The Effect of a Marine Seismic Exploration on Fish Populations in British Columbia Coastal Waters

by
Roger K. Kearns
and
Forbes C. Boyd

Fish Culture Development Branch, Department of Fisheries of Canada, Pacific Area, Vancouver, B.C.

Abstract

The Shell Oil Company of Canada conducted a marine seismic survey off the west coast of British Columbia during the summer months of 1963. Because of the potential damage to local fish populations through exposure to high velocity explosives, the Department of Fisheries of Canada conducted a program of supervision and control on the Company's field operations. The Company agreed that the on site departmental biologist would have full authority to suspend or terminate any shooting procedures judged to be detrimental to fish populations.

Observations throughout the survey revealed that 419 (4.3 percent) of a total of 9,638 shot points exhibited a total surface mortality of 59,277+ fish. Herring and rockfish represented 72.2 and 23.8 percent of the total kill respectively with the remaining four percent consisting of 189+ adult salmon, 467+ juvenile salmon and 1,732+ miscellaneous fishes. Large charges (50-300 pounds) of nitrene S.M., typical of refraction shooting, killed more fish more frequently than light charges (5-25 pounds) typical of reflection shooting. An increase in detonation depth increased the area of potential fish kill. In shallow water (less than 34 fathoms) the horizontal lethal range of a seismic explosion is greater than in deep water (greater than 34 fathoms). Surface observations of fish mortality were not a reliable measure of charge lethality since they do not account for subsurface mortality. Under existing operational conditions only the vertical scanner on the fish detection unit was found useful in detecting the presence of fishes. In view of the area covered and number of shot points subjected to high velocity explosives, the resulting fish mortality was considered relatively light.

Introduction

Marine seismic exploration for new petroleum resources has been accelerated on a world-wide basis since the end of World War II. The increasing energy
demands of industry and population growth are stimulating nations to look beneath the seas for new oil reserves. In this search seismic* techniques are used which reveal subterranean structure through interpretation of shock waves caused by controlled explosive detonations. Explorations were initially restricted to shallow water areas bordering continental coastlines. However, recent advances in drilling procedures have permitted oil companies to feasibly extend the continental shelf explorations into waters deeper than 100 fathoms. By 1966 such advances enabled marine seismic explorations to be carried out in the regions bordering the Persian Gulf, Sea of Japan, Gulf of Paria, Venezuela, North Sea, Holland, Nigeria, Africa and British Columbia, Canada (Rulifson and Schoning, 1963). Extensive surveys are presently underway along the coasts lines of the United States and Canada. This report will describe one of the more recent surveys off the west coast of British Columbia and the observed effects of conventional seismic methods on the local fish populations.

Shock waves produced by detonation of high velocity explosives provide the best information on substrata geology. Experimental evidence (Hubb Schultz and Wisner, 1960) has shown high velocity explosives to be capable of killing substantial numbers and many kinds of marine fauna. Hubbs and Rechnitzer (1952) found that low velocity black powder explosives up to 5 pounds proved to be relatively innocuous to fish populations. The former situation, if not carefully monitored, could result in a serious loss of commercial valuable fish and invite severe criticism from the fishing industry and general public.

During 1961 Shell Oil Company of Canada secured petroleum exploratory rights on 11.9 million acres of offshore water along the coast of British Columbia Canada. The area (see Figure 1) extends from Barkley Sound off the southwest coast of Vancouver Island northerly to north central Hecate Strait. In late 1961 the Company contacted the Department of Fisheries of Canada and briefly outlined their proposed program of exploration which would utilize the gas exploder and high velocity explosive techniques. The Company wished to discuss any recommendations or objections the Department might have concerning the proposed program.

In the course of subsequent technical meetings the Company described in detail the seismic techniques to be employed and presented a plan of operations which included the timing and specific locations of the survey lines.

In recognition of the potential damage inherent in an operation of this nature and magnitude, the Department concurrently presented a draft of conditions which would provide adequate protection to the fishery resource in an area frequented by salmon, herring, halibut and crab fisheries.

Responsibility for protection of the fishery is provided for in the 1937 Canada Fisheries Act.

*Seismic in this report will mean artificially created shock waves caused by controlled explosives as opposed to naturally created shock waves caused by earthquakes, etc.
To facilitate a clearer understanding of the seismic procedures and departmental conditions, a glossary of terms used is provided at this juncture:

**Glossary**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shot</td>
<td>a detonated explosive charge.</td>
</tr>
<tr>
<td>Shot Point</td>
<td>the point location where the explosive charge was dropped and detonated.</td>
</tr>
<tr>
<td>Shot Line</td>
<td>a line consisting of a series of shot points.</td>
</tr>
<tr>
<td>Shot Pattern</td>
<td>refers to shooting procedure; for example: multiple shots at one shot point or single shots at a series of shot points at predetermined intervals.</td>
</tr>
<tr>
<td>Shot Record</td>
<td>refers to the trace echo of the explosive detonation which was recorded on the tape of the fish detection unit.</td>
</tr>
<tr>
<td>Boil</td>
<td>the area of turbulent water caused by the explosive detonation.</td>
</tr>
<tr>
<td>Lethal Shot</td>
<td>any shot which killed or injured fish.</td>
</tr>
<tr>
<td>Tour or Cruise</td>
<td>a ten day period of operational seismic exploration. The program consisted of eight such tours with five-day intervals for maintenance, crew rest and supplies.</td>
</tr>
<tr>
<td>Leg (pass)</td>
<td>refers to the shooting procedure in which the shooting vessel moves along the shot line in one direction to make one leg and then returns in the opposite direction to make a second leg.</td>
</tr>
<tr>
<td>Echo</td>
<td>the repeating of a sound, produced by reflection of sound waves from a surface.</td>
</tr>
</tbody>
</table>

I. Seismic Operational Procedures

A. Vessel Utilization:

Three ships were used in the Shell Oil 1963 seismic survey.

