

D. SODIUM SALTS

Sodium sulfite is highly soluble and completely dissociates in water. The sulfite anion reacts with dissolved oxygen and other oxidizing agents and is quickly oxidized to sulfate. The toxicity of sulfite to aquatic organismsm is a function of the decrease of dissolved oxygen in the system. Most power plant discharges contain the oxidized sulfate product which is of low toxicity to aquatic organisms. Most algae can utilize and reduce sulfate as their sole source of sulfur, which is an essential component of the common amino acids methionine, cystine, and cysteine (Schiff 1962).

E. CHROMIUM

The chemical form and mode of toxic action of chromium varies not only with the valence but also with pH, temperature, and water hardness. Susceptibility of aquatic life to the trivalent metal may be complicated by the pH stress caused by the marked acidity of most trivalent chromium salts. In hard water, however, the solubility of trivalent chromium decreases (to an extent dependent on the pH and mineral content) through the formation of colloidal or flocculent precipitates. In aqueous solution, a dichromate salt ionizes according to the following expression:

$$2\ H^{+} + 2\ CrO_4^{=} \rightleftarrows 2\ HCrO_4^{-} \rightleftarrows Cr_2O_7^{=} + H_2O$$

The hydrogen ion concentration, therefore, affects the equilibrium between the chromate, hydrochromate, and dichromate ions. The dichromate ion does not occur in significant levels at physiological pH (7). The hydrochromate ion is the most common form encountered in water at low pH (6.0-6.8); at a higher pH (7.5-8.5), the chromate ion predominates. The hydrochromate is more toxic than the chromate ion, perhaps because monovalent ions tend to be more readily absorbed than the divalent ions. Consequently, aqueous solutions of hexavalent chromium are more lethal to aquatic organisms when the pH of the water is <7.0.

Chromium is a natural constituent of marine waters and can be concentrated several thousandfold by marine plants. The threshold of toxicity of chromium to *Nereis virens* was 1.0 mg litre^{-1} (FWPCA 1968). For representative benthic organisms from the Hudson River in the vicinity of Poughkeepsie, Rehwoldt et al. (1972) reported a 96-h TL_m for chromium of 3.2-50.0 mg litre^{-1}. The 96-h TL_m of mosquitofish for chromium was 92 mg litre^{-1} (Wallen et al. 1957). Hughes (1971), however, showed values of 75 mg litre^{-1} for fingerlings and 100 mg litre^{-1} for larvae of *Morone saxatilis*. For bluegills, Turnbull et al. (1954) showed a 48-h TL_m of 410 mg litre^{-1} of sodium dichromate.

Despite the great emphasis given to the importance of pH in bioassay literature, little is known of its direct physiological effects on aquatic organisms. Natural waters are well-buffered; the higher the concentration of dissolved solids, the better the buffering capacity. Extremely large additions of acids or bases are required to overcome this buffering capacity and change the pH. This is not likely to happen as a consequence of power plant discharges into the lower Hudson River because the river water in this region is hard and often brackish and the acids or bases that are added to the river are neutralized before release.

F. SULFURIC ACID

Bioassays conducted by Gift et al. (1971) arrived at the following 96-h static median tolerance limits (TL_m) for sulfuric acid (as SO_4):

	96-h TL_m
Fundulus heteroclitus	28.32 mg $litre^{-1}$
Menidia menidia	9.62 mg $litre^{-1}$

Lauer et al. (1973) conducted static bioassays to determine the effects of sulfuric acid (as H_2SO_4) on Hudson River fish:

	24-h TL_m	48-h TL_m
Morone americana	57 mg $litre^{-1}$	56 mg $litre^{-1}$
Morone saxatilis	65 mg $litre^{-1}$	65 mg $litre^{-1}$

None of these studies monitored pH changes caused by adding sulfuric acid at the selected test conditions.

G. SODIUM HYDROXIDE

Sodium hydroxide is readily soluble and highly dissociated in water; it is not directly lethal to adult fish unless the concentration is sufficient to raise the pH above 9.0. Lauer (1973) conducted bioassays to determine the effects of sodium hydroxide on Hudson River fish:

	24-h TL_m	48-h TL_m
Morone americana	91 mg $litre^{-1}$	88 mg $litre^{-1}$
Morone saxatilis	58 mg $litre^{-1}$	88 mg $litre^{-1}$

The calculated maximum boiler-water discharge concentrations at two Hudson River generating stations are 0.3×10^{-10} mg $litre^{-1}$ and 0.6×10^{-10} mg $litre^{-1}$. It is unlikely that any substantial quantities of free hydroxide would be discharged as it forms insoluble compounds with many polyvalent cations.

