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EFFECT OF DELAWARE RIVER FLOW ON OYSTERS IN THE NATURAL SEED BEDS OF DELAWARE BAY

By James B. Engle, Fishery Research Biologist
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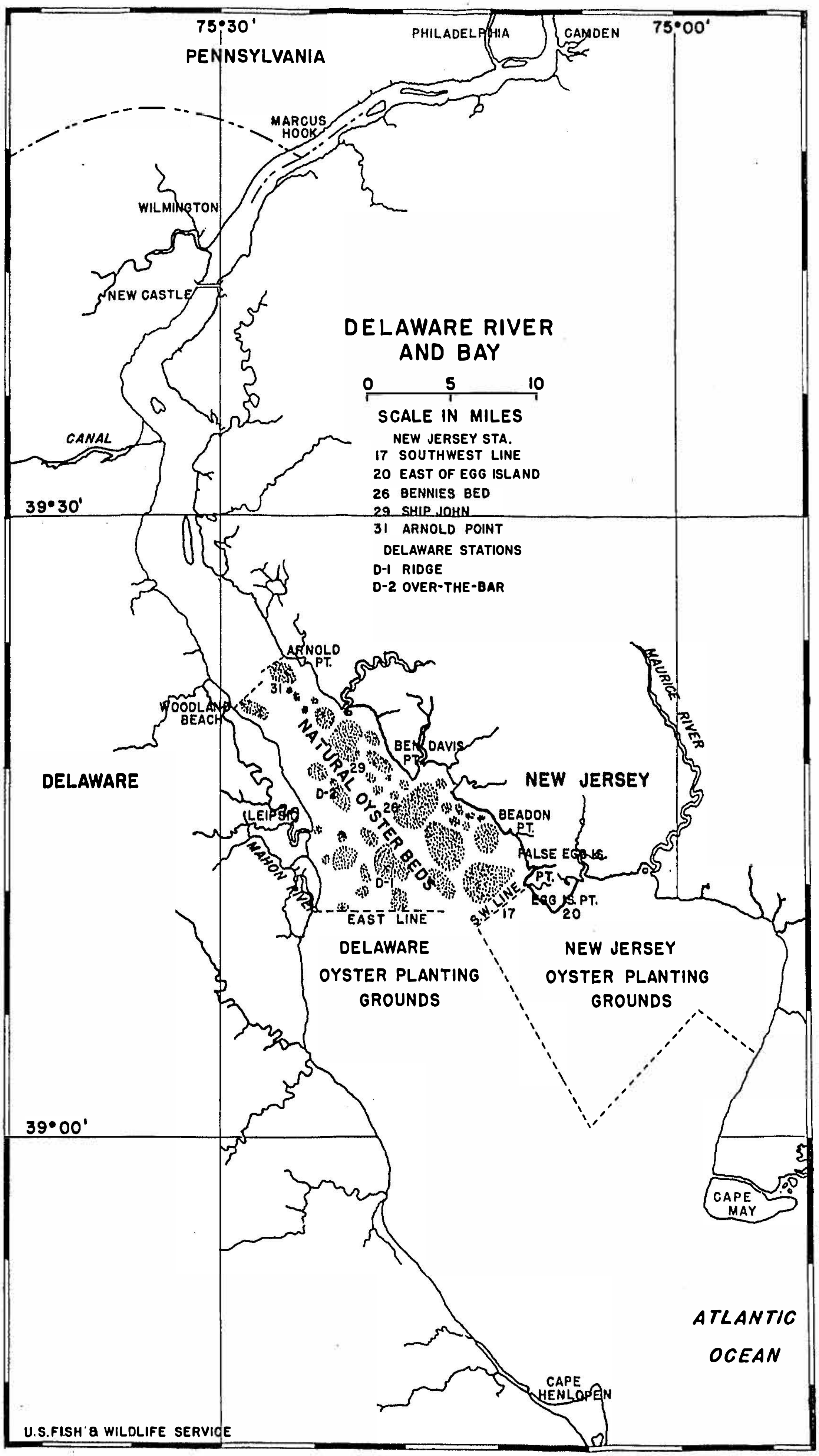
75°30'
75°00'
PENNSYLVANIA
PHILADELPHIA
CAMDEN
MARCUS HOOK
WILMINGTON
NEW CASTLE
DELAWARE RIVER AND BAY
0 5 10
SCALE IN MILES
NEW JERSEY STA.
17 SOUTHWEST LINE
20 EAST OF EGG ISLAND
26 BENNIES BED
29 SHIP JOHN
31 ARNOLD POINT
DELAWARE STATIONS
D-1 RIDGE
D-2 OVER-THE-BAR
CANAL
39°30'
ARNOLD PT.
WOODLAND BEACH
NATURAL OYSTER BEDS
BEN DAVIS PT.
MAURICE RIVER
DELAWARE
NEW JERSEY
LEIPSIC
MAHON RIVER
BEADON PT.
FALSE EGG IS. PT.
EGG IS. PT.
S.W. LINE
EAST LINE
DELAWARE OYSTER PLANTING GROUNDS
NEW JERSEY OYSTER PLANTING GROUNDS
39°00'
CAPE MAY
ATLANTIC OCEAN
CAPE HENLOPEN
U.S. FISH & WILDLIFE SERVICE

Introduction and Historical Background

The Delaware River and Estuary flow through or border four states, New York, New Jersey, Pennsylvania and Delaware. The use of their waters is intimately connected with the economies of each State. The use, however, is varied and different for each State. Any major change in the conditions of the river and estuary, while it may benefit one or more States, may also create conditions detrimental to others. The river from headwaters to Marcus Hook furnishes water used mostly for domestic and industrial purposes. In the lower part of the river and estuary is the environment that supports the oyster, a natural resource utilized in an important food industry.

The Interstate Commission on the Delaware River Basin and the New York Board of Water Supply are proposing to increase the utilization of the Delaware River water supply. Their plans, which include diversions, impoundments and releases, will result in diminution of the volume of fresh water flowing into the estuary. To what extent is this diversion likely to affect the welfare of the oysters by altering their environment? This paper is a report on a study conducted to answer that question.

Oysters live, grow and propagate within the salinity range of 5 to 32 parts of sea salts per thousand (o/oo) parts of water. Oyster drills, *Urosalpinx cinerea* and *Eupleura caudata*, can live in only the more saline half of this range (salinities over 15 o/oo). Thus there is left a safe area in the upper part of the Estuary, free of drills, which makes an excellent area for growing seed oysters. New Jersey, recognizing the value of this natural control of these predators of young oysters, set aside the area of the Bay upstream of an arbitrary line running southwest from False Egg Island Point to the ship channel. This line is commonly known as the Southwest Line. Delaware acted similarly and set aside its territorial Bay bottom upstream of a line running east from the mouth of the Mahon River to the Delaware Bay channel. These are the seed producing areas called the Natural Oyster Beds, which are vital to the existence of the oyster industry of the two States.

The investment in this industry in New Jersey, according to Perkins (1931), amounted to slightly more than 50 million dollars of private capital and State holdings. The value today in present day dollars is certainly no less. The production of oysters from 1929 to 1950, and the market value of these crops, as shown in Table 1, indicate some change in the production in 20 years, but only small change in the total value of the product. This is also generally true for that part of the industry located in the State of Delaware.

The oyster industry of Delaware River depends on seed grown in the upper part of the estuary and transplanted to growing grounds in the lower part of the estuary. Production from the seed area, called the Natural Oyster Beds, determines the amount of seed planted on the growing grounds. The oyster industry in New Jersey was developed under this system and has flourished. Maintenance of the Natural Oyster Beds, performed jointly by private and State efforts, is an integral part of the industry.

New Jersey

Year	PUBLIC BEDS Pounds Spring	Fall	PRIVATE BEDS Pounds Spring	Fall	Totals Pounds	Value	Cost Per Pound
1929	—	448,265	—	13,964,094	14,412,359	$3,076,365	.215
1931	28,490	59,230	—	13,261,525	13,349,245	1,479,659	.113
1933	8,296	11,897	3,423,250	3,428,459	6,871,902	488,110	.071
1935	4,000	—	3,786,400	3,787,900	7,587,900	585,750	.079
1939	35,300	216,200	2,110,600	2,113,600	4,475,700	440,505	.098
1940	1,600	200,800	4,000	5,348,900	5,555,300	638,569	.114
1943	43,400	26,000	2,809,700	2,809,800	5,688,900	1,222,778	.210
1948	22,000	22,800	2,786,500	3,010,300	5,841,600	2,336,640	.397
1949	25,200	37,800	2,781,400	4,170,900	7,015,300	2,755,993	.400
1950	30,000	33,392	3,136,900	4,002,400	7,202,692	2,881,337	.403

Delaware

Year	PUBLIC BEDS Pounds Spring	Fall	PRIVATE BEDS Pounds Spring	Fall	Totals Pounds	Value	Cost Per Pound
1929	—	—	—	4,900	4,900	$ 925	.189
1931	—	106,260	—	364,294	364,294	42,517	.119
1933	27,600	—	24,520	165,240	217,360	26,590	.123
1935	—	—	—	581,400	581,400	54,989	.095
1936	—	—	—	5,500	5,500	800	.145
1937	—	—	—	270,200	270,200	29,170	.107
1939	52,500	52,500	—	180,100	285,100	25,063	.086
1940	—	—	—	274,200	274,200	27,227	.100
1942	77,000	76,900	—	29,900	452,900	23,941	.053
1943	28,300	19,300	—	—	47,600	8,325	.173
1948	—	—	1,500,000	750,000	2,250,000	852,400	.370
1949	—	—	895,000	1,225,000	2,120,000	825,000	.400
1950	—	—	1,000,000	918,400	1,918,400	807,000	.426

Figures furnished by Mr. Wm. H. Dumont, Chief, Educational and Market Development Section, Branch of Commercial Fisheries, USF&WS, Washington, D. C.

