EFFECTS OF NAVAL ORDNANCE TESTS ON THE PATUXENT RIVER FISHERY

SPECIAL SCIENTIFIC REPORT—FISHERIES No. 143

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

EXPLANATORY NOTE

The series embodies results of investigations, usually of restricted scope, intended to aid or direct management or utilization practices and as guides for administrative or legislative action. it is issued in limited quantities for official use of Federal, State or cooperating agencies and in processed form for economy and to avoid delay in publication.

United States Department of the Interior, Douglas McKay, Secretary,
Fish and Wildlife Service, John L. Farley, Director

EFFECTS OF NAVAL ORDNANCE TESTS ON THE PATUXENT RIVER FISHERY

by

R. E. Tiller and C. M. Coker[1]
Maryland Department of Research and Education
Solomons, Maryland

Special Scientific Report: Fisheries No. 143

Washington, D. C.
January, 1955

1/ Now attached to School of Medicine, Univ. of Puerto Rico.

EFFECTS OF NAVAL ORDNANCE TESTS ON THE PATUXENT RIVER FISHERY

Introduction

Naval ordnance research, an essential part of our national defense program, cannot be effectively conducted without extensive field experiments. These experiments obviously entail the detonation of heavy submerged explosive charges. The effects of this type of work on marine resources has been the subject of much speculation, but little study. Seismic surveys for coastal oil resources have been studied to a considerable extent, but these projects have generally been of short duration, in scattered areas, and for the most part have utilized light charges of nonmilitary types of explosives.

The proximity of the Maryland Department of Research and Education to the U. S. Naval Ordnance Laboratory's test facility at Solomons, Md., provided opportunity for a cooperative, continuing study of the effects of heavy submerged charges of TNT-type explosives on the fish populations of the Patuxent River. This study is based on observations made during 1946-49 and 1953.

Acknowledgments

Throughout the entire course of these observations, personnel of the U. S. Navy and U. S. Naval Ordnance Laboratory at White Oaks, Md., and at the Test Facility at Solomons, Md., offered all possible cooperation and assistance. Special thanks are due Mr. J. J. Green, Lt. Comdr. W. F Tutt, and Mr. V. M. Korty for their interest and help in the final stages of the project. The authors also thank all members of the staff of the Department of Research and Education who assisted in field observations.

The Problem

Basically, the problem may be stated as follows: "What has been the effect of the U. S. Naval Ordnance Laboratory's explosive test work on the Patuxent River fishery?" This question immediately resolves itself into four individual phases.

(1) What has been the trend of fish production in the Patuxent River since the initiation of explosive test work?

(2) Has this trend been markedly different from the trend of the Chesapeake Bay during the same period?

(3) Has the explosive test program damaged the Patuxent River fishery? If so, to what extent?

(4) Can the damage be eliminated, lessened, or minimized?

An attempt was made to answer these four questions in the compilation of the data presented in the pages following.

Methods

(1) Compilation of data pertaining to the Patuxent River fishery.

Records of the licensed commercial fishery of the entire State have been collected by the Department of Research and Education since 1944. The catches of all species of fish by gear, area, and month, and the catch by month of four major species were tabulated for the period 1944-53.

During the summer months of 1952 the Department of Research and Education conducted an intensive survey of the sport fishery of the Patuxent River from Solomons to Benedict, an area approximately 20 miles in length extending above and below the test area. These data were reviewed and summarized.

(2) Explosive test observations.

The observations on which the study is based were made by the staff of the Department of Research and Education, using in most instances Departmental boats. Occasionally, Navy craft were employed, but similar observational techniques were employed.

Nearly all of the tests were conducted in one area in the river (fig. 1). To increase the validity of the study, and to aid in interpreting seasonal changes, results of the small number of explosions observed in other localities are not included in the seasonal analyses, but are presented as supplementary data.

The test site was entered immediately after the explosion, and as many as possible of the dead or injured fish floating at the surface were collected. These were identified, counted, and weighed, and the data recorded. Data pertaining to weight of the explosive used and the depth at which the charge was detonated were obtained from the Navy. Depth of water, time, tidal phase, and weather conditions were recorded by the observer.

Results

Examination of records of the commercial fishery of the Patuxent River for the period 1944-53 show trends which follow generally the pattern of the Chesapeake Bay fishery. No decline has occurred which has not been evident in other areas supporting similar fisheries, and in which no explosive test programs have been conducted.