Standards for natural waters recommend that chemical additions should not drop the pH below 6.5 or raise it above 8.5. The range of pH should not be extended by more than 0.2 pH units nor should the range vary by more than 0.5 pH units (NAS 1973).

H. CHLORINE

In solution, chlorine hydrolizes to form hypochlorous acid and hydrochloric acid (McKee and Wolf 1963). Hypochlorous acid is the primary toxic principal making chlorine an effective biocide: therfore, the pH - HOCl relationship is very important.

McKee and Wolf (1963) observed that marine fish exhibited a slight irritant activity at a chlorine concentration of 1.0 mg litre^{-1} and a violent reaction at 10.0 mg litre^{-1}; the exposure time was 2 min, suggesting that toxic activity occurs at a point easily exposed to the oxidizing activity of chlorine, e.g., the gills. Minnows have been shown to tolerate residual chlorine levels to 0.8 mg litre^{-1}, exhibiting stress at 0.09-0.04 mg litre^{-1}, while carp tolerated residual levels to 1.2 mg litre^{-1}. Work conducted by Lauer et al. (1973) on white perch and striped bass indicated the short-term (2 h) TL_m level for both species to be 2.8 mg litre^{-1} but the maximum safe concentration to be 0.8 mg litre^{-1}. Gift et al. (1971) observed a 96-h TL_m of 4.8 mg litre^{-1} for *Fundulus heteroclitus* and a 24-h TL_m of 0.70 mg litre^{-1} for *Menidia menidia*; the safe concentrations would be 0.48 mg litre^{-1} and 0.07 mg litre^{-1} respectively. Chlorination has been found to increase the mortality of entrained zooplankton (Lauer et al. 1974) and to decrease phytoplankton productivity (Brooks 1974; Lauer et al. 1974).

Data presented in Section 1.1.2 indicated that Indian Point Unit 2 chemical discharges are within the guidelines established by EPA for safeguarding the survival and reproduction of aquatic species. Therefore, no significant detrimental impact on Hudson River life is anticipated as a result of continuing present levels of chemical discharges from Indian Point Unit 2. Furthermore, except for chlorine, which is well below limits set by the EPA, annual chemical discharges from a cooling tower system probably would not be less than the quantities used anually in the present once-through cooling system.

I. CARBON DIOXIDE, pH, AND ALKALINITY

These three parameters are considered together because they are chemically and biologically interdependent. Their mean and range for 1970-72 are summarized in Figure D-1.

The pH of a water body is an expression of the hydrogen ion activity (i.e., acidity) of that water. More precisely, pH is the logarithm of the reciprocal of the hydrogen ion concentration in moles per litre. This parameter is significant for biological systems because specific chemical and biochemical reactions frequently take place only at specific pH values or within a narrow pH range. The pH of natural waters is a result of substances in solution, particularly carbonates, carbon dioxide, certain chemical salts, and organic substances. Generally, water more acid than pH 5.0 or more basic than pH 9.0 is not found in inland streams (NAM 1973). In addition to being directly harmful to aquatic organisms, pH extremes are indirectly harmful because they may interact synergistically with other substances (e.g., heavy metals) to increase their toxicity.

Another result of the combined effects of several chemical substances and environmental conditions is alkalinity, which is a measure (in milligrams per litre) of a solution's ability to neutralize hydrogen ions. It results from the presence of carbonates, bicarbonates, hydroxides, and to a lesser extent, borates, silicates, phosphates, and organic substances. Waters having an alkalinity >100 mg litre^{-1} are said to be well-buffered and highly resistant to pH changes; waters with alkalinity values <25 mg litre^{-1} tend not to support abundant aquatic life.