1. The shooting vessel carried the explosives and the shooting crew who prepared and dropped explosives at designated locations.

2. The instrument vessel carried the recording hydrophones and recording instruments. The chief operator (in charge of field operations) was located on this vessel.

3. The gas-exploder vessel operated in the same general area but operated independently of the aforementioned vessels and was not included in the monitoring program.

B. Shooting Patterns

Shooting patterns consist of two principal types with minor variations. The following is a brief description of each type.

1. Reflection Profile: This pattern provides information on seismic waves as they travel vertically through sub-strata levels. This technique involves the shooting boat travelling along the shot line at a constant speed and detonating a shot every 600 or 1800 feet depending on the reflection information required (Figure 2). The instrument vessel travels on the same course but maintains a position approximately 100 yards ahead and 30 yards abeam of the shooting vessel. Reflection charges ranged from five pounds set to explode at 1.5 feet below water surface to 25 pounds set at three feet. Most reflection shot patterns involved up to 200 shots detonated at intervals of one to three minutes, depend-
ng on the distance between shot points (600 or 1800 feet). At the end of the first pass along a shot line the pattern would be re-established in the reverse direction. As many as four passes or legs over the same line could be required.

2. Refraction Profile: This pattern provides information on seismic waves as they travel horizontally through sub-strata levels. This technique involves the shooting vessel making repeated passes over the same shot point in a figure eight maneuver while the instrument vessel moves away and along the shot line (Figure 3). As the instrument vessel moves along the shot line every 3600 feet, the shooting vessel is maneuvered into shot point position and the charge

---

**Figure 2. Diagrammatic Presentation of Reflection Shooting Procedure, Vessel Location and Type of Seismic Record Produced.**

**Figure 3. Diagrammatic Presentation of Reflection and Refraction Shooting Methods.**
is dropped into the water. The detonation occurs after the all-clear signal is
given by the shooting vessel and is triggered by a remote control device aboard
the instrument vessel. The size and depth setting of the charges used ranged from
10 pounds set to explode three feet from the surface to 300 pounds set at 40
feet. Charge sizes are increased as the distance between the instrument vessel
and the shot point increases. Between shots there is usually a six minute time
interval before the two vessels are in position for the next shot. Usually 10 to 20
charges are exploded on a shot point whereupon the shooting vessel proceeds
to a shot point at the opposite end of the shot line and the procedure is repeated
with the instrument vessel retracing its path to the original shot point. A modified
version of refraction shooting was the reverse refraction procedure. This
pattern involves the shooting vessel starting at some distant shot point and
then proceeding toward the stationary instrument vessel. Charge sizes, initially
heavy, were reduced as the shooting vessel approached the instrument vessel.

3. Bottom Hydrophone Refraction: This pattern involves the shooting vessel
moving along the shot line dropping 100 to 300 pound charges at 3600 foot
intervals while the instrument vessel is stationed on one shot point with hydro-
phones set on the bottom to pick up the shock wave energy.

C. Explosive Used:
The blasting agent used throughout the program was nitroine S.M. (Seismic
Marine) which by itself is not an explosive, but can be made to explode by use
of a high explosive primer. It is composed of ammonium nitrate and is known as
nitro-carbo-nitrate (NCN). It produces a detonation velocity of 15,100 feet/sec.,
midrange of the dynamites (4000-23,000 feet/sec.) but lower than T.N.T.
(20,000 feet/sec.). NCN has the principal advantage of being relatively safe to
handle and mainly for this reason, it is almost exclusively used for seismic work
today (Rulifson and Schoning, 1963). Additional preference for nitroine comes
from the fact that it creates an abrupt wave of great pressure intensity producing
a much better quality seismographic record than is possible with slower velocity
explosives such as black powder (Hubbs and Rechnitzer, 1960).

II. Department Procedures
The Department was not unduly concerned with the effects of the gas-
exploding technique since both the literature on this subject and previous
Department experience demonstrated that fish kill by this method is negligible.
However, the Department was fully aware of the adverse effects of conventional
seismic explosions on fish populations. Every aspect of the proposed program
was examined by headquarters technical staff. Information was requested and
received from several fisheries agencies in the United States, which had previous
experience in monitoring marine seismic operations and the International Pacific
Salmon Fisheries Commission staff reviewed the program and submitted perti-
nent recommendations. As a result the following conditions governing seismic
operations were drafted to ensure operational control and minimize mortality
to the fishery.
A. Conditions Governing Seismic Operations:

1. A Department of Fisheries biologist observer will be carried aboard the shooting vessel. This shooting vessel will be equipped with a fish scanning device for locating fish and recording bottom depth.

2. An observation vessel will be provided by the Company for the Department. An assistant observer will be carried aboard the observation vessel for the purpose of observing and numerically recording fish mortality.

3. It is understood that both the observer and his assistant will be hired by the Department and be responsible to the Department and paid for by the Company.

4. The vessels carrying the observers and the chief operator should be equipped with a radio set capable of transmitting and receiving on the Department's frequency.

5. The observer will have full authority to stop the program or delay it if time is required to check for the presence of fish. The Company will be expected to miss shots or avoid areas where fish concentrations have been observed or where in the opinion of the observer damage to fish would result.

6. The exact location of both the survey lines for reflection and the exact location of the refraction shot points are to be provided to the Department's Vancouver office as soon as plans are completed. Changes in plan should be cleared through this office a week prior to shooting.