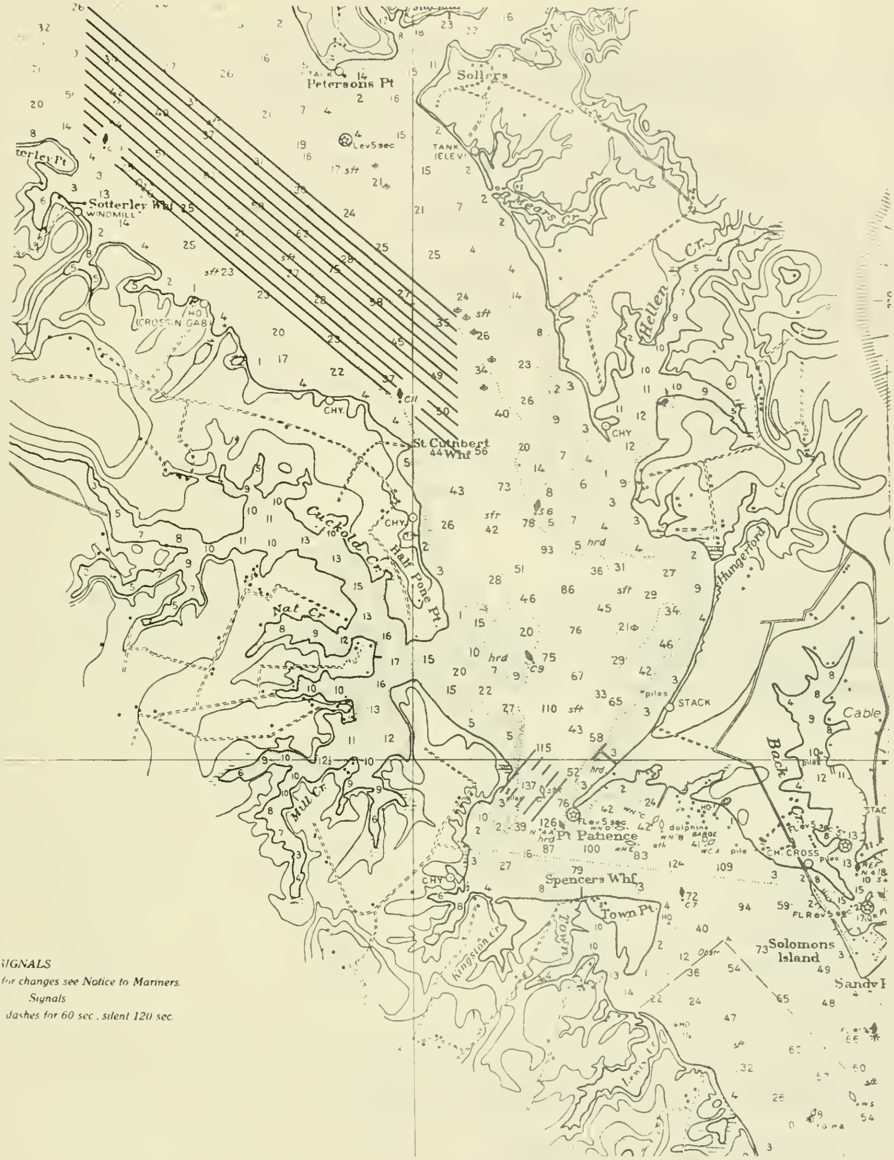


Fig. 1. Explosive test areas, lower Patuxent River

Table 1 and figure 2 present data which indicate the trends in the Patuxent River and Chesapeake Bay during the period from 1944 to 1953.

Table 1 - Commercial Fish Catch
Chesapeake Bay vs. Patuxent River, 1944 - 1953

	Patuxent River	Chesapeake Bay
1944	286, 169	13, 873, 017
1945	228, 096	9, 777, 562
1946	212, 485	11, 506, 921
1947	542, 884	10, 964, 734
1948	319, 289	11, 996, 233
1949	322, 084	15, 272, 114
1950	580, 374	16, 436, 850
1951	848, 042	15, 219, 447
1952	360, 436	12, 992, 612
1953	417, 786	13, 176, 935

The sport fishery in the Patuxent River was found to be of considerable magnitude. Analyses of the information collected during the summer of 1952 indicate that sportsmen's catches were excellent during the entire season from Solomons to Benedict. Table 2 summarizes this information.

Table 2 - Summary of the Summer Sport Fishery
in the Patuxent River, 1952

Area	No. Trips	No. Persons	Catch (Pounds)
Benedict	6, 000	18, 000	32, 000
Broomes Is.	4, 000	15, 000	81, 000
Solomons	3, 000	15, 000	100, 000
St. Marys Co.	4, 000	13, 000	23, 000

Principal species of fish taken in descending order of abundance were: spot, white perch, croaker, striped bass, and sea trout.