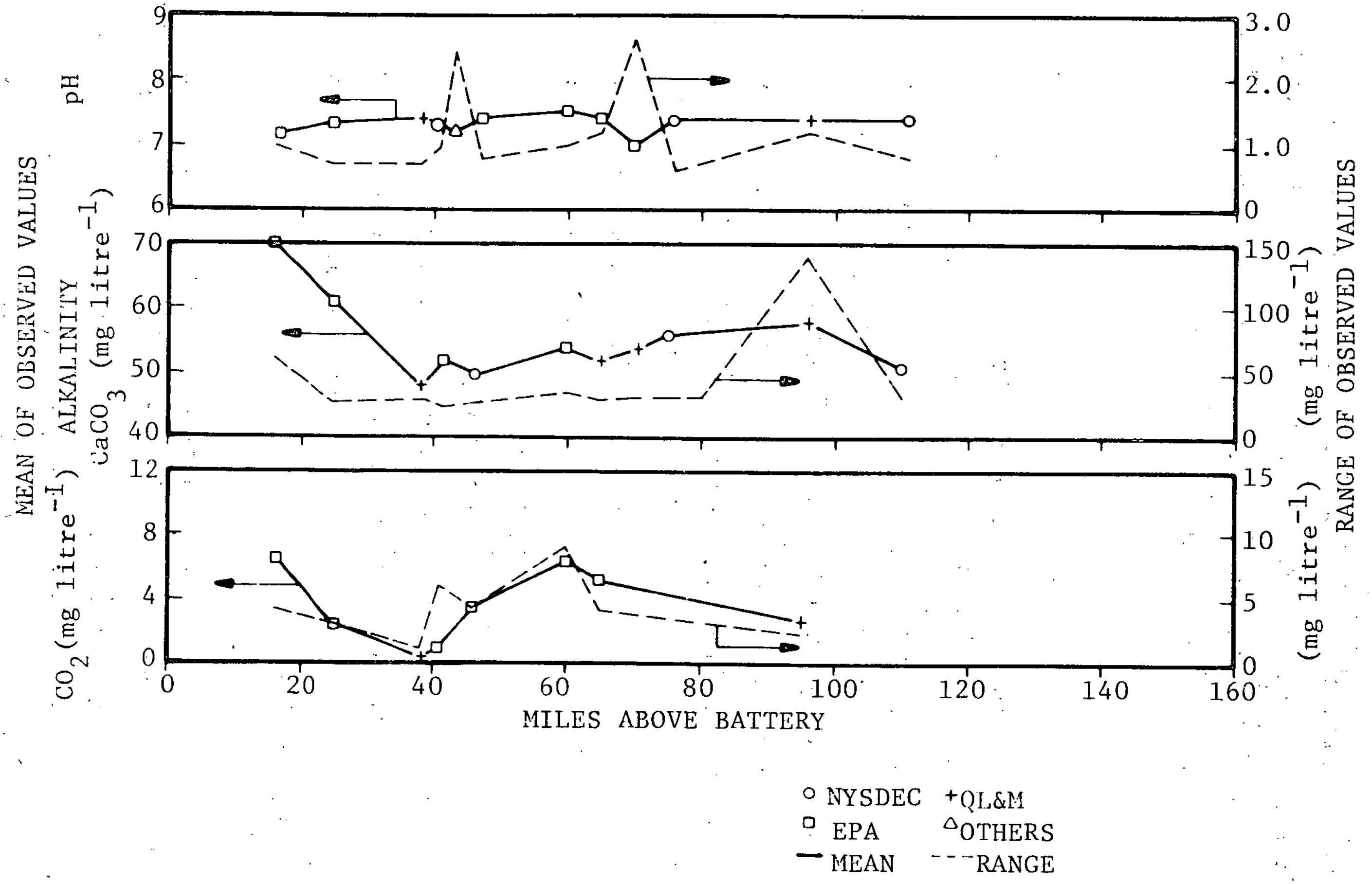

Figure D-1 Alkalinity, pH, and Carbon Dioxide of Lower Hudson River, 1970-72

Although carbon dioxide is a common constituent of the atmosphere and is readily soluble in water, the primary source of CO_2 in water is the respiration of aquatic organisms or the decomposition of organic matter. Dissolved carbon dioxide reacts with water to form carbonic acid, which, in turn, dissociates to produce bicarbonate ions. The bicarbonate ion then acts to buffer the pH of the system.

J. NUTRIENTS

Nitrogen and phosphorus are two important nutrients that may limit the growth of aquatic organisms. If sufficient concentrations of other nutrients are also available, large inputs of nitrogen and phosphorus may permit blooms of undesirable algal species, which may lead to a degradation of water quality. Data for Hudson River estuary phosphorus (total phosphate and orthophosphate) and nitrogen (ammonia nitrogen, organic nitrogen, and nitrate nitrogen) are presented in figures D-2 and D-3, respectively.