7. Shooting will not be approved within:
   (a) one mile of vessels fishing.
   (b) one mile of river estuaries.
   (c) one mile of the low tide line on any body of land.

8. The sizes of charges approved will depend upon depth governed by the following:
   (a) up to 5 pounds of nitroine in depths of 200 feet (34 fathoms) or less.
   (b) up to 25 pounds of nitroine in depths of 200 to 300 feet (34 to 50 fathoms).
   (c) up to 300 pounds of nitroine in depths in excess of 300 feet (50 fathoms).

   Each shot of over 25 pounds in waters of less than 50 fathoms in depth will require special consideration before approval can be granted. The approval to fire charges of any size will be subject to on-site restrictions set by the observer.

9. The portion of the survey in waters off the west coast of Vancouver Island is to be completed by June 15th.

B. Deleted Areas:

Early in the planning stage of the survey, Fishery Officers, Fisheries Patrol Boat Captains and Fisheries Research Board of Canada Scientists were contacted with a view to obtaining information on the distribution and probable density of fish populations in the survey area. Based on the information gained, specific areas which were known to support substantial stocks of ground fish, herring and salmon, were deleted from the Company's program. The major portion of these deleted areas were located in Hecate Strait and Queen Charlotte Sound. Small areas along the west coast of Vancouver Island were also deleted from the Company's program (Figure 1).
C. Field Representatives:

In accordance with the aforementioned agreement the Department contracted the services of a professional fisheries biologist who, as the departmental observer, was assigned the following responsibilities under the direction of headquarters technical personnel.

1. Supervise and regulate shooting procedures with the objective of avoiding excessive fish kill. It was considered impossible to avoid killing small numbers of fish without seriously handicapping the purpose of the exploration.

2. Search by means of a suitable fish detection device for presence of fish in the vicinity of the proposed shot points.

3. Record observations and prepare a final report on the effects of the seismic program on local fish populations.

4. Co-ordinate observations and recording procedures.

The assistant observer recorded species and estimated the number of dead or injured fish at each shot location.

As outlined in the original agreement pre-planned maps were submitted to the Department by the Company well in advance of the commencement date. Close liaison was maintained between the Department field personnel and headquarters staff. Requests for major program changes were referred to the Area Director of Fisheries for clearance. Minor changes requested by the Company were cleared through the on-site fisheries observer while on tour.

D. Fish Detection Unit:

Considerable effort was spent selecting the type of fish detection unit that would provide the best possible results. After corresponding with several American agencies which had experience with such units, a Simrad White Line Recorder was selected. However, this choice was abandoned when it was apparent that this machine was not adaptable to the vessel that the Company had chartered. A comparable alternative was found in the Kelvin Hughes, Ceres Fish Finder, Model MS 29 F. Features of this machine include:

1. Uses either moist or dry recording paper.

2. A whiteline amplifier for distinguishing bottom fish from the bottom.

3. A flashing neon light on the pen arm for initial target and depth indication.

4. A loudspeaker (or headphones) for audible signals.

5. A hand-operated hydraulic training unit which permitted scanning 135° to port and starboard.

6. Time indicator marker which records at one-minute intervals on the recording paper.

7. Four echo ranges selected by a simple gear adjustment.

8. Horizontal detection up to 960 yards and vertical depth detection down to 480 fathoms.

9. One recorder provided the comprehensive search facilities detailed above, namely long horizontal sound beam or short range searching (intermediate angle sound beam) and echo sounding (vertical sound beam) (Figure 4).
E. Field Procedures:

1. Radio Contact: Direct radio contact between the assistant observer and the biologist observer was maintained throughout all shooting patterns. On occasions when the fish detection unit did not record the presence of fish, assessment of potential mortality and resultant decisions in respect to shot pattern suspension were facilitated by immediate communication between the observers.

2. Refraction: Before commencing a refraction series the shooting boat passed over the shot point and the area was searched with the Ceres Recorder for evidence of fish. If fish were detected the chief operator aboard the instrument vessel was requested to move to a new shot point location or to be prepared to do so if indication of sizeable fish kills were observed. If, however, there were no indications of substantial numbers of fish the shot pattern commenced with small charges and increased to larger charges as the instrument vessel moved away from the shot point. After the first shot of a refraction pattern the fish detector unit was alternately switched from its horizontal to vertical components to continually search for indications of fish. The assistant observer on board the observation vessel examined the boil for a period of 4-6 minutes and then moved out of the area when the shooting vessel returned for the next shot. At some refraction shot points where the chief operator wished to commence shooting with heavy charges and where there were indications of fish, test charges were detonated. If no fish were observed on the surface following the test shot, the shot pattern was permitted to begin.

3. Reflection Procedure: During reflection shooting the vertical component of the fish detection unit was kept in continuous operation in order to record water depth, shot record and fish presence. Since the speed of the shooting vessel was relatively constant, fish indications could be more accurately located in terms of their horizontal and vertical distances from the shot point. The observation vessel during reflection shooting was usually located from two to four hundred yards behind the shooting vessel.

4. Diving Assessment Program: During the last cruise, at the Department's request, the Company allotted one day for an assessment of the effects of under-
water explosives on fish populations. Two professional scuba divers and a departmental diver made pre-explosion and post-explosion observations of fish at shot points. Anchored marker buoys were set in shallow water areas inhabited by fish as indicated on the fish detection unit. Prior to shooting, the divers, using pre-measured ropes tied to the anchor, searched for and recorded the number of fish in 25, 50, 75 and 100 foot radius circles. After the shot was detonated beside the marker buoy, the divers repeated the search pattern and recorded the number, location and condition of fish present. Through comparison of the pre-examination and post-examination periods, the data obtained provided additional information concerning:

(a) The extent of the horizontal radial effect of underwater explosions in relatively shallow water (10–12 fathoms).
(b) The difference in numbers between observed surface fish mortality and total mortality.
(c) The effect of explosions on fish with and without gas bladders.