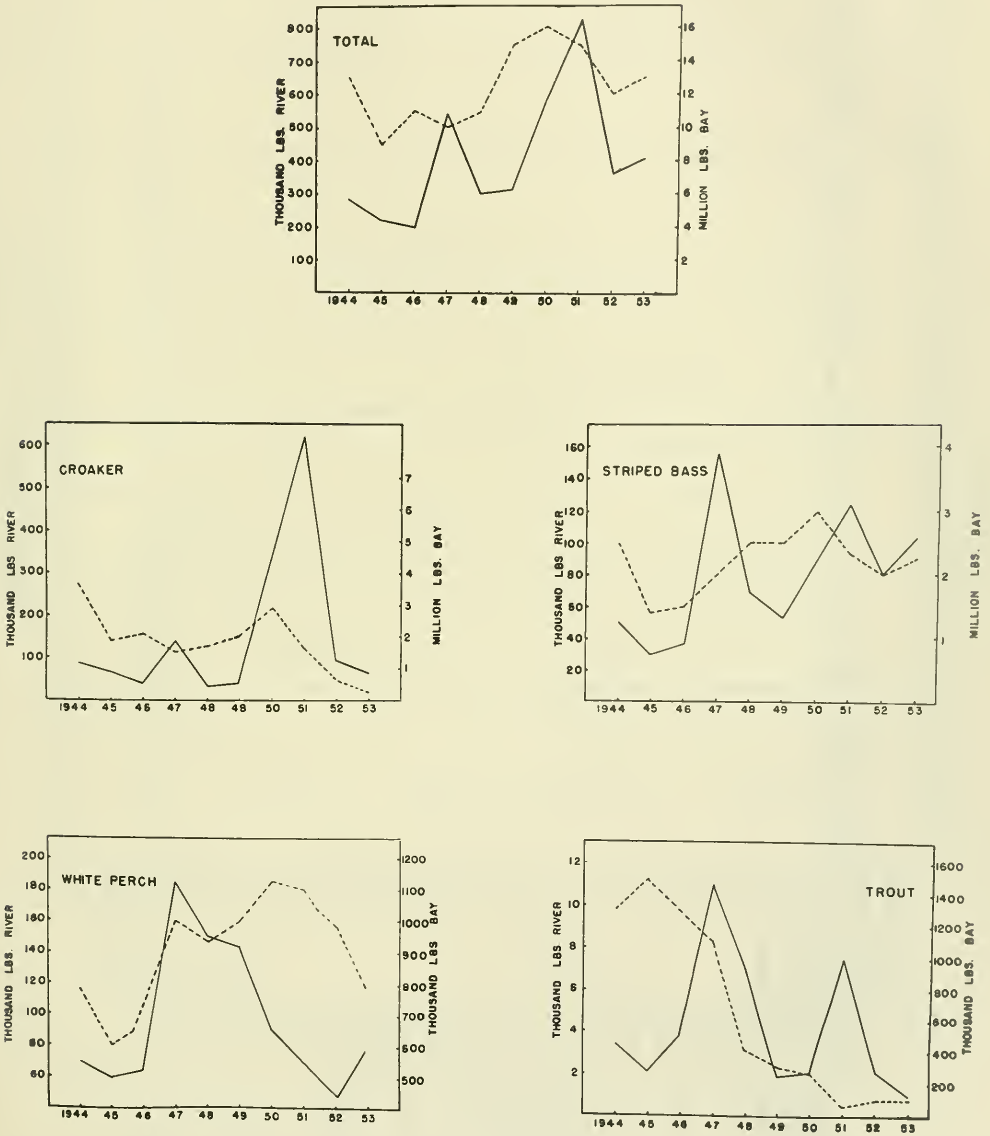
(2) Explosive test observations

Tables 3 and 4 present all data from the selected test area. Supplemental observations from an area 2 miles downriver, close to Patience, and from an area in Chesapeake Bay near Barren Island are presented in table 3a.

COMMERCIAL FISH CATCH

CHESAPEAKE BAY VS. PATUXENT RIVER

1944 - 1953



BAY ----- RIVER ——

TABLE 3

Observed Kill (Lbs.) of Fish Resulting from Explosive Tests in Patuxent River, Area C-11 to C-13

Date	Lbs. Expl.	Depth Expl. (ft.)	Depth Water (ft.)	Striped Bass	White Perch	Her-ring	Shad	Trout	Croaker	Spot	Cat-fish	Eels	Sand Perch	Harvest Fish	Ancho-vies	Men-haden	Total
1/10/47	660	Bottom	35		4												4
2/13/47	300	30	60														0
2/14/47	1200	Bottom	65														0
"	1200	"	65														0
"	1200	"	65														0
2/19/48	560	"	50														0
"	560	"	50														0
"	560	"	50														0
3/4/49	2000	30	60		2	100						.5					102.5
3/23/48	2400	Bottom	50	32	2												34
3/24/48	2400	"	40	8													8
4/15/48	2540	"	65	61								3				300	364
4/16/48	2540	"	65													50	50
"	2400	"	65	51								4				40	95
5/6/48	1200	"	65	33	.5			27				1.5				256	318
"	1200	"	65	12				21								210	243
5/14/48	1200	"	70			1										308	309
"	1200	"	70													1425	1425
"	1200	"	70	32												250	282
5/22/53	300	"	50			15											15
"	300	"	50			19											19
"	55	"	55						2		1						3
5/28/48	300	30	70														0
"	300	30	70	126	259			.5	31	10.5	4	3				79	513
"	300	30	70														0
"	300	30	70														0
6/2/48	300	40	70			.5										.5	1
"	300	40	70													.5	.5
"	300	40	70		1.5	.5										77.5	79.5
"	300	40	70								4					168	172
"	300	40	70													97.5	97.5
"	300	40	70									2				73	75