Phosphorus is a key element in determining the biological activity in a water body; it is a critical nutrient for algae, whose growth into blooms is a major manifestation of the eutrophication process; and it is an essential element for living organisms, invariably occurring in several organic forms in natural waters as well as in inorganic forms. Although the critical levels of organic and inorganic phosphorus are not yet well-established, concentrations in most lakes producing nuisance blooms average >0.10 ppm and 0.01 ppm, respectively.

Natural unpolluted waters generally contain minute amounts of ammonia nitrogen, which results primarily from aerobic decomposition of aquatic organisms or from organic matter brought into the system from surrounding areas by surface runoff. The organic nitrogen in a water body is considered an indicator of the metabolic activity of its living organisms and the decomposition of its dead organisms. Approximately 60-80% of this organic nitrogen is composed of free amino acids, polypeptides, proteins, and also occurs as albuminoid nitrogen.

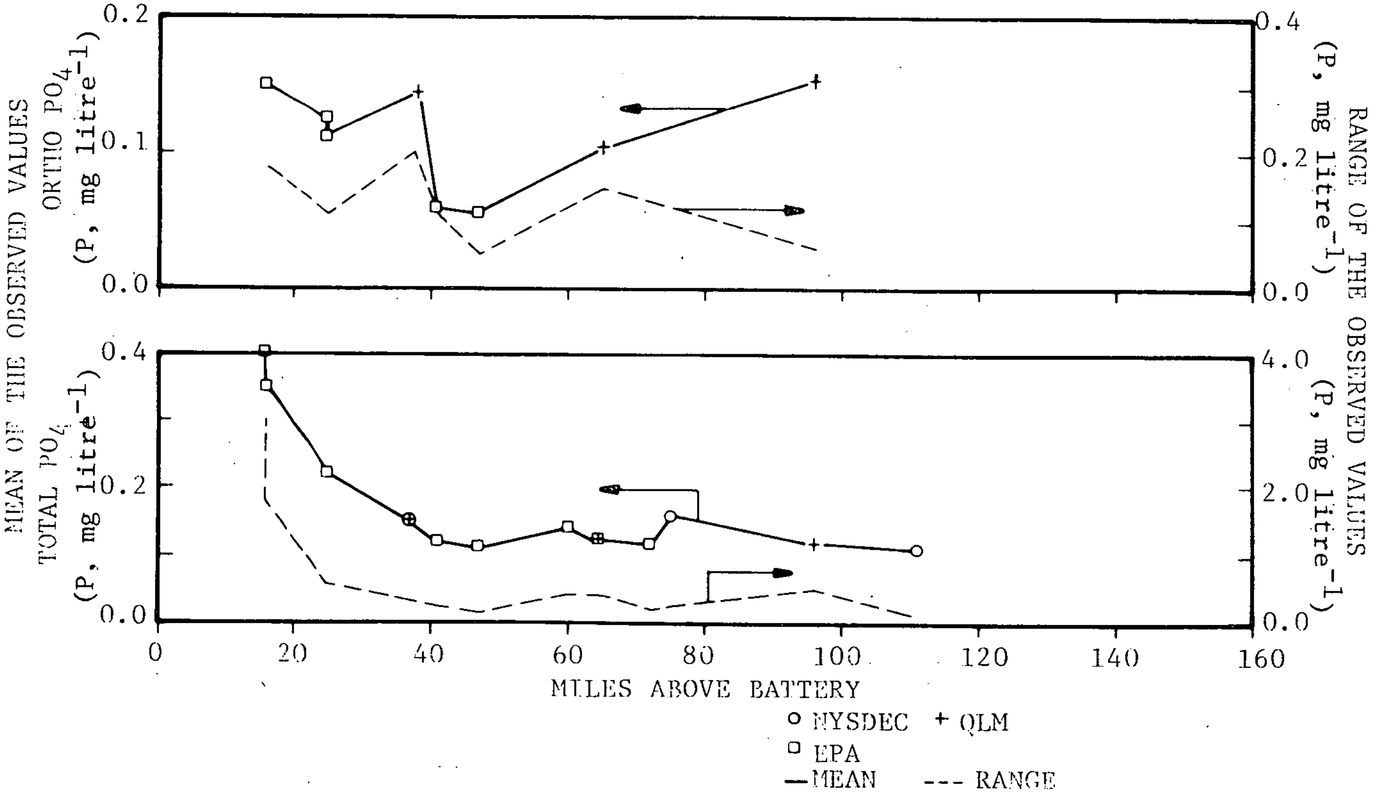

Figure D-2 Total Phosphate and Orthophosphate in Lower Hudson River, 1970-72

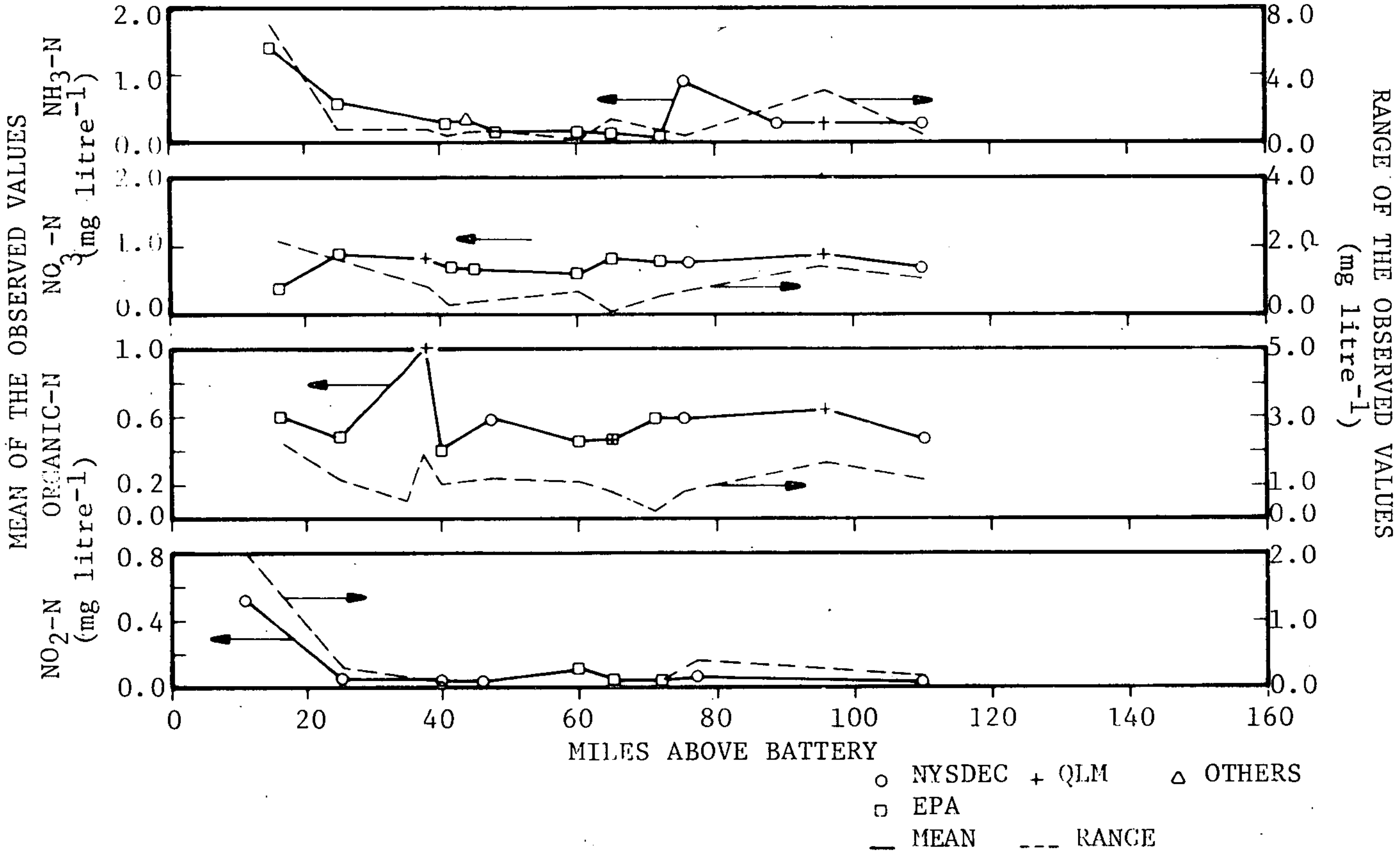

Figure D-3 Ammonia Nitrogen, Organic Nitrogen, and Nitrate Nitrogen in Lower Hudson River, 1970-72

Nitrate nitrogen usually occurs in fresh water as a by-product of bacterial nitrification or as a result of runoff from fertilized land. Nitrification normally increases with higher temperatures of summer, when bacterial activity is greatest. Nitrate nitrogen is generally high in estuarine areas because of runoff and organic releases.