5. Species Identification: In order to determine what fish species were affected by the seismic explosives, random fish samples were taken and preserved for later identification by personnel in the Fisheries Institute at the University of British Columbia.

III. Results and Discussion

A. General:

Examination of data shown in Tables I and II show that 809 (7.6 percent) of a total of 10,676 shots killed or injured 59,277+ fish. Herring and rockfish constituted 72.2 and 23.8 per cent respectively of the total kill with the remaining four per cent comprising 189+ adult salmon, 467+ juvenile salmon and 1,732+ miscellaneous fishes. The total recorded mortality was considered a minimum estimate for the following reasons:

1. Estimates were based on surface observations only.
2. Field observations and available literature (Rulifson and Schoning, 1963) indicate that many dead or seriously damaged fish do not rise to the surface.
3. The low deck of the observation vessel provided limited observation. This condition was particularly critical in rough water and during twilight or early morning hours.
4. Mortality estimates included only those fish which rose to the surface during the observation period. Extended observation periods following completion of a shot pattern often doubled earlier estimates. However, these were not always included because wind and tidal action often distributed fish over a wide area making accurate estimates impossible.

Inspection of Table I, Table II and Figure 5 reveals that the percentage of shots which killed fish increased sharply when charges larger than 25 pounds were used. An extension of Table I into the individual tours as shown in Table III shows a consistent increase in the incidence of fish kill when charges of 50 pounds or more were used, except in tour eight. During this tour the increase
Table I.
Total Numbers and Percentages of Shots Resulting in Fish Mortality During Cruises One to Eight

<table>
<thead>
<tr>
<th>Charge Size in Pounds of Nitrogen</th>
<th>5</th>
<th>10</th>
<th>16t</th>
<th>25 or 26t</th>
<th>30</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Number of Shots..................</td>
<td>1251</td>
<td>2215</td>
<td>4727</td>
<td>1534</td>
<td>156</td>
<td>211</td>
<td>118</td>
<td>464</td>
<td>10,676</td>
</tr>
<tr>
<td>Total Number of Lethal Shots............</td>
<td>21</td>
<td>99</td>
<td>200</td>
<td>82</td>
<td>49</td>
<td>101</td>
<td>57</td>
<td>200</td>
<td>809</td>
</tr>
<tr>
<td>Percentage of Shots Resulting in Fish Mortality</td>
<td>1.7</td>
<td>4.5</td>
<td>4.2</td>
<td>5.4</td>
<td>31.4</td>
<td>47.0</td>
<td>48.3</td>
<td>43.1</td>
<td>7.6</td>
</tr>
</tbody>
</table>

Table II.
Mortality Per Charge Size For Different Kinds Of Fishes

<table>
<thead>
<tr>
<th>Charge Size Pounds</th>
<th>5</th>
<th>10</th>
<th>16t</th>
<th>25 or 26t</th>
<th>30</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>Total</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rockfish.............</td>
<td>19</td>
<td>225</td>
<td>204</td>
<td>207</td>
<td>57</td>
<td>299</td>
<td>214</td>
<td>11,059</td>
<td>14,159</td>
<td>25.8</td>
</tr>
<tr>
<td>Herring..............</td>
<td>139</td>
<td>1,275</td>
<td>1,519</td>
<td>3,246</td>
<td>3,189</td>
<td>16,420</td>
<td>7,074</td>
<td>9,818</td>
<td>42,730</td>
<td>72.2</td>
</tr>
<tr>
<td>Adult salmon........</td>
<td>6</td>
<td>9</td>
<td>50</td>
<td>33</td>
<td>14</td>
<td>16</td>
<td>9</td>
<td>45</td>
<td>189</td>
<td>0.3</td>
</tr>
<tr>
<td>Juvenile salmon.....</td>
<td>1</td>
<td>0</td>
<td>143</td>
<td>69</td>
<td>20</td>
<td>46</td>
<td>98</td>
<td>99</td>
<td>467</td>
<td>0.8</td>
</tr>
<tr>
<td>Miscellaneous*....</td>
<td>0</td>
<td>268</td>
<td>281</td>
<td>241</td>
<td>89</td>
<td>249</td>
<td>166</td>
<td>438</td>
<td>1,732</td>
<td>2.9</td>
</tr>
<tr>
<td>Totals...............</td>
<td>159</td>
<td>1,807</td>
<td>2,797</td>
<td>3,867</td>
<td>3,349</td>
<td>17,621</td>
<td>7,618</td>
<td>22,059</td>
<td>59,277</td>
<td></td>
</tr>
<tr>
<td>Percentage of total kill</td>
<td>0.3</td>
<td>3.0</td>
<td>4.7</td>
<td>6.5</td>
<td>5.6</td>
<td>29.7</td>
<td>12.9</td>
<td>37.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Needle Fish, Mackerel Jack, Whiting, Grey Cod, Pacific Hake, Sea Perch

Table III.
Numbers and Percentages of Shots Resulting in Fish Mortality During the Eight Cruises of 1963