TABLE 3 (Cont'd)

Observed Kill (Lbs.) of Fish Resulting from Explosive Tests in Patuxent River, Area C-11 to C-13

Date	Lbs. Expl.	Depth Expl. (ft.)	Depth Water (ft.)	Striped Bass	White Perch	Her-ring	Shad	Trout	Croaker	Spot	Cat-fish	Eels	Sand Perch	Harvest Fish	Ancho-vies	Men-haden	Total
6/2/48	300	40	70													99.5	99.5
6/3/48	300	40	70					2.5			5	8				20	35.5
6/5/53	600	Bottom	53						.5			2					2.5
"	600	"	56	6													6
"	600	"	56	10													10
6/11/48	600	"	60													.5	.5
6/15/49	2400	"	50					1				1				70	72
"	2400	"	50	1	72											60	133
"	2400	"	50		3			1				1				6	11
6/24/53	600	"	53	.5								1				2	3.5
"	600	"	53	30								2				2	34
6/26/53	200	40	80	.5													.5
6/28/46	300	20	70				1.5					.5				30	32
7/2/46	900	Bottom	55													4	4
7/3/53	200	40	80						.5	.5							1
7/20/53	500	Bottom	76		3							20					23
7/24/53	600	"	50	4	15					25						3750	3794
"	500	"	53	16	3					2						1200	1221
"	500	"	53	25						2						500	527
7/31/53	600	"	40						2	6		1				15	24
"	600	"	46						1	2.5						20	23.5
"	600	"	50						.5	2							2.5
8/5/53	500	30	75														0
"	500	30	75	100													100
"	500	30	75	20													20
8/6/53	600	Bottom	40	3	3					2							8
"	600	"	46	12	7												19
"	600	"	50														0
8/12/53	300	"	80	.5					2								2.5
"	300	"	80	1					1								2
9/2/53	1200	"	75	23													23
9/11/53	600	"	75	2													2

TABLE 3 (Cont'd)

Observed Kill (lbs.) of Fish Resulting from Explosive Tests in Patuxent River, Area C-11 to C-13

Date	Lbs. Expl.	Depth Expl. (ft.)	Depth Water (ft.)	Striped Bass	White Perch	Herring	Shad	Trout	Croaker	Spot	Catfish	Eels	Sand Perch	Harvestfish	Anchovies	Menhaden	Total
9/16/48	1200	Bottom	60											1		150	151
"	1200	"	60					1						1		50	52
"	1200	"	60			1		1					.5			25	27.5
9/23/53	300	25	70					4							2	100	106
"	600	30	70	3				3							1	4	11
"	600	30	70	3				2								2	7
9/29/48	600	Bottom	60	1.5				33		1							35.5
10/14/48	2400	"	50	2.5	30.5			78								96	207
10/21/48	2400	"	50			10		2								24	36
"	2400	"	50	.5	1			1									2.5
"	2400	"	50	2.5	3.5			15		1.5							22.5
10/28/48	2400	"	50	6				2.5								16.5	25
"	2400	"	50	1	3.5			1								12	17.5
"	2400	"	50														0
11/4/47	1200	"	50														0
11/9/48	300	"	30									3					3
"	300	"	30														0
"	300	"	30		1												1
"	300	"	30		1												1
11/18/48	1200	"	30	.5	26							.5					27
11/25/47	600	"	40		1												1
"	1200	"	40		4												4
12/2/48	2400	"	50														0
"	2400	"	50									.5					.5
"	2400	"	50		.5												.5
12/9/48	240	30	50		1												1
12/10/47	600	--	--		4												4
"	1200	--	--	4	360											30	394

TABLE 3-A

Observed Kill (Lbs.) of Fish Resulting from Explosive Tests

Patuxent River at Point Patience

Date	Lbs. Expl.	Depth Expl. (ft.)	Depth Water (ft.)	Striped Bass	White Perch	Herring	Trout	Croaker	Eels	Sand Perch	Anchovies	Menhaden	Total
6/25/48	55	Bottom	130		1			5		.5		199	205.5
"	55	"	90	163	.5				.5			79.5	243.5
"	55	"	90	22	.5							40	62.5
"	55	"	90	30.5								30	60.5
"	55	"	130									30	30
11/3/48	55	30	137	513	2.5							24.5	540
"	55	30	137										0
"	55	30	137	195	6.5		1					10	212.5
"	55	30	137		3							8	11
"	55	30	137										0
"	55	30	137										0
"	55	30	137						1				1
"	55	30	137										0
11/12/48	55	30	137										
"	55	30	137									3	3
"	55	30	137										
"	55	30	137										
"	55	30	137	5					1.5		3	11	20.5
"	55	30	137										