K. HARDNESS

Hardness is caused by bivalent metallic cations that are capable of reacting with soap to form precipitates and with certain anions present in the water to form scale. The principal hardness-causing cations are Ca, Mg, Sr, Fe, and Mn. Hardness stems from minerals that are carbonates of calcium and magnesium. Other hardness-producing metallic ions are included when they are present in significant amounts. The hardness of water, usually expressed in terms of $CaCO_3$, reflects the nature of the geological formations with which it has been in contact.

Hardness data for the lower Hudson River during 1970-72 are summarized in Figures D-4 and D-5.

L. HEAVY METALS

When the concentrations of any heavy metal such as lead, zinc, copper, iron, cadmium, or chromium become sufficiently high, the water quality is degraded to a point at which it becomes unfit for human use and/or adversely impacts aquatic organisms. The heavy metals (mercury and lead), which generally occur in low concentration in estuarine water, may accumulate in living tissues of some phytoplankton and zooplankton. The heavy metals, when ingested by invertebrates, are passed on to the second trophic (feeding) level. Fish and other predators then accumulate the metals by feeding on any of the lower levels in the food web. In this way, toxic amounts of heavy metals have been observed to accumulate in organisms at higher trophic levels, even though they have not been directly exposed to toxic concentrations of those metals in the water of the estuary. Hudson River data for lead (Pb), copper (Cu), and iron (Fe) are summarized in Figure D-6.