River flow varies greatly from season to season and from year to year, affecting temporarily the populations of oysters and oyster predators by changing salinities to levels more favorable or less favorable to these animals. The oyster, sedantary throughout its adult life, has, as its only protection against an unfavorable environment, the ability to tightly close its shells. The length of time it can remain closed depends on the temperature of the water. If river flow lowers salinity below 5 to 6 o/oo when water temperature is low (under 5 degrees Centigrade or 41 degrees Fahrenheit) no appreciable mortality is likely to occur. If the same condition of salinity occurred in the summer with high temperature, oysters would die in a short time, Engle (1946), Loosanoff (1952). The latter condition prevailed in July and August 1938 in Delaware Bay, for example, and oysters died from New Beds off Beadon Point upstream to Arnold Point.

Oyster re-population may be rapid when salinity conditions are favorable because the larvae, being pelagic for several weeks, can spread over the area of depletion and settle on the shells of the dead oysters. The predators, drills, while not sessile organisms, do not migrate very rapidly. If a fall in salinity destroys the drills in an area, other drills invade and repopulate the area slowly when favorable salinities again become established. An example occurred in Tangier Sound, Maryland, several years ago. The natural recruitment of oysters consequently the production in Tangier Sound had been low in years preceding 1944, at a time when salinities were high, above 18 o/oo. At the same time, drills were abundant, as shown by the following facts. In April 1944 the State of Maryland planted seed oysters on a bar called Great Rock. Drills killed 50 percent of the seed by July, and 100 percent of it by October. Other places in Tangier Sound when examined that fall, showed a distribution of drills widely covering the area. The presence of drilled small old oyster shells indicated that drill damage was a contributing cause of low recruitment in that and previous years. In 1945 and 1946 excessive rainfall in the entire area reduced salinities during the warm weather below 15 o/oo for many months. The reduced salinities killed drills and inhibited their activities on the fringe areas for several years. During this time oyster recruitment increased because the reduced salinities did not reach a level low enough to damage oysters.

Such a situation paralleling that of the conditions in Tangier Sound in 1945 and 1946, but produced artificially, is the proposal in essence of the Interstate Commission on the Delaware River Basin (Incodel). In their report (1950) under the heading of "Improvement in Sanitary and Salinity Conditions in Lower River", the following statement appeared after an explanation that impoundments would remove and store water during high river flows, and release water into the river system during low flows sufficient to establish a minimum at Trenton, New Jersey, of 4,000 c.f.s. and 4,800 c.f.s. based on two plans of storage:

> "Probably the greatest benefits from this feature of the project, however, will accrue to the heavily industrialized sections of Pennsylvania and New Jersey between Philadelphia and Wilmington and to the oyster and shellfish industry in the lower river and bay along both the New Jersey and Delaware shores. This area is particularly

vulnerable to the devasting (devastating) effects of the encroachment of salt water from the ocean in seasons of deficient rainfall. The proposed program provides for the release of large quantities of impounded waters to minimize such occurrences. Its operation in this manner will go a long way in eliminating the current periodic damages to manufacturers caused by salinity. These are estimated to amount to approximately three-fourths of a million dollars a year on the average; in some years this damage has reached an estimated $2,000,000. The multi-million dollar oyster industry in the lower river and bay should benefit to an equal or greater extent because maintenance of favorable salinity prevents the destruction of young oysters by their natural enemies."

In conclusion their report has this to say in summing up the benefits accruing to the oyster in the natural seed area.

"(9) Salinity conditions in the important shell fish propagation areas will be so improved as to reduce materially the damage caused by drills which feed upon and destroy young oysters."

Incodel recognized the value of the shellfish industry and the danger that exists because of oyster drill invasions. Because principal damage to seed oysters comes from the depredation of drills, some ecological requirements of these animals should be known. In general the drills are widespread over most oyster-producing waters of the middle and north Atlantic coast. Their range is restricted in nature by their salinity tolerance. In Long Island Sound drills occur in great numbers throughout the whole oyster-producing area along the Connecticut shore. Their depredations present a major problem to the oyster industry. The salinity of these waters is fairly constant around 25 o/oo. The same is true for the leased and planted grounds of lower Delaware Bay where salinity usually exceeds 15 o/oo. Likewise in Chincoteague Bay and other coastal bays in Maryland and Virginia, where salinities usually run high, drills are prevalent. Drills are the principal enemy of oysters in lower Chesapeake Bay, and are the cause of much damage to the industry. In upper Chesapeake Bay, north of the Potomac River, this problem does not exist because the salinity during a substantial portion of each year is 15 o/oo or less. The tributaries of lower Chesapeake Bay have drills present only when the salinity level for most of the year exceeds 15 o/oo. In the James and York Rivers, two of these tributaries, drills are present in the lower portion and none are found in the upper part.

The James River in many respects resembles Delaware Bay. It is a tidal estuary fed by the drainage of a huge watershed. Fresh water mixes with the ocean salt water under the influence of tidal action and finally some of it reaches the sea. The mixing produces an environment of constantly decreasing salinity from the mouth to the upper reaches of tidal influence; part of this supports oyster growth and part, oysters and drills. The point in the James River, upstream of which the drills do not occur in dangerous quantities, is approximately at the James River Bridge. This is the point corresponding in many ways to the Southwest Line in Delaware Bay above which the natural seed beds produce a commercial crop of seed oysters. In fact this area in the upper James River contains the world's most productive oyster seed grounds that furnish the source of seed for transplanting sufficient to make Virginia the current leading oyster-producing State. The loss of this seed, like the loss of seed from the Natural Oyster Beds of the Delaware River, would be disastrous to the oyster industry.

Control of drills at present is being attempted by mechanical removal and physical destruction. In Delaware Bay considerable effort has been expended in drill control. The results of these efforts produced temporary respite from drill damage. The control imposed by nature through fresh water influence on salinity is, up to this time, much more effective. The continuously high production of seed oysters on the Natural Oyster Beds of upper Delaware Bay and also on the seed grounds of the upper James River attest this.

Salinity and Drill Mortality

In the laboratory the salinity tolerance of drills was examined by several biologists, Federighi (1931), Engle (1938), who found that salinities below 15 o/oo are usually lethal to drills. Both workers determined the amount of time required to kill drills at different salinities. Engle noted the effect of temperature on the time of exposure to low salinities observed to kill drills. Federighi pointed out that the salinity death point is influenced by early conditioning.

The following mortality curve (Figs. 1 and 2) summarize the results of Engle's observations. Figure 1 shows the results of four experiments designed to test the resistance of drills, Urosalpinx cinerea, to low salinities. The range of salinity from 2.98 to 14.15 o/oo was lethal to all drills. While no drills were exposed to absolutely fresh water in these experiments, the fact that no drills survived any of the lower salinities suggests a similar fate for drills in fresh water. All drills in waters where salinity was 16 o/oo or higher through 27 o/oo, survived with no apparent ill effects for 30 days, the duration of the experiment with this series. Therefore, somewhere between 14.15 and 16 o/oo is the minimum salinity tolerance level.

The time it took to kill drills in salinities of 14.15 o/oo or less, varied with the salinity level and with the temperature within the range of 15.4 to 23.0° C. (Table 2). Experiments at intermediate temperatures gave mortality results that lay between those for the example cited. The relation between elapsed time for total destruction and temperature became erratic at the 14 o/oo salinity level (Fig. 1). At low salinities up to this point, temperature appeared to be a controlling factor, but at a salinity of 14.15 o/oo some unknown factor became dominant.

Table 2.-- Data on mortality of oyster drills in relation to temperature and salinity

Experiment Number	Temperature °C. Range	Mean	Time in days for 100% mortality at salinity of: 7.5 o/oo	10.0 o/oo	12.0 o/oo
I	19.5 - 23.0	20.5	7	9	12
IV	15.5 - 19.8	17.5	13	22	30

At salinities of 3 and 5 o/oo, the survival time of drills roughly fits the curve established by Experiment IV for the average temperature of 17.5°C. These results suggest that death is never instantaneous from an exposure to fresh or nearly fresh water.

Figure 2 illustrates the number of days required to kill the first drill, half the drills and all drills in salinities of 3, 5, 7.5, 10, 12 and 14 o/oo. It further demonstrates that, within the range of observation, the hardiness of individuals increases as the salinity increases.