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Charge Size in Pounds</th>
<th>5</th>
<th>10</th>
<th>16t</th>
<th>25 or 26t</th>
<th>30</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Number of shots...........</td>
<td>3</td>
<td>20</td>
<td>86</td>
<td>17</td>
<td>8</td>
<td>31</td>
<td>8</td>
<td>23</td>
<td>196</td>
</tr>
<tr>
<td>1</td>
<td>Number of lethal shots.....</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>17</td>
<td>4</td>
<td>15</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Percentage of shots resulting in mortality</td>
<td>5.0</td>
<td>1.1</td>
<td>5.9</td>
<td>25.0</td>
<td>55.0</td>
<td>50.0</td>
<td>65.2</td>
<td>20.9</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Number of shots...........</td>
<td>24</td>
<td>400</td>
<td>366</td>
<td>388</td>
<td>18</td>
<td>30</td>
<td>11</td>
<td>77</td>
<td>1314</td>
</tr>
<tr>
<td>2</td>
<td>Number of lethal shots.....</td>
<td>1</td>
<td>14</td>
<td>1</td>
<td>8</td>
<td>10</td>
<td>7</td>
<td>44</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Percentage of shots resulting in mortality</td>
<td>.3</td>
<td>3.8</td>
<td>.3</td>
<td>44.4</td>
<td>33.3</td>
<td>63.6</td>
<td>57.1</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Number of shots...........</td>
<td>33</td>
<td>433</td>
<td>222</td>
<td>25</td>
<td>27</td>
<td>33</td>
<td>14</td>
<td>17</td>
<td>804</td>
</tr>
<tr>
<td>3</td>
<td>Number of lethal shots.....</td>
<td>3</td>
<td>5</td>
<td>1</td>
<td>6</td>
<td>18</td>
<td>9</td>
<td>11</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Percentage of shots resulting in mortality</td>
<td>.7</td>
<td>2.3</td>
<td>4.0</td>
<td>22.2</td>
<td>54.5</td>
<td>64.3</td>
<td>64.7</td>
<td>6.6</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Number of shots...........</td>
<td>126</td>
<td>2</td>
<td>808</td>
<td>308</td>
<td>20</td>
<td>18</td>
<td>12</td>
<td>26</td>
<td>1320</td>
</tr>
<tr>
<td>4</td>
<td>Number of lethal shots.....</td>
<td>2</td>
<td>0</td>
<td>33</td>
<td>37</td>
<td>7</td>
<td>13</td>
<td>8</td>
<td>18</td>
<td>118</td>
</tr>
<tr>
<td>4</td>
<td>Percentage of shots resulting in mortality</td>
<td>1.6</td>
<td>4.1</td>
<td>12.0</td>
<td>35.0</td>
<td>35.0</td>
<td>35.0</td>
<td>35.0</td>
<td>8.9</td>
<td></td>
</tr>
</tbody>
</table>
Table III (Concluded)
Numbers and Percentages of Shots Resulting in Fish Mortality During the Eight Cruises of 1963 (Concluded)

<table>
<thead>
<tr>
<th>Cruise</th>
<th>5</th>
<th>10</th>
<th>161</th>
<th>25 or 261</th>
<th>50</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of shots</td>
<td>4</td>
<td>249</td>
<td>38</td>
<td>30</td>
<td>32</td>
<td>21</td>
<td>211</td>
<td>585</td>
<td></td>
</tr>
<tr>
<td>Number of lethal shots</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>57</td>
<td>74</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage of shots resulting in mortality</td>
<td>2.0</td>
<td>10.0</td>
<td>15.6</td>
<td>19.0</td>
<td>27.0</td>
<td>12.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of shots</td>
<td>3</td>
<td>5</td>
<td>1532</td>
<td>273</td>
<td>13</td>
<td>3</td>
<td>5</td>
<td>40</td>
<td>1874</td>
</tr>
<tr>
<td>Number of lethal shots</td>
<td>26</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage of shots resulting in mortality</td>
<td>1.7</td>
<td>1.8</td>
<td>20.0</td>
<td>20.0</td>
<td>2.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of shots</td>
<td>16</td>
<td>2</td>
<td>1433</td>
<td>468</td>
<td>21</td>
<td>44</td>
<td>47</td>
<td>70</td>
<td>2730</td>
</tr>
<tr>
<td>Number of lethal shots</td>
<td>18</td>
<td>1</td>
<td>98</td>
<td>26</td>
<td>10</td>
<td>25</td>
<td>24</td>
<td>47</td>
<td>249</td>
</tr>
<tr>
<td>Percentage of shots resulting in mortality</td>
<td>2.8</td>
<td>6.8</td>
<td>5.6</td>
<td>47.6</td>
<td>56.8</td>
<td>51.1</td>
<td>67.1</td>
<td>9.1</td>
<td></td>
</tr>
<tr>
<td>Number of shots</td>
<td>413</td>
<td>1353</td>
<td>31</td>
<td>17</td>
<td>19</td>
<td>20</td>
<td>1853</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of lethal shots</td>
<td>1</td>
<td>18</td>
<td>12</td>
<td>13</td>
<td>13</td>
<td>130</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage of shots resulting in mortality</td>
<td>6.9</td>
<td>38.0</td>
<td>70.5</td>
<td>68.4</td>
<td>65.0</td>
<td>8.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total number of shots per charge size</td>
<td>1251</td>
<td>2215</td>
<td>4727</td>
<td>1534</td>
<td>156</td>
<td>211</td>
<td>118</td>
<td>464</td>
<td>10,676</td>
</tr>
</tbody>
</table>

Occurred when charges larger than 10 pounds were used. Much of this tour was conducted in the relatively shallow waters of Northern Hecate Strait and this may account for the increased lethality of 16\frac{2}{3} pound charges.

It is interesting to note that Aplin (1947) later supported by the Chesapeake Biological Laboratory (Anon., 1948), found no apparent relation between water depth or charge size and fish mortality. Knight (1907) reported however that destructiveness varied with charge size, water depth, number of fish present in the locality of explosion, distance of fish from the explosion site and kinds of fish present.