TABLE 3-A (Cont'd)

Observed Kill (Lbs.) of Fish Resulting from Explosive Tests

Chesapeake Bay near Barren Island

Date	Lbs. Expl.	Depth Expl. (ft.)	Depth Water (ft.)	Striped Bass	White Perch	Herring	Trout	Croaker	Eels	Sand Perch	Anchovies	Menhaden	Total
5/18/53	1200	Bottom	100									350	350
"	1200	"	100									350	350
"	300	"	55									70	70
"	300	"	46									1000	1000
5/20/53	300	"	40				.5					30	30.5
"	300	"	40				.5	.5	1			50	52
"	600	"	47			.5						15	15.5
"	600	"	45	10.5								15	25.5
5/21/53	55	"	35									.5	.5
"	300	"	45									10	10
"	300	"	45									10	10
"	600	"	53									60	60
"	600	"	53									120	120
6/3/53	300	"	108										
"	300	"	108	22		12							34
"	300	"	63			60					1	160	221
"	300	"	63									6	6

Table 4. Observed kill of marketable fish by month in Patuxent River, Area C-11 to C-13, June 1946 - June 1949 and May - Sept. 1953

Date	Tide	Depth Water	Depth of Expl.	Wt. of Expl.	Lbs.Mkt'ble. Fish Killed	Total for Month	Av. No. Lbs/Expl.
1/10/47	Fl.	35'	Bottom	660	4	4	4.0
2/13/47	--	60'	30'	300	0		
2/14/47	Ebb	65'	Bottom	1200	0		
" " "	"	"	"	1200	0		
" " "	"	"	"	1200	0		
2/19/48	--	50'	Bottom	560	0		
" " "	--	"	"	560	0		
" " "	--	"	"	560	0	0	0
3/4/49	Ebb	60'	30'	2000	102.5		
3/23/48	Ebb	40'	Bottom	2400	34		
3/24/48	--	40'	"	2400	8	144.5	48.1
4/15/48	--	65'	Bottom	2540	61		
4/16/48	--	65'	Bottom	2540	0		
" " "	--	"	"	2400	51	112	37.3
5/6/48	Fl.	65'	Bottom	1200	60.5		
" " "	"	"	"	1200	33		
5/14/48	--	70'	Bottom	1200	1		
" " "	--	"	"	1200	0		
" " "	--	"	"	1200	32		
5/22/53	Ebb	50'	Bottom	300	15		
" " "	"	"	"	300	19		
" " "	"	"	"	55	3		
5/28/48	Ebb	70'	30'	300			
" " "	"	"	"	300	431		
" " "	"	"	"	300			
" " "	Slack	"	"	300		594.5	47.1
6/2/48	Slack	70'	40'	300	.5		
" " "	"	"	"	300	0		
" " "	Ebb	"	"	300	2		
" " "	"	"	"	300	4		
" " "	"	"	"	300	0		
" " "	"	"	"	300	0		
" " "	"	"	"	300	0		
6/3/48	Ebb	70'	40'	300	7.5		
6/5/53	Fl.	53'	Bottom	600	.5		
" " "	"	56'	"	600	6		
" " "	"	"	"	600	10		
6/11/48	--	60'	Bottom	600	0		
6/15/49	Slack	50'	Bottom	2400	1		
" " "	Ebb	"	"	2400	73		
" " "	"	"	"	2400	4		
6/24/53	Ebb	53'	Bottom	600	.5		
" " "	"	"	"	600	30		
6/26/53	Fl.	80'	40'	200	.5		
6/28/46	Ebb	70'	20'	300	1.5	141.0	7.4

(a). Magnitude of observed Mortalities

The sizes of the various species of fish collected during the study varied widely, from juvenile individuals weighing only a few ounces, to large adults weighing nearly 20 pounds. An "average" size for any species would have been difficult to establish, and misleading. Values for the magnitude of the kills are therefore expressed in pounds.

The heaviest observed mortality for any single explosion, including nonmarketable species was 3, 794 pounds, of which only 44 pounds were marketable fish. Other heavy kills were 1, 425 pounds, all nonmarketable; 1, 221 pounds, of which 1, 200 were nonmarketable, 1, 000 pounds, all nonmarketable, and in one instance, outside of the regular test area, 540 pounds, of which 515 pounds were marketable fish. Observed kills of marketable species were for the most part light. Table 5 and figure 3 show the percentage frequencies of observed kills by weight groups. The kill of marketable fish exceeded 100 pounds in less than 8 percent of the observed explosions, and in only 1 of the 92 shots fired in the C-11-C-13 area, was the kill more than 150 pounds.