Federighi (1931) stated that early conditioning in the natural saline environment determines the salinity death point, but a weakness in his results stems from the manner in which he terminated his observations. He allowed the drills 10 days' exposure and then calculated the percentage mortality. In only one of ten series of experiments in which he exposed drills to low salinity did he record a total mortality. In all the others about 10 percent of the number exposed survived the so-called death point salinity. The results of Federighi's experiments upon which these conclusions are based are shown in Table 3.

Table 3.-- Effects of Varying Salinity on Urosalpinx cinerea (from Federighi, 1931)

Experiment	Salinity Drills Killed	% Died 10 days	Salinity Drills Survived	% Survived 10 days
1 1/	10.12	90	12.26	95
2 1/	12.52	75	15.05	90
3 1/	11.35	90	13.91	85
1-a 2/	12.81 3/	95	16.89 4/	90
2-a 2/	14.45 3/	90	16.22 4/	85
3-a 2/	16.00 3/	70	17.43 4/	100
V 5/	15.25	94	18.25	94
VI 6/	16.64	92	18.87	82
VII 6/	16.51	76	19.93	86
VIII 6/	10.63	100	12.79	75

1/ Drills from Hampton Roads, Va., salinity 15 - 20 o/oo
2/ Drills from Beaufort, N. C., salinity over 30 o/oo
3/ Salinity at which 50% of drills died
4/ Salinity at which 85% of drills survived
5/ Sterile glassware and seawater used
6/ Seawater of proper salinity changed daily

Destruction of Oysters by Drills

Information on the destruction of oysters by drills is pertinent to this discussion. Engle (1952) made observations in the laboratory and the field to measure the damage done by this pest. The field observations were made in Tangier Sound and are described elsewhere in this report. Laboratory observations were made on rates of destruction, size of drills and temperature. The salinity range was 22 to 27 o/oo, and the bait, one-inch seed oysters, was comparable to most of the seed on the Natural Oyster Beds of New Jersey and Delaware. Table 4 summarizes the results, showing the annual rate of destruction of oysters by different drills of specified size. From this table it is apparent that large drills destroyed more seed oysters in a season than small drills, and that in each size group the rate of destruction of oysters increased with the seasonal increase in temperature.

Table 4.-- Seed Oysters Destroyed per Drill per Month

Date Exam. 1939-1940	16 mm. Drills	18 mm. Drills	20 mm. Drills	22 mm. Drills	24 mm. Drills	26 mm. Drills
Jan. 9 to May 8	0.0	0.0	0.0	0.0	0.0	0.0
June 9	2.3	1.0	0.0	0.5	0.5	1.3
July 12	2.7	3.3	5.0	2.5	5.0	4.0
Aug. 10	5.3	5.7	4.0	4.0	5.0	5.5
Sept. 6	5.7	9.7	12.0	9.0	11.5	11.5
Oct. 6	5.0	3.3	5.0	3.5	4.5	5.5
Nov. 6	1.7	1.7	1.7	1.5	2.5	2.5
Dec. 16	0.0	0.3	lost	0.0	0.5	0.5
Jan. 8	0.0	0.0	lost	0.0	0.0	0.0
Season Total:	22.7	25.0	27.7	21.0	29.5	30.8

From Engle (1952) "The Destructiveness of the Common Oyster Drill, *Urosalpinx cinerea*, Say", USF&WS, Annapolis, Maryland. Manuscript on file USF&WS, Washington, D. C.

Table 5.-- Days Required for Drills of Different Size to Kill One Seed Oyster at Certain Temperature Intervals

Temp. Range, °C	16-18 mm. Drills	19-20 mm. Drills	21-22 mm. Drills	23-24 mm. Drills	25-26 mm. Drills	27 mm. Drills
13.2 16.2	20.0 days	28.8 days	20.0 days	19.1 days	16.8 days	12.4 days
16.2 18.5	12.2 days	14.5 days	10.2 days	7.3 days	6.7 days	6.1 days
18.5 22.5		8.8 days	6.0 days	7.3 days	5.6 days	
22.5 23.5			3.1 days	3.9 days	2.4 days	2.4 days

From Engle (1952) "The Destructiveness of the Common Oyster Drill, *Urosalpinx cinerea*, Say," USF&WS, Annapolis, Maryland. Manuscript on file USF&WS, Washington, D. C.

Table 6.-- Number of Oysters Destroyed per Drill During Average Exposure of 30 Days at Certain Temperature Levels

Temp. Range, °C.	16-18 mm. Drills	19-20 mm. Drills	21-22 mm. Drills	23-24 mm. Drills	25-26 mm. Drills	27 mm. Drills
13.2 16.2	1.5 oyst.	1.1 oyst.	1.5 oyst.	1.6 oyst.	1.8 oyst.	2.4 oyst.
16.2 18.5	2.6 oyst.	2.2 oyst.	3.1 oyst.	4.3 oyst.	4.7 oyst.	5.2 oyst.
18.5 22.5	1/	3.3 oyst.	4.8 oyst.	4.0 oyst.	5.2 oyst.	
22.5 23.5	1/	1/	8.7 oyst.	6.9 oyst.	11.1 oyst.	11.1 oyst.

1/ These drills grew beyond the size range.

From Engle (1952) "The Destructiveness of the Common Oyster Drill, *Urosalpinx cinerea*, Say", USF&WS, Annapolis, Maryland. Manuscript on file USF&WS, Washington, D. C.

The influence of temperature on the rate of destruction of oysters by drills is further indicated in Tables 5 and 6. Table 5 demonstrates that time in days required for one drill to kill one oyster decreased as the temperature increased. Table 6 shows the effect of temperature change on the number of oysters destroyed per month. Both tables demonstrate that large drills at a given temperature are more destructive than smaller ones to seed oysters.

The season of drilling activity appears to be determined by the temperature of the water. The first drilling of oysters occurred from May 8 to June 9 (Table 4), when the temperature was 11.6 to 17.4°C. The lower temperature limits shown in Tables 5 and 6 are the averages of all temperatures recorded for the first half of the period; likewise the upper temperature limits are the averages of all temperatures recorded for the second half of the period. In Long Island Sound, drilling activity started after the water reached a temperature of 11.6°C. or about the middle of May. Federighi (1931) in his experiments in Virginia observed that drills began feeding at approximately 15° C, but did not stop until a lower temperature was reached; drilled oysters were found after November 6 when the water temperature dropped below 7.6°C. In Delaware Bay the water temperature reached 12.0°C. about May 1, 1936, and dropped below 8.0°C. November 25, 1935. Thus when drills are on the seed beds of Delaware Bay, they may feed for the 7 months from May through November.

The menace to oysters of newly hatched drills must not be overlooked. Table 7 is a record of feeding activity of very small drills eating very small oysters. Drills hatch from the egg cases completely equipped to begin drilling, and unfortunately the period of hatching coincides with the period of oyster setting. At drill hatching time the drill population may be increased several fold by this addition, and these small drills, 2 to 4 millimeters (.08 to .16 inches) in length, swarm over the shells that contain the new oyster set. In the laboratory (Table 7) baby drills killed small oyster spat at an average rate of 4.8 per day per drill.

Reactions of Oysters to Low Salinities

In the laboratory Loosanoff (1952) and in the field Engle (1946) observed the effects of low salinities on the mortality and physiological reactions of oysters. Loosanoff shows that temperature is a factor in determining the mortality of oysters due to low salinity. Table 8 illustrates the differential effect of temperature on mortality of oysters in low salinities. Tables 9, 10, 11 and 12 report in detail the observations summarized in Table 8. Loosanoff also observed growth, pumping and gametogenesis in oysters under these conditions and found that low salinity interfered with normal physiological functions.

Table 7.-- Oyster Spat Killed by Newly Hatched Drills 1/

No. of Drills	Average Size Drills in mm.	No. of Days	No. of Spat Killed	No. of Spat Killed Per Drill-Day
2	2.0	2	11	2.8
2	3.03	2	29	7.3
2	3.21	3	49	8.2
2	3.60	2	5	1.3
2	4.09	2	23	5.8
2	4.09	4	25	3.2

1/ Drills hatched in laboratory aquarium.

From Engle (1952) "The Destructiveness of the Common Oyster Drill, *Urosalpinx cinerea*, Say", USF&WS, Annapolis, Maryland. Manuscript on ~~file~~ USF&WS, Washington, D. C.

Table 8.-- Total number of dead oysters at the end of 30-day exposure at different temperatures and salinities. Sample in each salinity consisted of 50 adult Long Island Sound oysters.

Temperatures °C.	SALINITIES			
	Fresh Water	3.0 p.p.t.	5.0 p.p.t.	Control 27.0 p.p.t.
8.0-12.0	2	1	1	0
13.0-16.0	17	12	10	0
17.0-20.0	46	47	19	1
23.0-27.0	50	50	38	1

From Loosanoff (1952) "Behavior of Oysters in Water of Low Salinities", USF&WS, Milford, Connecticut. Paper presented at National Shellfisheries Association Meeting, August 1952.

Table 9.— Daily mortality of oysters exposed to various salinities and at temperatures ranging from 23.0 to 27.0° C. Sample in each salinity consisted of 50 adult Long Island Sound Oysters.