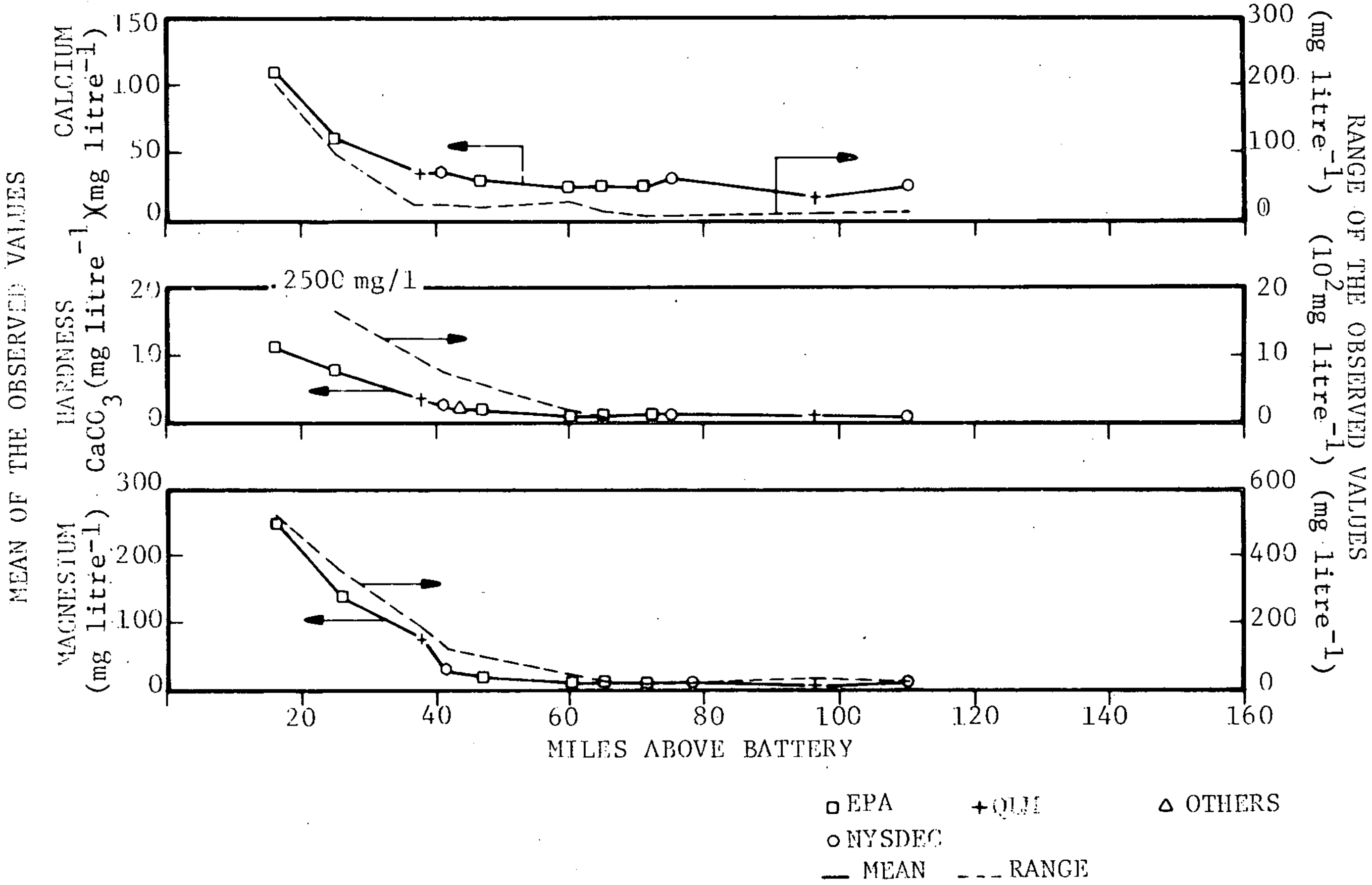

Figure D-4 Calcium, Hardness ($CaCO_3$), and Magnesium in Lower Hudson River, 1970-72