(b). Observed kill vs. weight of charge

A complete lack of relationship was apparent between weight of the explosive charge and the observed fish mortality. Even superficial examination of the data shows that heavy mortality may result from relatively light charges, while in many instances no kill was observed following the heaviest charges.

(c). Observed kill vs. depth of charge

A similar lack of relationship was apparent between the position of the charge in the water; i.e., on the bottom, or suspended at an intermediate depth. Mortalities of similar magnitude were observed from both suspended and bottom charges.

Table 5. Observed kill of marketable fish (lbs.) per shot expressed in percent occurrence

Lbs. Observed Killed	No. of Instances	Percent of Instances	Cumulative Percent
0 - 1	35	38.0	--
2 - 50	45	48.9	86.9
51 - 100	5	5.4	92.3
101 - 150	6	6.5	98.8
Over - 150	1	1.1	99.9
	92	99.9	

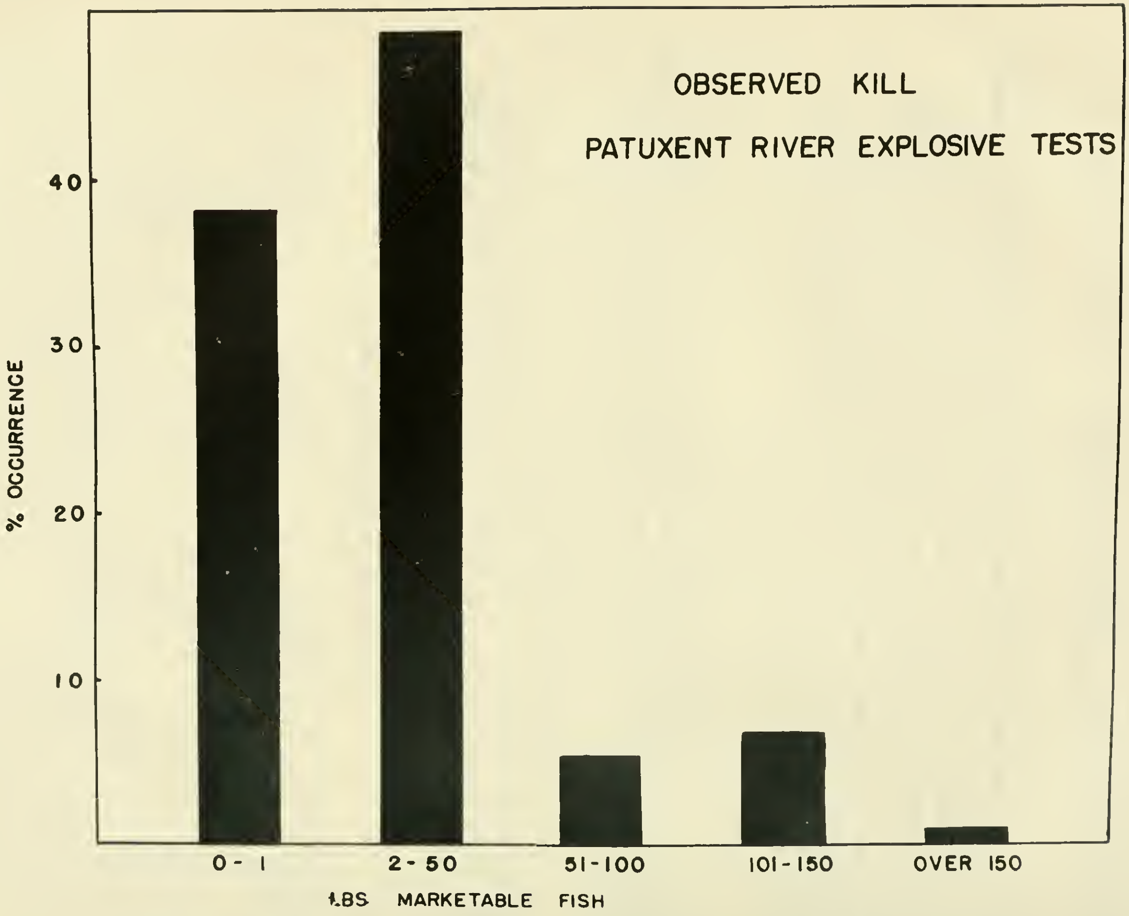


Figure 3.--Observed kill, Patuxent River explosive tests.

(d) Observed kill vs. species of fish

Heaviest total mortality, and heaviest mortality from any individual explosion, expressed in numbers of dead fish observed or collected at the surface occurred in the menhaden (Brevoortia tyrannus), a fish of no food value, used only for crab bait and in the manufacture of fish meal, oil and fertilizer.

Other species killed, listed in descending order of abundance in the observations, were river herring (Pomolobus pseudoharengus and P. aestivalis), white perch (Morone americana), anchovies (Anchoviella mitchilli), striped bass (Roccus saxatalis), gray sea trout (Cynoscion regalis), spot (Leiostomus xanthurus), and croaker (Micropogon undulatus). All of these, with the exception of the anchovy, are marketable species of value to the commercial fisherman and to the sportsman.