Days of Exposure	Fresh Water	3.0 p.p.t.	5.0 p.p.t.	7.5 p.p.t.	10.0 p.p.t.	12.0 p.p.t.	15.0 p.p.t.	Control 27.0 p.p.t.
1								
2								
3	1		1					
4	2		1					
5	10	2	3					
6	12	7	4		1			
7	6	6	11					
8	5	9	2					
9	6	8	7					
10	4	7	2					
11	1	4	1					
12	1	2	1					
13	2	1	1			1		
14		1	1		1			
15		3	1					
16								
17								
18								1
19								
20								
21								
22								
23				1				
24			1					
25				1	1			
26								
27			1					
28						1		
29								
30								
Total Mortality	50	50	38	2	3	3	0	1

From Loosanoff (1952) "Behavior of Oysters in Water of Low Salinities", USF&WS, Milford, Connecticut. Paper presented at National Shellfisheries Association Meeting, August 1952.

Table 10.-- Daily mortality of oysters exposed to various salinities at temperatures ranging from 17.0 to 20.0°C. Sample in each salinity consisted of 50 adult Long Island Sound oysters.

Days of Exposure	Fresh Water	3.0 p.p.t.	5.0 p.p.t.	Control 27.0 p.p.t.
1				
2				
3				
4	1			
5	1	2	3	
6	2	2	3	
7	2	3	2	
8	8	8	2	
9	6	3		
10	5	4		
11	3	2		
12	3	2		
13	4	3	1	
14	1			1
15		3		
16	5	2		
17		2		
18	2	2		
19	2	1	1	
20		2	1	
21			1	
22		2	1	
23	1			
24		1	1	
25				
26		1		
27				
28		1		
29		1	1	
30			2	
Total Mortality	46	47	19	1

From Loosanoff (1952) "Behavior of Oysters in Water of Low Salinities", USF&WS, Milford, Connecticut. Paper presented at National Shellfisheries Association Meeting, August 1952.

Table 11.— Daily mortality of oysters exposed to various salinities at temperatures ranging from 13.0 to 16.0°C. Sample in each salinity consisted of 50 adult Long Island Sound oysters.

Days of Exposure	Fresh Water	3.0 p.p.t.	5.0 p.p.t.	Control 27.0 p.p.t.
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11	1			
12				
13				
14				
15				
16	1	1		
17			1	
18		1		
19				
20				
21				
22	3		1	
23	1		1	
24	1		3	
25	1	4	1	
26				
27	4			
28	1			
29	2	3	2	
30	2	3	1	
Total Mortality	17	12	10	0

From Loosanoff (1952) "Behavior of Oysters in Water of Low Salinities", USF&WS, Milford, Connecticut. Paper presented at National Shellfisheries Association Meeting, August 1952.

Table 12.-- Daily mortality of oysters exposed to fresh water, water of low salinities and to normal salinity of the control at low temperatures ranging from 8.0 to 12.0°C. Sample in each salinity consisted of 50 adult Long Island Sound oysters.

Days of Exposure	Fresh Water	3.0 p.p.t.	5.0 p.p.t.	Control 27.0 p.p.t.
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17	1			
18				
19				
20			1	
21				
22				
23				
24				
25				
26				
27		1		
28	1			
29				
30				
Total Mortality	2	1	1	0

From Loosanoff (1952) "Behavior of Oysters in Water of Low Salinities", USF&WS, Milford, Connecticut. Paper presented at National Shellfisheries Association Meeting, August 1952.

Table 13.-- Mortalities and production losses of oysters from the bars in the upper part of Chesapeake Bay, 1945-6 and unmarketable residue in bushels.

Name of Bar	Expected crop 1945-6	Mortality loss	Unmarketable residue
Love Point1/	100,000	92,000	8,000
Broad Creek1/	200,000	100,000	100,000
Gum Thicket1/	60,000	15,000	45,000
Bloody Point1/	50,000	10,000	40,000
Chester River1/	25,000	10,000	15,000
Anne Arundel 1/	15,000	5,000	10,000
Totals	450,000	232,000	218,000
Swan Point2/	500,000	300,000	200,000
Anne Arundel2/	500,000	150,000	350,000
Totals	1,000,000	450,000	550,000
Combined Totals	1,450,000	682,000	768,000

1/ Bars cultivated under the State of Maryland Oyster Management Plan.
2/ Natural bars with oysters too poor to harvest during 1945-6 oyster season.

From Engle (1946) "Commercial Aspects of the Upper Chesapeake Bay Oyster Bars in the Light of Recent Oyster Mortalities", USF&WS, Annapolis, Maryland. Third Annual Report of the Maryland Board of Natural Resources.

Engle (1946) observed the effects of freshets in 1945-46 on the salinity changes and subsequent mortalities of oysters in upper Chesapeake Bay. Figure 3 shows the resulting seasonal salinity changes for three years, 1944, 1945 and 1946. The geographical distribution of oyster mortalities occurring at this time appears in Figure 4 as percentage loss of oysters for 1945-46 in excess of that occurring in the population present in the normal year of 1944. Estimated mortalities in bushels of oysters lost are given for some areas in upper Chesapeake Bay for the above period in Table 13. The freshets reduced the salinity below 5 o/oo almost continuously from March 1 to August 15, 1945. Oysters died in great numbers during this period and through the following fall and winter. Those oysters not killed during 1945 were killed during the summer of 1946 when again fresh water invaded the area from May 15 to August 1. Most of the area affected by these two wet years is still barren of oysters.

In 1938 upper Delaware Bay suffered a similar salinity reduction during high river flows in summer. Conditions unfavorable to oysters still prevailed in April of 1939 (Stauber 1943) but the harm to oysters occurred in 1938 because the high summer temperature made oysters more vulnerable to low salinity. In September 1932, an exceptionally dry month, salinity of upper Delaware Bay well above Arnold Point was about 15 o/oo. At this point in the river the usual salinity is considerably lower than this and here are located the uppermost parts of the Natural Oyster Beds.

Effect of River Flow on Salinities

Fluctuations in river flow cause changes in estuarian salinities, and when the drainage area is large this effect is felt far down the estuary. The Delaware River drains an area of about 13,600 square miles in four States; 7,000 square miles of this are above Trenton, New Jersey. The amount of runoff is measured at gauging stations as rate of river flow in cubic feet per second (c.f.s.). The principal station for measuring the river flow of the Delaware River is located at Trenton, and maintained by the U. S. Geological Survey.

Examples of the relation between river flow and salinity may be seen in graphs, Figures 5 and 6, compiled from data collected by the U. S. Geological Survey, the University of Delaware, the New Jersey State Agricultural Experiment Station, the U. S. Bureau of Fisheries, (Galtsoff, Prytherch and Engle, 1937), and the U. S. Fish and Wildlife Service. River flow from June to October, 1935, was generally low, from 3,000 to 7,000 c.f.s. Salinities during that period at the Southwest Line increased slowly as the river flow decreased. These salinities fluctuated between 18 and 21 o/oo from June through September and 21 and 23 o/oo from October through December. The effect of the driest month, October, appears to have lasted well into November. Average monthly river flow jumped from 3,000 c.f.s. in October to 22,000 in November and back to 15,000 in December and January. Salinity, following the high flow of November, dropped to 17 o/oo and with some fluctuation remained there through January.

Ice in the River and Bay precluded sampling during February; but it was resumed at the beginning of March, 1936, when, following a river flow of 7,000 c.f.s. in February, salinity rose again to 21 o/oo. River flow for March was exceedingly high (monthly average, 61,000 c.f.s.) and rapidly lowered the Bay salinity to about 5 o/oo at the Southwest Line. River flow during the next three months gradually subsided until it reached 6,500 c.f.s. in June. The salinity in these three months rose gradually to 18 o/oo.

The March, 1936, high river flow was sufficient to lower salinities at the Southwest Line below 15 o/oo from the middle of March to the first of May. Water temperature was below 12° C. during this period of reduced salinity, minimizing the harmful effect of fresh water on the organisms under study.

Salinity records for the twelve months June, 1935 to May, 1936, from a station at the lower extremity of the Natural Oyster Beds showed some of the fluctuations resulting from the recorded river flows. An average flow of 15,000 c.f.s. was not enough to reduce the salinity any lower than 16 o/oo. At an average flow of 23,000 c.f.s. there was a slow recovery from the minimum salinity of 5 o/oo to one of about 15 o/oo.

Throughout the period of these studies salinities from other stations in the Natural Oyster Beds were occasionally recorded. When the salinity at the Southwest Line was 20 o/oo, it was 19 at Bennies and 17 at Ship John. These salinities occurred when the average river flow was 5,000 c.f.s. In October 1935, when river flow averaged about 4,100 c.f.s., salinities at these three stations were 21, 19 and 17 o/oo. During the month of March 1936, when the average flow was 61,000 c.f.s salinities at the same three stations were 5, 3.4, and 0.4 o/oo, respectively. On May 2, 1936, salinity at the Southwest Line was 14 o/oo, and at Ship John it was 7 o/oo following a river flow of 23,000 c.f.s.