Table IV.
Comparison of the Observed Lethal Effect of Different Shot Patterns on Fish Populations

<table>
<thead>
<tr>
<th>Shooting Pattern</th>
<th>Total Number of Shot Points</th>
<th>Number of Lethal Shot Points</th>
<th>Percentage of Lethal Shot Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refraction</td>
<td>81</td>
<td>56</td>
<td>69.1</td>
</tr>
<tr>
<td>Reflection</td>
<td>9,382</td>
<td>343</td>
<td>3.7</td>
</tr>
<tr>
<td>Velocity Profile</td>
<td>76</td>
<td>1</td>
<td>1.3</td>
</tr>
<tr>
<td>Hydrophone and Reverse Refraction</td>
<td>99</td>
<td>19</td>
<td>19.0</td>
</tr>
<tr>
<td>Total</td>
<td>9,638</td>
<td>419</td>
<td></td>
</tr>
</tbody>
</table>
As shown in Table IV, 419 (4.3 percent) of a total of 9,638 shot points demonstrated fish mortality. The incidence of fish mortality was 18 times greater at refraction shot points than at reflection shot points. The incidence of fish mortality during the hydrophone and reverse refraction (heavy charges) shooting was five times greater than that for reflection shooting with light charges.

Inspection of Table V shows that 75 shot points accounted for 86.2 per cent of the total observed mortality. The remaining 13.8 per cent were distributed over 344 shot points which included all types of shooting. Nine refraction shot points accounted for 75.3 per cent of the total observed mortality. In all cases single or multiple shots of heavy charges on a shot point resulted in a consistently higher mortality than for shot points subjected to light charges.

Table V.
Analysis of the 15 Refraction and Reflection Shot Patterns Which Resulted in Major Fish Kills

<table>
<thead>
<tr>
<th>Shooting Pattern</th>
<th>Herring Mortality</th>
<th>Rockfish Mortality</th>
<th>Total</th>
<th>Percentage of Total Mortality</th>
<th>Number of Lethal Shot Points</th>
<th>Number of Kills Detected on the Scanner</th>
<th>Number of Shot Suspensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refraction</td>
<td>36,244+</td>
<td>8,374+</td>
<td>44,618+</td>
<td>75.3</td>
<td>9</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Reflection</td>
<td>2,155+</td>
<td>702+</td>
<td>2,857+</td>
<td>4.8</td>
<td>61</td>
<td>32</td>
<td>3</td>
</tr>
<tr>
<td>Hydrophone Refraction</td>
<td>2,640+</td>
<td>2,640+</td>
<td>5,280+</td>
<td>4.4</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity Profile</td>
<td>1,000+</td>
<td>—</td>
<td>1,000+</td>
<td>1.7</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>—</td>
<td>—</td>
<td>51,115+</td>
<td>86.2</td>
<td>75</td>
<td>43</td>
<td>5</td>
</tr>
</tbody>
</table>

Figure 5. Percentage Comparison of Lethal Shots for Various Charge Sizes.
B. Effect of Water Depth on Incidence of Mortality:

Table VI and Figure 6 show that the increased lethal effect of light charges on fish located in shallow water (less than 34 fathoms) is greater than that on fish in deep water (more than 34 fathoms). Every shallow water shot point involving charges of 5, 10, 16$\frac{1}{2}$ and 25 pounds resulted in fish mortality, whereas charges of the same magnitude at deep water shot points demonstrated a much lower incidence.

Table VI.
Comparison of Lethal Effects of Light Charge Refraction Shots Detonated at Shallow and Deep Water Shot Points$^1$.

<table>
<thead>
<tr>
<th>Charge Size in Pounds</th>
<th>Shallow Water (less than 34 fathoms)</th>
<th>Deep Water (greater than 34 fathoms)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of Shot Points</td>
<td>Number of Lethal Shot Points</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>16$\frac{1}{2}$</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>25</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

$^1$Fish were present at all shot points as revealed by surface mortality occurring after detonation of heavier charges.

Table VII also supports the conclusion that incidence of fish mortality is greater in shallow water. Ten pound charges detonated in shallow water killed approximately 14 times as many fish as the deep water shots. In shallow water an increase in charge size from five to ten pounds resulted in a fourfold increase in the incidence of lethal shots.

Table VII.
Comparison of the Incidence of Mortality Resulting from Detonation of Light Charges in Shallow and Deep Water During Reflection Shooting

<table>
<thead>
<tr>
<th>Charge Size in Pounds</th>
<th>Shots Detonated in Shallow Water (less than 34 fathoms)</th>
<th>Shots Detonated in Deep Water (greater than 34 fathoms)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of Shots</td>
<td>Number Killing Fish</td>
</tr>
<tr>
<td>5</td>
<td>1206</td>
<td>18</td>
</tr>
<tr>
<td>10</td>
<td>1322</td>
<td>89</td>
</tr>
<tr>
<td>16$\frac{1}{2}$</td>
<td>45</td>
<td>1</td>
</tr>
<tr>
<td>25</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>
The foregoing is supported by previous investigators who have pointed out that enclosed areas such as underwater canyons and shallows tend to reflect seismic shock waves more readily than unconfined water areas and they therefore amplify the lethal effects of underwater explosives (Hubbs and Rechnitzer, 1952).
C. Lethal Range Analysis:

In cases where fish were located at the same depth and distance from the shot point, light charges used in refraction shooting were lethal to fish whereas those used in reflection shots were not. This is demonstrated by the following examples in which the horizontal distances have been estimated. Refraction charges of 25 pounds set to explode 32 feet from the surface killed fish which were located at 240 feet depth and approximately 850 feet from the shot point, although the same charge employed in reflection shooting, but set to explode four feet from the surface, did not kill fish located at 240 feet depth and 100 feet from the shot point. Knight (1907) reported that fish mortality increases as the detonation depth of dynamite charges increases. There is thus some evidence that charges of the same magnitude set to explode at greater depths are more lethal to fish populations than those exploding at shallow depths. Charges set at shallow depths lose more shock wave energy at the surface than deep set charges. Consequently less energy is directed below the surface which in turn is less lethal to fish populations.