Heaviest mortalities occurred rather consistently in those species which typically live and feed at or near the surface, or which move frequently into the middle or upper layers of water. Menhaden, river herring, and anchovies are planktonic feeders, and find their food only at or near the surface. Striped bass and trout are predatory, feeding sometimes on the bottom, but foraging frequently at the surface among schools of small menhaden or anchovies. White perch are of generally similar feeding habits, feeding much of the time on the bottom but moving frequently into the middle or upper layers of water.

Croakers and spot are strictly bottom species, dependent for their food on worms, shellfish, small crabs, and other marine fauna, and although they may move into shallow water during the summer months, rarely come to the surface.

(e) Seasonal aspects of fish mortality

In order that the data be grouped to demonstrate most closely any possible relation to the seasons, the year was divided into four 3-month periods: winter (Dec., Jan., Feb.); spring (March, April, May); summer (June, July, August); fall (Sept., Oct., Nov.).

Heaviest mortality was observed during the spring period, followed in descending order by winter, fall, and summer (table 6).

TABLE 6.- SEASONAL ASPECT OF OBSERVED KILL OF MARKETABLE FISH, AREA C-11-C-13

Season	No. of Observations	Total Monthly Kill	Av. Kill per Explosion	Seasonal Total Obs.	Seasonal Total Kill	Seasonal Av. Explosion
Winter						
Dec.	6	369.5	61.6			
Jan.	1	4	4.0			
Feb.	7	0	0	14	374	26.7
Spring						
March	3	144.5	48.1			
April	3	112	37.3			
May	12	594.5	49.5	18	851.0	47.3
Summer						
June	19	141	7.4			
July	9	110	12.2			
August	8	151.5	18.9	36	403	11.2
Fall						
Sept.	9	81	9.0			
Oct.	7	162	23.1			
Nov.	8	33.5	4.2	24	277	11.5
				92		

Discussion

The data compiled in this study do not fit the curve of a normal distribution. In the frequency of occurrence of mortalities, there is some resemblance to the Poisson distribution, but the fit is poor. The data represent simple empirical discoveries in a particular location over an appreciable length of time, and are valid in expressing what occurred under recorded conditions. Only very limited previous studies of this type have been conducted, and from these only very limited conclusions can be drawn. Controlled experiments conducted cooperatively by the Naval Ordnance Laboratory and this department (1948) indicated that the effective killing range of underwater explosions (using 30 to 300 pounds of explosive) usually does not exceed 100 yards from shot point. Observations by Coker and Hollis (1950) confirm this lethal distance estimated under conditions where the weight of charges of similar explosives ranged from 250 to 1200 pounds. No accurate estimates were obtained for the explosions observed in the course of this report, but much the same pattern of kill occurred. Cole (1948) describes the "slick" of darkened water, which moves across the surface as an enlarging circle from the site of an underwater explosion, and which indicates the points to which the shock wave has advanced. This phenomenon was seen regularly, and gave a rough means of measuring the range of the mortality. Complicating factors are present in this study which account for the peculiar distribution, which must be considered.

First, the pounds of fish killed in any particular explosion is dependent upon the number of fish present, and the sizes of those fish. Second, several species of fish share the area, each of which has a characteristic and different abundance (in both number and weight) from season to season, and from year to year. Third, the distribution of fish in any area is dependent to a considerable extent on their behavior and ecological relationships. Tide, temperature, salinity, oxygen, weather conditions, even time of day all exert influences on the movements and behavior of fish.

Although the characteristic feeding habits and movements of the several species of fish encountered in this study apparently have some relationship to the magnitude of their respective mortalities, there are other factors which must be considered. For example, would those species typically inhabit the explosive test area in equal concentrations? Specifically, would as many croaker and spot be feeding over the bottom in the test area as in other areas? Would striped bass, river herring or menhaden be distributed in the same manner over the shot point as in the rest of the river? Do physical barriers exist which would tend to exclude or limit certain species? Nash (1947) in a hydrographic survey of the Patuxent River, detected the seasonal occurrence in June and July of oxygen-poor water in the deeper areas. This phenomenon occurs during the summer months when density gradients are made more stable by higher temperatures. On the other hand, experimental fishing with a 16-foot shrimp trawl yielded consistent catches of hog-chokers (Achiurus fasciatus) from the test area immediately following the explosion, indicating that the water was sufficiently rich in oxygen to sustain fish life.