Comparison of Annual River Flow with 45 Year Average

The U. S. Geological Survey and other agencies collected daily records of river flow in c.f.s. at Trenton, New Jersey for many years, and monthly and annual averages were calculated. Average annual river flow over the 45-year period 1907 to 1951 (142,800 c.f.s.) was used as a norm from which the annual departure was calculated; this is illustrated in Figure 7. During 1935 and 1936 annual river flow was 133,700 and 158,100 c.f.s. respectively, with departures from the norm of -9,100 for 1935 and of +15,300 for 1936. Falling within these limits were 16 years when river flow should have produced conditions of salinity similar to those we observed in 1935 and 1936. River flow departure exceeded +15,300 c.f.s. for 11 years and exceeded -9,100 c.f.s. for 18 years. These departures indicate 20 years wetter than normal and 25 years drier than normal.

Annual departure from the norm is the albegraic sum of the departures during subdivisions of the year, which was broken into quarters to show seasonal amounts of river flow. From these we can determine when the departure was sufficient to create abnormal salinities detrimental to oysters. Excessively high or low river flow in spring and summer when temperatures are high, changes salinity to levels detrimental to oysters either through direct osmotic action (low salinities) or through increased survival of the drills (high salinities). The same river flow in fall and winter, however, even though creating the same salinity changes has little effect on oysters or drills because of low temperature which renders them relatively dormant and metabolically inactive.

In 1938 the departure from the summer norm of 18,300 c.f.s. was +30,400 c.f.s., exceeded only slightly by two other summers in the past 45 years. Stauber (1943) reported heavy oyster mortalities on the Natural Oyster Beds during this year. In 1935 the summer departure was only -2,200 c.f.s. No oysters died in the seed area except the few that could be attributed to drill predation. There is not enough information available to us at this time to compare river flow effects on the oyster and drill populations of many of the former years. Excessive departures from the annual river flow norm are infrequent (Fig. 7), and even some of these abnormal flows reflect an abnormality which occurred in the season when it was least likely to affect the oyster or drill population.

Distribution of Drills in Delaware Bay

All investigators studying oysters in Delaware Bay declared drills to be the principal oyster predators. Moore (1911) found them in considerable numbers on the planted beds of Delaware, and some were in the vicinity of the East Line on the public or Natural Oyster Beds. Dr. Thurlow C. Nelson, Biologist for the State of New Jersey, in Annual Reports of the Biologist, New Jersey Agricultural Experiment Station, repeatedly refers to drill distribution in Delaware Bay. In a mimeograph supplement to a report by Stauber and Lehmuth (1937), Nelson stated that droughts from 1930 to 1935 sent salinities well above former limits, and as the salinity increased, the activities of drills kept pace.

Drills destroyed much of the seed on the Natural Beds in 1934 and 1935. Engle (1936) from field records of drill distribution in Delaware Bay for 1935 and 1936 showed drills present on the Natural Oyster Beds as far up river as Bennies Bed offshore of Ben Davis Point.

Dr. L. Eugene Cronin, Marine Biologist, University of Delaware, during annual oyster surveys in Delaware waters, found evidence of drills in 1951 at Ridge, about 2 miles north of the East Line; and in 1952 as far north as Over-the-Bar, about 6 miles north of the East Line. This placed drill invasion of the Delaware Natural Oyster Beds about as far up river as in New Jersey at Bennies.

Drill distribution on the Natural Beds of Delaware and New Jersey is dependent on salinity. When several dry years occur consecutively the salinity gradually increases upriver, and from the enormous reservoir of drills on the planted beds there is an upstream migration which is limited only by the upstream limit of tolerable salinity. Freshets during other years reduce the salinities again and kill the invading drills. Thus the alternating condition of drought and freshet in the drainage of the Delaware River watershed controls the salinity in the Bay and consequently the distribution of drills, especially on the Natural Oyster Beds (Nelson 1931).

Discussion and conclusions

Delaware Bay provides the peculiar ecological conditions which are conducive to production of oysters. There are large areas of natural beds, which, through centuries of natural deposition of oyster shells, have acquired the geological qualities that are necessary for the attachment of seed oysters. State conservation agents and private oystermen have planted additional shells on the natural beds at frequent intervals in recent years to supplement and maintain the cultch. Also, there are other large areas, near the mouth of the Bay, which oyster growers have artificially built up enough to support seed transplanted there from the natural beds. The combination of natural beds for seed production and of planting bottoms for maturing oysters constitutes parts of environment favorable to the economic development and maintenance of an oyster industry.

Another part of the environment required for producing oysters is water with tolerable salinity. Oysters endure salinities as low as 5 o/oo high and as high as 32 o/oo without injurious effect. Wide annual fluctuations in salinity occur naturally in the upper part of Delaware Bay as a result of fluctuations in river flow and hence indicate changes in the influx of fresh water from rain and melting ice and snow. In extremely dry years when little fresh water accumulates, a substantial increase in salinity occurs far up the river. Conversely, in wet years the abnormally high flow of fresh water reduces salinity downriver. Both these conditions, when extreme, may be detrimental to oysters on the natural beds. When salinity drops below 5 o/oo for extended periods during the warm months of the year, the mortality rate of oysters becomes abnormally high, and when it exceeds 15 o/oo oyster predators become abnormally abundant.

The principal oyster predators of Delaware are the carnivorous marine snails, Urosalpinx cinerea and Eupleura caudata, called oyster drills or borers by the industry. When salinity increases above 15 o/oo, which occurs during periods of low river flow, oyster predators, especially drills, invade the upper part of the Bay and kill seed oysters. The distribution and abundance of drills are controlled by salinity changes created in the estuary by seasonal fluctuations in river flow. A substantial alteration in the amount of flow will change the distribution of these organisms, and influence the production of oysters.

An oyster industry exists in Delaware Bay because good natural and artificial beds are present and because salinities are normally favorable for the propagation and survival of oysters and unfavorable for the survival of drills in the seed area. Oysters on the Natural Beds occasionally suffer mortalities from low salinity on the one hand and from drill depredations on the other. These infrequent catastrophic conditions cause temporary setbacks to the Delaware Bay oyster industry but rehabilitation occurs naturally when normal conditions return.

The Interstate Commission on the Delaware River Basin and the New York Board of Water Supply submitted proposals to increase the utilization of Delaware River water. Their plans, which include diversions, impoundments and releases will result in some change in the volume of fresh water flowing into the estuary. The proposed programs, when carried out, might slightly improve the environment for oysters by reducing the extreme anomalies in river flow that occur from time to time. However, it must be pointed out that such anomalous conditions rarely last long enough to have a significantly deleterious effect on either oysters or drills on the Natural Oyster Beds.

During the one year period for which we obtained a continuous record of salinity, June 1935 to May 1936, river flow was normal except for early spring, 1936, when it was great enough to depress the salinity at the Southwest Line below 15 o/oo for about one and one half months. This occurred during March and April, when the water was too cold for low salinities to be harmful to drills or oysters. At no time during these observations did the salinity drop low enough for a long enough period to be lethal to oysters at the Southwest Line. Both these years, except for late fall of 1935 and winter of 1936, were moderately dry and river flow departed only slightly from the 45-year average.

Any diversion of river water would effect an increase in salinity in the lower part of the river and the estuary. During seasonal high flow, this would probably not create detrimental conditions and might even improve the environment for oysters. Diversion during seasonal low flow, however, would tend to aggravate a condition already dangerous to oysters, i. e., it would increase salinity and extend the range for drills upriver.

Proposed alterations of river flow by impounding water during high river flow and by releasing some of this during low river flow would undoubtedly reduce the extremes of salinity. Theoretically, therefore, the proposed plans of utilization and river management will modify the fluctuations in salinity in the right direction for oyster seed production. The amount of water planned for release during low river flow, however, will not reduce the salinity at the Southwest Line to or below 15 o/oo, although it should extend the area of 15 o/oo salinity farther downriver than its present low flow boundary. From the limited data available to us at this time we conclude that river flow at Trenton, New Jersey, should not be permitted to fall below 8,000 c.f.s. Keeping it at this level or above would insure a low enough salinity at the Southwest Line to inhibit the migration of drills from the planted grounds into the Natural Oyster Beds. Excessively high river flows which reduce salinity enough to kill oysters are infrequent, especially during the period of warm weather from April to November, and plans for impoundment now being considered should reduce the small loss resulting from them. Hypothetically, a program that would hold river flow between 8,000 c.f.s. and 20,000 c.f.s. would be most satisfactory for survival of oysters. None of the plans now being considered will do this.