D. Analysis of Fish Mortality Samples:

Examination of Table VIII shows that all 25 species killed by the seismic explosions possessed an air bladder. It is also believed that only those fish with air bladders were observed on the surface throughout the duration of the survey. Literature reviews show that bladderless fish are not as adversely affected as fish with air bladders (Rulifson and Schoning, 1963).

Examination of fish killed by seismic explosions revealed specimens with internal ruptures, displaced visceral organs, torn musculature, haemorrhaging blood vessels, protruding eyes, everted stomachs and gas bladder damage. Observations from the Chesapeake Biological Laboratory (Anon., 1948) revealed that exposure of fish to explosions usually results in rupture or haemorrhage of the gas bladder, abdominal vein, spleen, liver and ripe gonads. Severe damage to any one organ is usually fatal, but moderate or slight injury is often survived. The organ most commonly damaged was the gas bladder. Post mortem observation showed that the edges of holes in the gas bladder were turned outward and that blood from broken vessels in the wall of the bladder had been blown into the abdominal cavity. Such evidence suggests that ruptured or distended gas bladders are caused from an increase of internal pressure from within rather than without.

Examination of gas bladder damage provided the basis for the following conjectures: herring and salmon usually suffered ruptured gas bladders which may be the direct result of the explosion pressure wave. Tyler (1960) reported that caged salmon subjected to dynamite explosions exhibited ruptured gas bladders. Both fishes exhibit the physostomous condition in which the gas bladder is connected to the esophagus by a pneumatic duct. Such a connection would permit a severe pressure change to directly enter the gas bladder. In the event that the gas bladder does not, or cannot, adjust to a sudden pressure difference, serious damage such as a rupture could occur. The released gas could
escape into the abdominal cavity and considerably increase the buoyancy of the fish. The buoyancy period was extremely short for salmon which, if they came to the surface at all, remained there for only a few minutes; whereas herring exhibited a longer buoyancy, frequently in excess of one hour.

Rockfishes often showed portions of the stomach extending into the mouth cavity (Figure 7). Dissection revealed that this stomach protrusion was caused by a greatly distended gas bladder which had forced the stomach anteriorly. Since rockfish exhibit the physoclistous condition (no connecting pneumatic duct between gas bladder and esophagus), they would not react to pressure differences in the same way as herring or salmon do. Since the gas bladder is under the control of the central nervous system, damage to this system caused by a seismic shock wave could conceivably relax hydrostatic control. Ward, Montgomery and Clark (1948) have presented a theory of the mechanism of the nervous system damage which results from an intense positive pressure wave followed by negative pressure. They postulate that such injury occurs in the negative phase of the pressure wave, and results directly from the process of cavitation, or the rapid formation and collapse of cavities in the brain fluids. Rockfish disorientated in this fashion could rise to the surface. If the rate of ascent was faster than the pressure adjustment capacity of the rockfish, the gas bladder would expand and displace internal organs as exhibited by the everted stomach. In this case hydrostatic control may be lost indirectly through destruction of central nerve control. Salmon and herring lose hydrostatic control because of the pressure wave entering the gas bladder through the pneumatic duct and directly rupturing the gas bladder.

**Figure 7.** Samples of rockfish mortality showing protruding eyes, everted stomachs and gill haemorrhage.
Table VIII.
List of Fish Species Killed by Seismic Explosions

<table>
<thead>
<tr>
<th>Number of Specimens</th>
<th>Species</th>
<th>Common Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sebastodes alutus</td>
<td>Longjaw rockfish</td>
</tr>
<tr>
<td>1</td>
<td>Entomelas</td>
<td>Widow rockfish</td>
</tr>
<tr>
<td>2</td>
<td>Mystinus</td>
<td>Blue rockfish</td>
</tr>
<tr>
<td>10</td>
<td>Zacentrus</td>
<td>Sharpchin rockfish</td>
</tr>
<tr>
<td>1</td>
<td>Pinniger</td>
<td>Orange rockfish</td>
</tr>
<tr>
<td>1</td>
<td>Nigrocingtus</td>
<td>Blackbanded rockfish</td>
</tr>
<tr>
<td>2</td>
<td>Ruberrimus</td>
<td>Red snapper</td>
</tr>
<tr>
<td>2</td>
<td>Helomaculatus</td>
<td>Rosethorn rockfish</td>
</tr>
<tr>
<td>4</td>
<td>Brevispinus</td>
<td>Shortspine rockfish</td>
</tr>
<tr>
<td>2</td>
<td>Melanopsis</td>
<td>Black rockfish</td>
</tr>
<tr>
<td>8</td>
<td>Proriger</td>
<td>Redstripe rockfish</td>
</tr>
<tr>
<td>2</td>
<td>Caurinus</td>
<td>Copper rockfish</td>
</tr>
<tr>
<td>3</td>
<td>Flavidus</td>
<td>Yellowtail rockfish</td>
</tr>
<tr>
<td>2</td>
<td>Maliger</td>
<td>Quillback rockfish</td>
</tr>
<tr>
<td>1</td>
<td>Hexagrammos decagrammarius</td>
<td>Kelp greenling</td>
</tr>
<tr>
<td>1</td>
<td>Theragra chalcogrammarius</td>
<td>Whiting</td>
</tr>
<tr>
<td>3</td>
<td>Gadus macrocephalus</td>
<td>Pacific cod</td>
</tr>
<tr>
<td>1</td>
<td>Trachurus symmetricus</td>
<td>Mackerel jack</td>
</tr>
<tr>
<td>1</td>
<td>Merluccius productus</td>
<td>Pacific hake</td>
</tr>
<tr>
<td>1</td>
<td>Oncorhynchus tsawytscha</td>
<td>Spring salmon</td>
</tr>
<tr>
<td>1</td>
<td>Oncorhynchus nerka</td>
<td>Sockeye salmon</td>
</tr>
<tr>
<td>14</td>
<td>Cymatogaster aggregata</td>
<td>Shiner seaperch</td>
</tr>
<tr>
<td>1</td>
<td>Ammodites hexapterus</td>
<td>Pacific sand lance</td>
</tr>
<tr>
<td>1</td>
<td>Aulorrhynchus flavidus</td>
<td>Tube snout</td>
</tr>
<tr>
<td>30</td>
<td>Clupea pallasii</td>
<td>Pacific herring</td>
</tr>
</tbody>
</table>