Any attempt to predict fish mortality resulting from an underwater explosion must therefore take into account the facts that no fish will be killed unless they happen to be within the lethal range of the explosion and that this lethal range of conventional types of explosives is definitely limited as has already been indicated. Although large kills will sometimes occur, these are most frequent in characteristically "schooling" species, and during those seasons when migrations tend to concentrate the fish in relatively small areas. Practically, a prediction is best based on three factors: (1) recognition of the lethal range of explosives; (2) knowledge of the seasonal abundance of fish and of their habits in the particular locality; and (3) empirical evidence. The third factor provides the soundest foundation. Nevertheless, the second factor is very valuable either in the absence of or in conjunction with empirical evidence. This is well shown by comparing the biological data pertaining to seasonal movements and abundance of fish in area C-11 to C-13. That the area (with its own biological characteristics) selected for explosion experiments is quite important in regulating the amount of fish killed is shown in table 7, which indicates the total and average kill (pounds) for one month (June) in three separate, but not far distant, localities in the same year (1948). These were, the C-11-C-13 test area, Point Patience, and an area near Barren Island in Chesapeake Bay. The Barren Island data were extracted from a table appearing in an earlier publication by Coker and Hollis (1950). The average kill (119.0 pounds) in each of six explosions near Barren Island far exceeded both the maximum and average kills observed in 19 explosions fired at C-11 - C-13 during June in the several years of this study. Likewise, the June average at Patience (38.6 pounds) is well above both the June (1.6 pounds) and total (16.8 pounds) averages at C-11 - C-13. The total average kill at Barren Island (21 explosions) was 70.7 pounds per explosion, and at Patience (19 explosions), 50.0 pounds.

Table 7

Comparison of kill of marketable fish in different areas
June, 1948

Locality	No. Explosions	Pounds of Fish	Average per Explosion
C-11 - C-13	9	14.0	1.6
Barren Island	6	714.0	119.0
Point Patience	5	193.0	38.6

It is evident from an examination of the master table (table 3) that one explosion or a whole series of explosions did not prevent fish from entering the area subsequently. For example, on October 21, 1948, there were three 2400 pound explosions, and each explosion killed fish. When explosions were conducted on two consecutive days (April 15 and 16, 1948 and August 5 and 6, 1953), fish were killed on both days. Then, too, marketable fish were killed in every month of the year except February.

PREDICTION OF FUTURE EFFECTS OF NAVAL ORDNANCE EXPLOSIVE TESTS

If further explosions of the type described in this report are continued in the Patuxent River area C-11 - C-13, the following predictions can be made with reasonable confidence, based on the facts and reasoning outlined above: (1) Explosions during the spring will, on the average, produce more kills, and probably higher kills, of marketable fish than explosions during any of the other seasons; (2) the average kill of marketable fish, on a yearly basis, assuming that all seasons are represented, will be relatively small; (3) extremely large kills will be of exceptional occurrence, but may occur at any season; (4) in a considerable percentage of the explosions no marketable fish will be killed; (5) the size of the charge, from 240 to 2540 pounds, will have no appreciable effect, in itself, on the amount of marketable fish killed; (6) fish will continue to recur in the area where the explosions take place; (7) in practically all instances the lethal range of the explosions will not exceed one hundred or two hundred yards radius from the shot-point; (8) no changes in the fishery may be expected other than those of a biological nature which might occur in an area in which no explosive tests were conducted.

It is quite impossible to set specific figures on future expected kill in the area C-11 - C-13, for this would be dependent largely upon the biological characteristics of abundance and habits of fish. If there should be no major change in the biological characteristics, then the order of magnitude of the measurements recorded during the seven-year period covered by this report could be extended to the future as the best available estimate.

Bibliography

Aplin, J. A.
1947. The Effect of Explosives on Marine Life. Calif. Fish and Game, 33(1):23-30.

Baldwin, W. J.
1954. Underwater Explosions Not Harmful to Salmon. Calif. Fish and Game, 40(1):77.

Chesapeake Biological Laboratory
1948. Effects of Underwater Explosions on Oysters, Crabs and Fish. Publication No. 70, Ches. Biol. Lab., Solomons, Md. 43 pp.

Coker, C. M. and E. H. Hollis
1950. Fish Mortality Caused by a Series of Heavy Explosions in Chesapeake Bay. Jour. Wildlife Mgt., 14(4):435-445.

Cole, Robert H.
1948. Underwater Explosions. Princeton Univ. Press, Princeton, N. J. 436 pp.

Fitch, J. E. and P. H. Young
1948. Use and Effect of Explosives in California Coastal Waters. Calif. Fish and Game, 34(2):53-70.

Fry, Donald H. and K. W. Cox
1953. Observations on the Effect of Black Powder Explosions on Fish Life. Calif. Fish and Game, 39(2):233-236.

Hubbs, Carl L. and A. B. Rechnitzer
1952. Report on Experiments Designed to Determine Effects of Underwater Explosions on Fish Life. Calif. Fish and Game, 38(3):333-366.

Nash, C. B.
1947. Environmental Characteristics of a River Estuary. Pub. No. 64, Ches. Biol, Lab., Solomons, Md. 27 pp.