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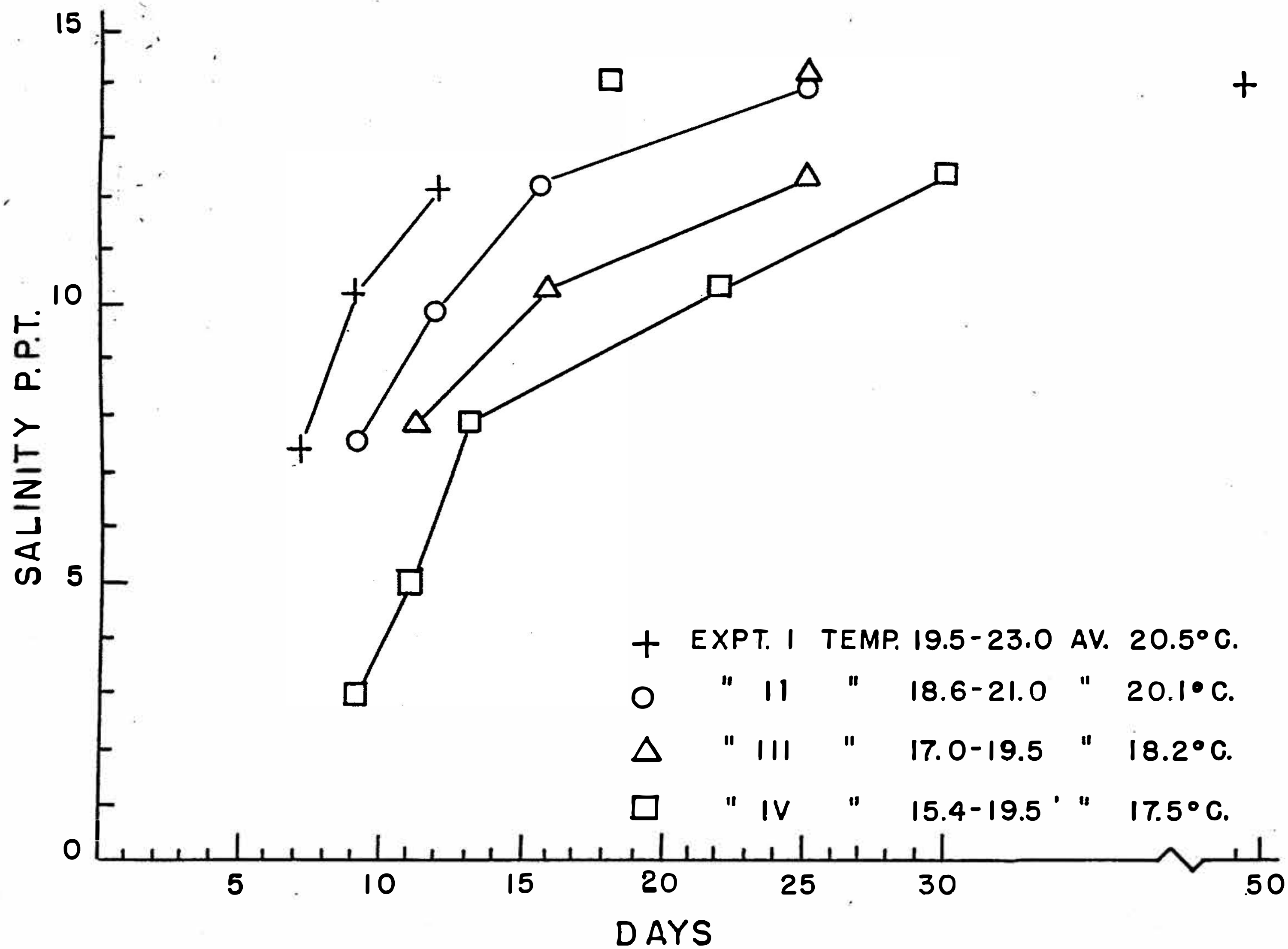

Figure 1. Time in Days Required to Kill Drills in Different Salinities and in Different Temperatures

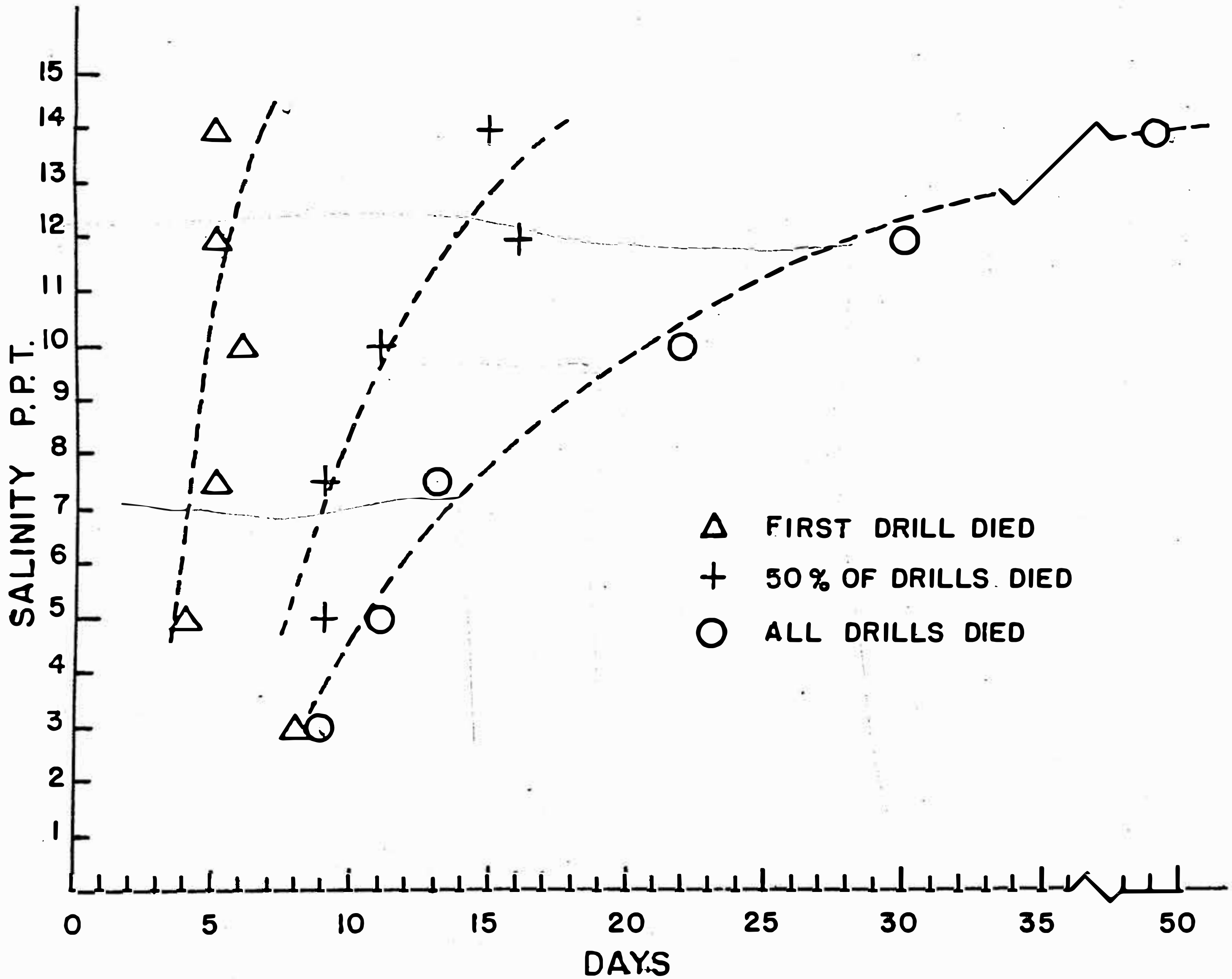

Figure 2. Time in Days to Kill First Drill, Half of Drill Population and All Drills in Different Salinities