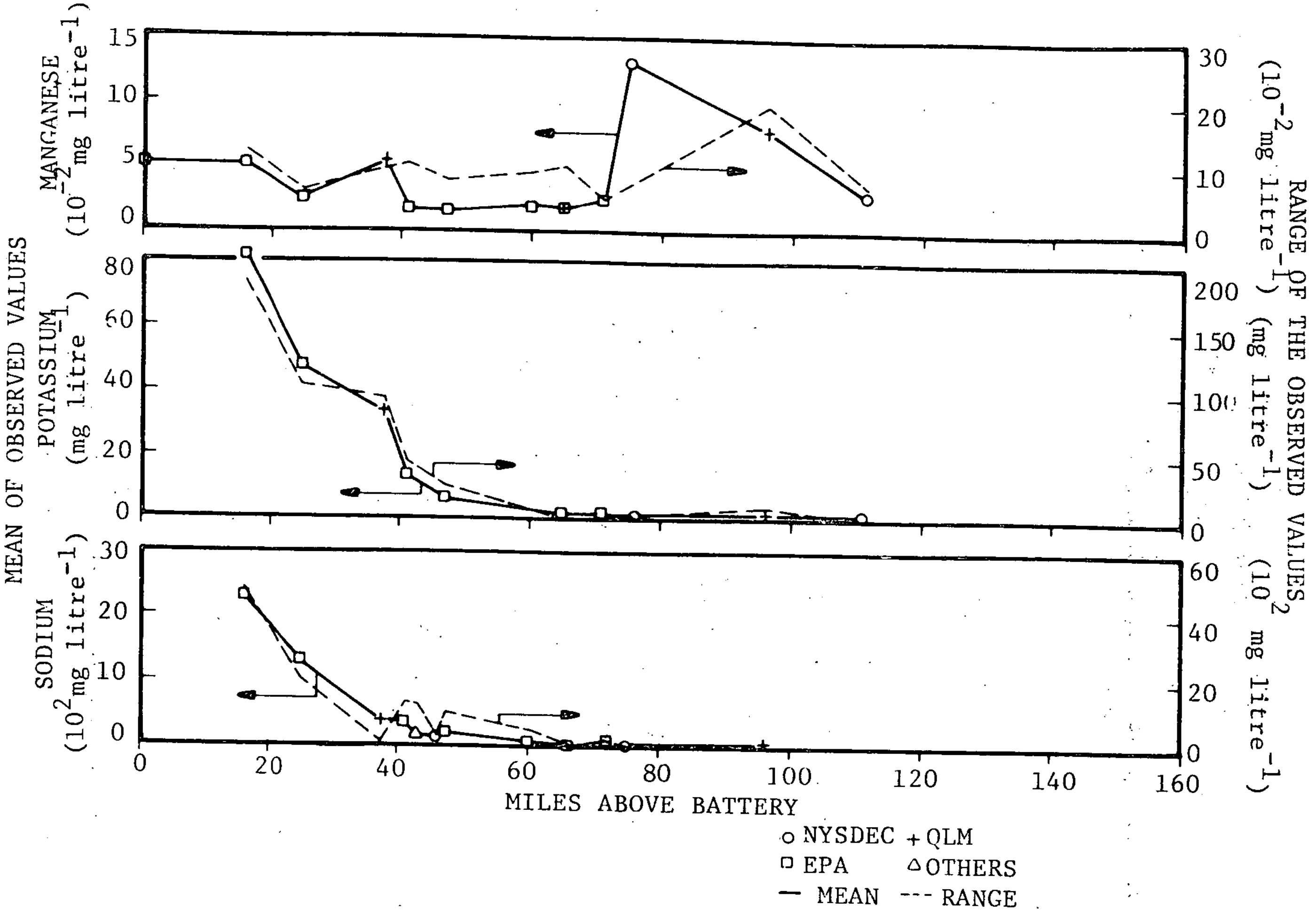

Figure D-5 Sodium, Potassium, and Manganese in Lower Hudson River, 1970-72

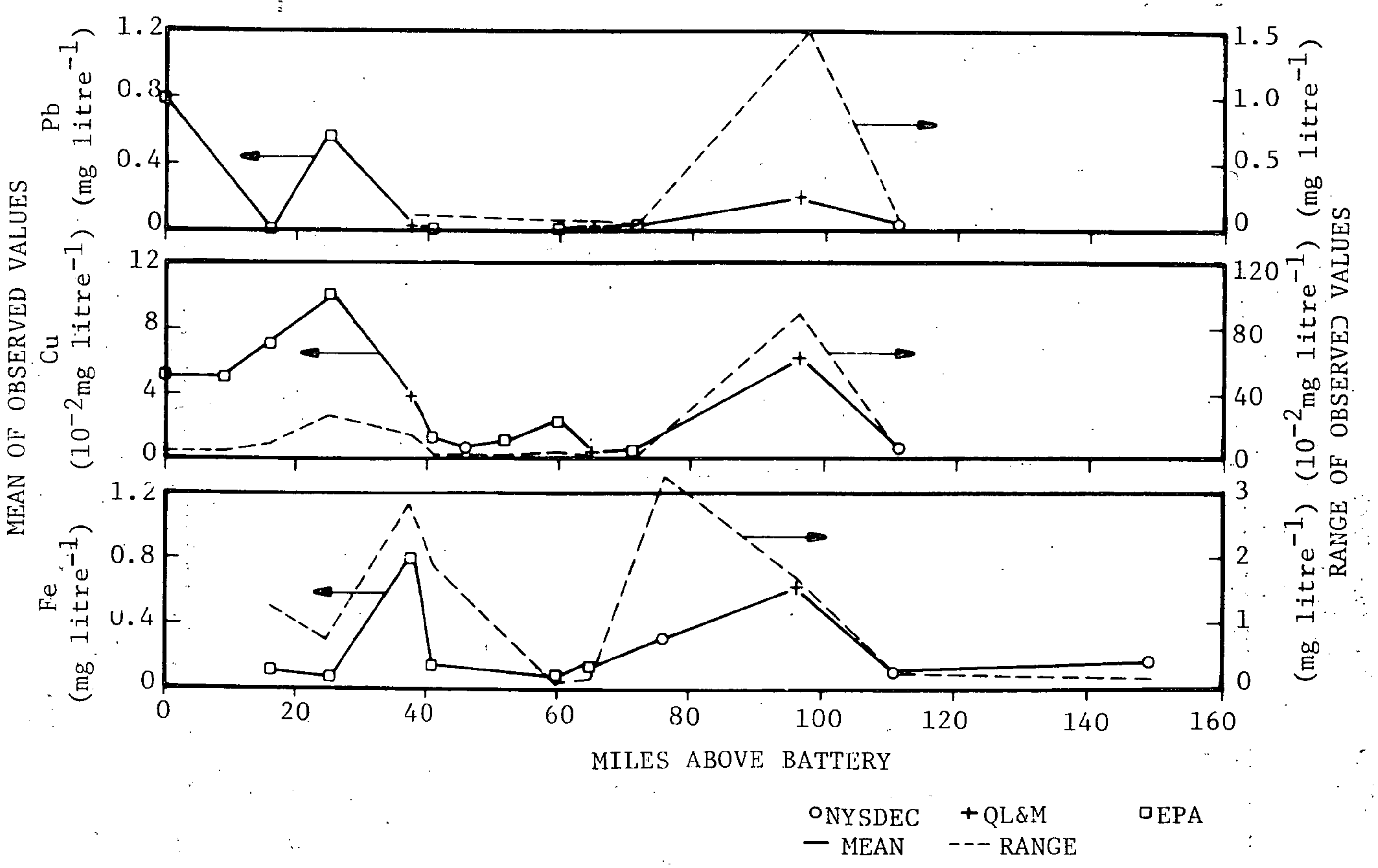

Figure D-6 Iron, Copper, and Lead in Lower Hudson River, 1970-72