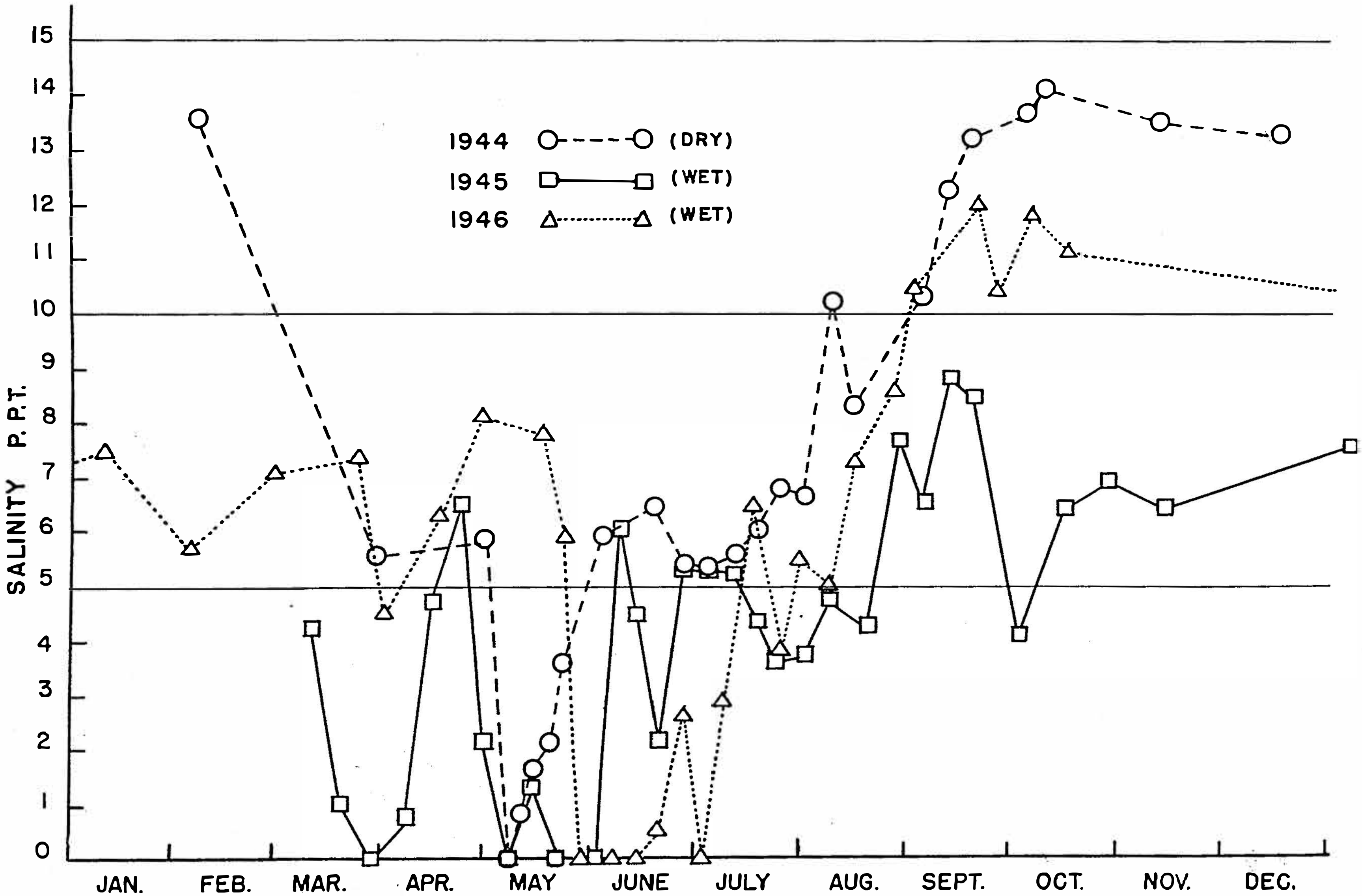

Figure 3. Average Salinity in the Upper Chesapeake Day

(From "Commercial Aspects of the Upper Chesapeake Bay Oyster Bars in the Light of Recent Oyster Mortalities" Page 135, Engle 1946)

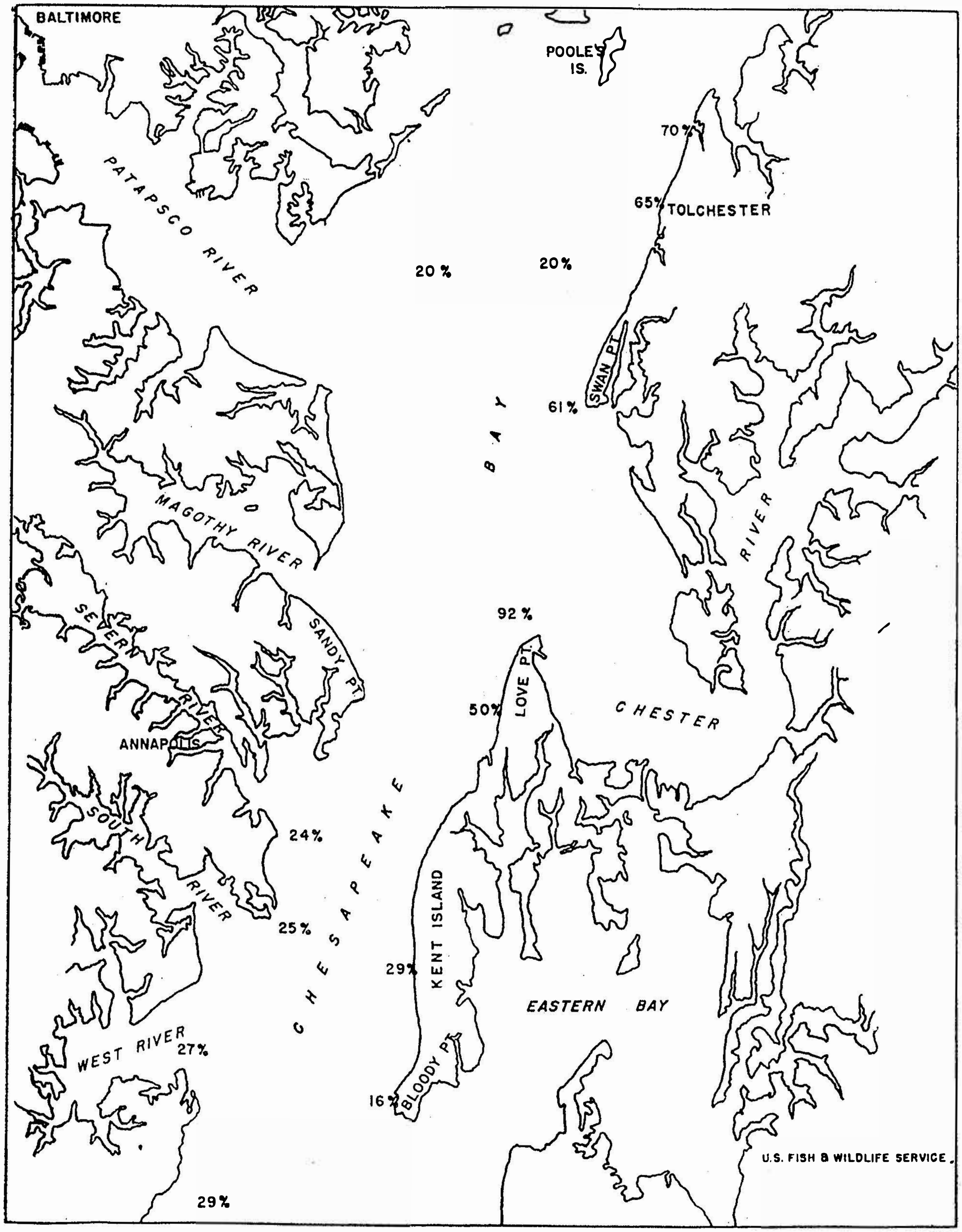

Figure 4. Per Cent of Oyster Mortality in the Upper Chesapeake Bay for the Period October, 1945 through March, 1946.

(From "Commercial Aspects of the Upper Chesapeake Bay Oyster Bars in the Light of Recent Oyster Mortalities" Page 135, Engle 1946)

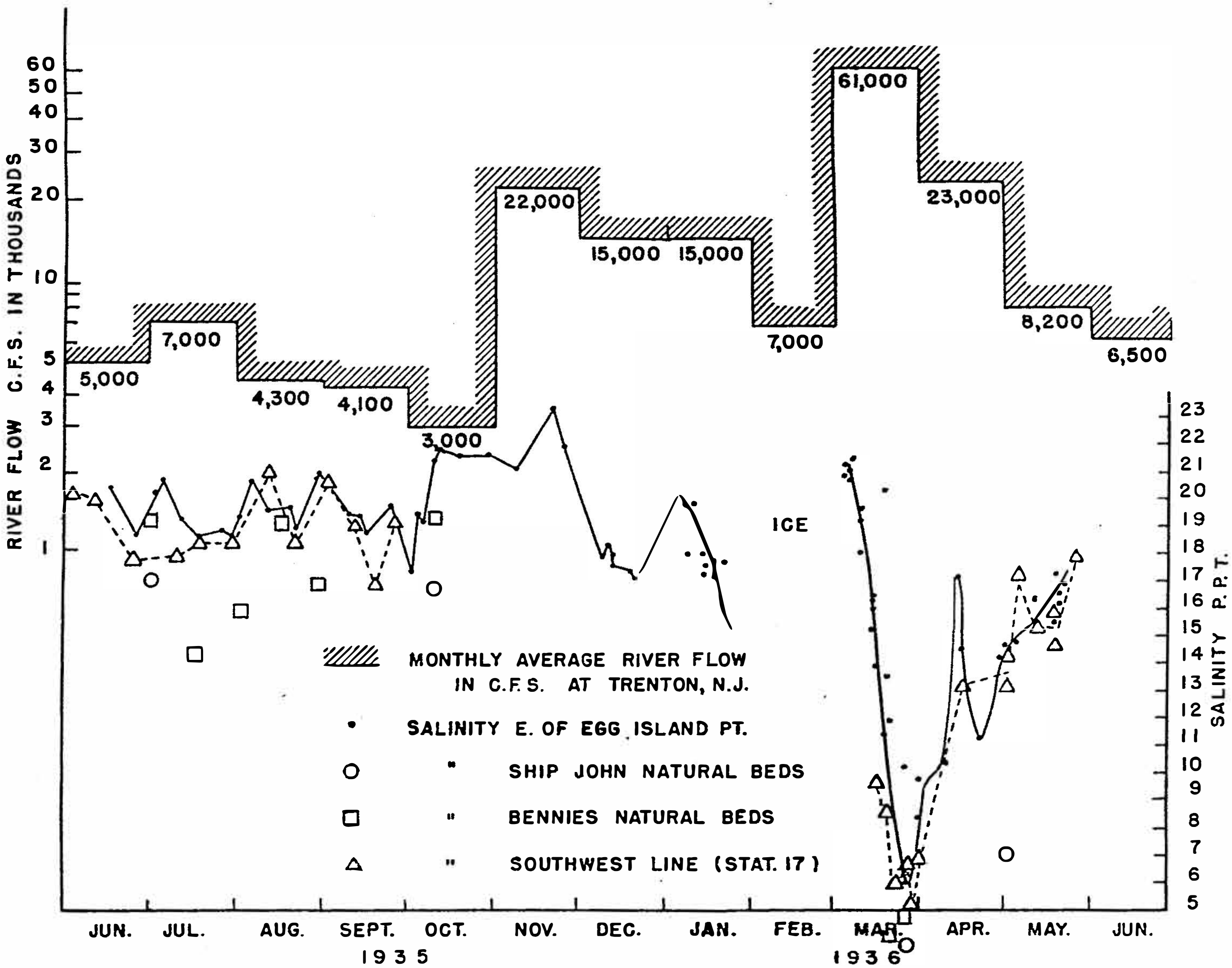

Figure 5. Comparison of Salinities and Monthly Average Riverflow in Delaware Bay for 1935 and 1936

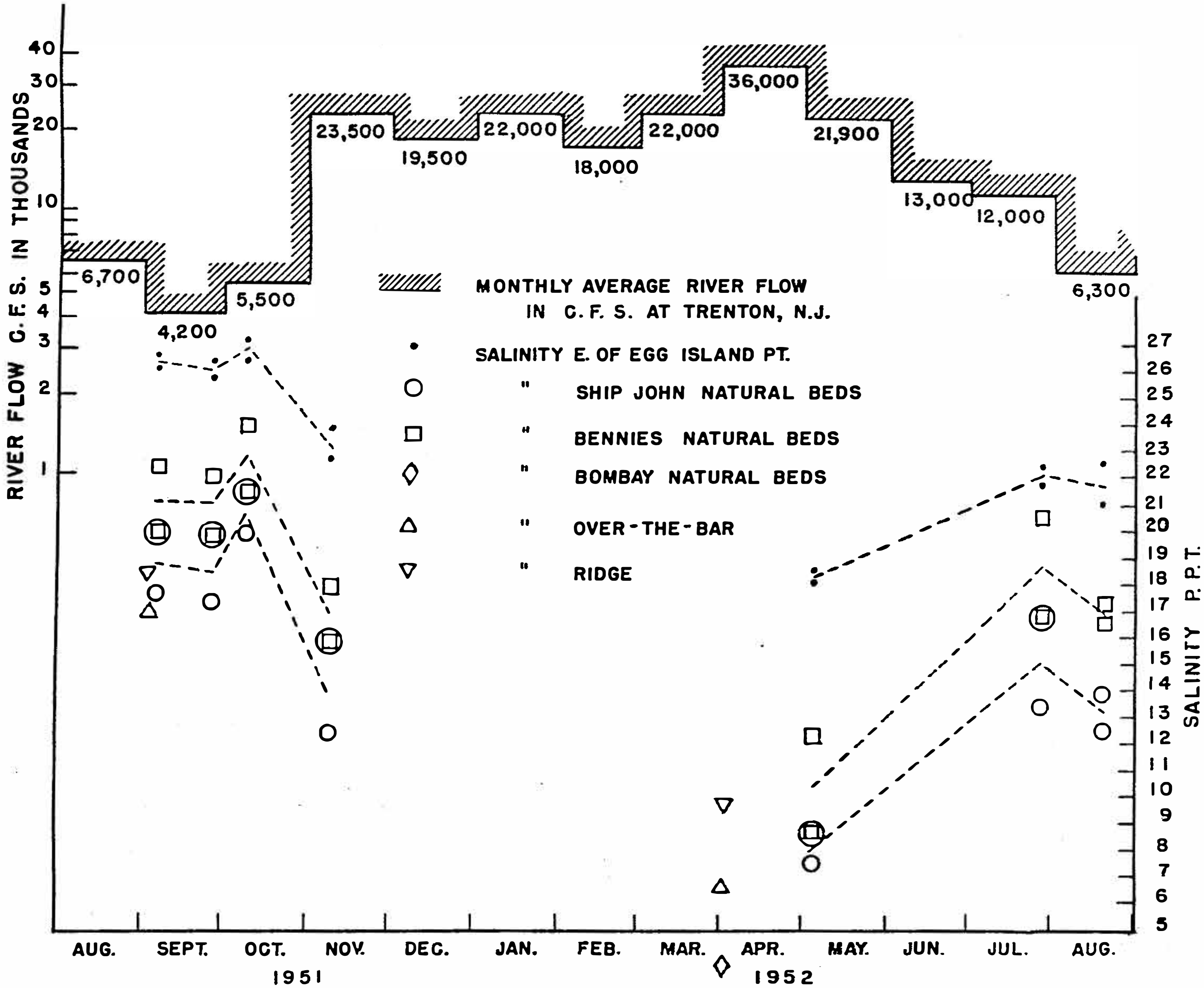

Figure 6. Comparison of Salinities and Monthly Average Riverflow in Delaware Bay for 1951 and 1952

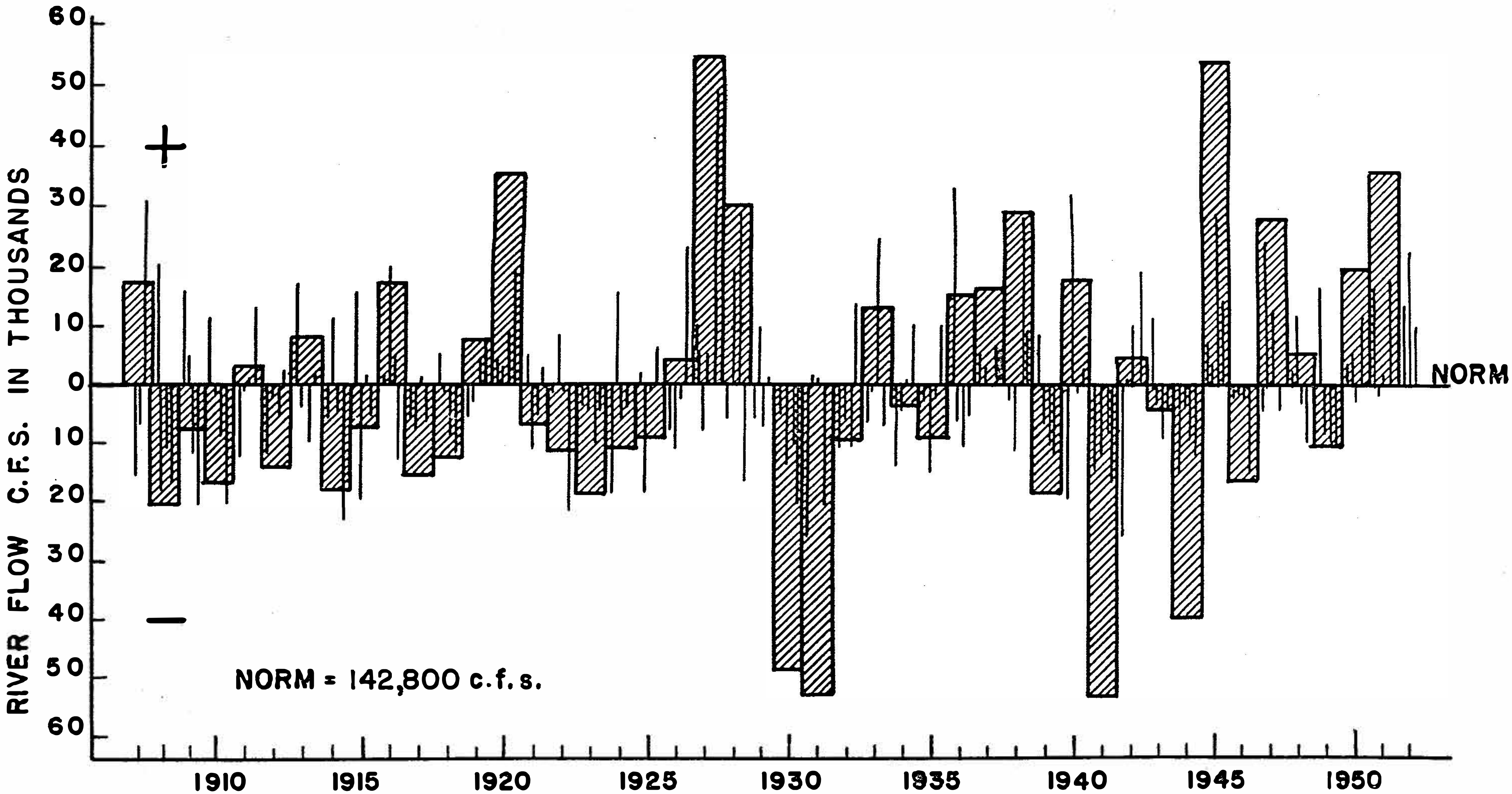

Figure 7. Average Annual and Quarterly Riverflow Departure from 45 year Norm in c.f.s.

(Annual Departure shown by cross-hatched columns and Quarterly Departure, winter, spring, summer and fall by vertical lines.)