E. Utilization of the Fish Detection Unit:

An analysis of the recordings from the Kelvin Hughes Ceres Fish Recorder demonstrated that the vertical echo sounder was the only functional component which provided useful and accurate data concerning fish indications. The horizontal and angle asdic scanners gave no satisfactory results. During refraction shooting horizontal scanning showed some excellent tracings which were first interpreted as indications of fish presence. However, these tracings showed up each time that the shooting vessel returned for another pass over the shot point. It was also noted that after the first shot in a refraction series these tracings began to appear as the shooting vessel returned to the boil of the shot point. It was reasonable to assume that these tracings were the result of the sonar sound waves reflecting off water turbulence caused by previous shots and if there were fish present in the "boil" area they were not discernible on the horizontal scanner. The extent of turbulence resulting from detonations of small and large charges is indicated in Figure 8.

No fish were located by the horizontal scanner, followed through to the angle scanner and then picked up on the vertical scanner. During reflection shooting the vertical recordings gave the most reliable data for lethal distance calculation since the ship travelled at a constant speed and fish position could be determined on both horizontal and vertical planes. Fish scanner data correlated with observed mortality showed that herring schools were the most
Figure 8. Surface disturbances following detonation of:
(a) 16½ pound charge suspended three feet below surface.
(b) 300 pound charge suspended 40 feet below surface.
(c) boil area following detonation of 300 pound charge.
readily detected whereas rockfish showed up only occasionally. No fish indications were positively correlated with salmon kills. Fish schools were readily detected while indications of single fish were not confirmed.

In eleven out of the 15 major kills, (see Table V) fish presence was indicated on the recording tape before and/or during shooting. In five of those eleven cases the fish mortality was considered excessive and the shot pattern was suspended. On some occasions the observer refrained from requesting shot suspension despite indications of fish on the detection unit for the following reasons:

1. Indications on the recorder did not reveal actual size of the fish schools. In many cases only a small part of a school was detected, especially in those instances when fish apparently were located quite close to the surface, as revealed by dead or injured fish appearing on the surface within one or two minutes.

2. Experience had demonstrated that interpretation of every “blip” on the recorder as an indication of fish presence was not valid as a significant number of false echoes and interference made such interpretation highly questionable.

3. In several cases excellent recordings of fish presence were not substantiated by surface observations of mortality.

4. In many cases where the accumulated fish kill was small, the observer permitted shooting to continue as long as mortality did not exceed more than a few hundred fish depending on the species. In other cases where the first few shots produced light mortality but subsequent shooting did not, the shot pattern was permitted to continue.

5. Shooting patterns during initial cruises were not interrupted or suspended, since the observer wished to determine the lethal effect of various charge sizes on fish populations, and evaluate the usefulness of the fish detection unit by correlating fish indications with surface mortalities.

Examination of 61 reflection patterns showed that 78 fish kills (36.3 percent) out of a total of 215 were detected on the Kelvin Hughes Recorder. The detection efficiency was found to vary with the rate of sound impulse, water depth, and fish species. Very satisfactory results were obtained in a reflection series completed in 10 to 15 fathoms of water. On this line 32 (58.2 per cent) observed fish kills out of a total of 55 were detected. The increase in detection efficiency is probably related to the increased pulse rate of sonar transmission required when working in shallow water.

It is evident that the operator of the Ceres Fish Recorder was using an instrument under operational conditions for which it was not intended. This was largely due to the limited maneuvers of the shooting vessel (which did not permit homing on fish schools) and the successive shots at refraction shot points which masked the shot point area with water turbulence. In reflection shooting the advance position of the instrument vessel interfered with the fish scanner's horizontal beam in that echoes were reflected off the instrument vessel propellers and prop wash and masked any recorder indications of fish.
F. Diver's Assessment Program:

The area chosen for the diver's assessment program was not abundantly populated with fish and the strong tidal currents limited the accuracy of distance estimates by the divers. Only one out of eight proposed shot points demonstrated fish presence on the vertical scanner. Since fish were of limited abundance five shots were made at this single shot point located in 60 feet of water. Pre- and post-examination data for each shot appear in Table IX. The results reveal that five and ten pound shots killed rockfish and sculpins within a 25-foot radius of the shot point and that a 16½ pound shot killed rockfish and salmon within a 50-foot radius. The 16½ pound shot had no effect on gas-bladderless fish, which included a few sculpins, one flatfish and five dogfish sharks, located approximately 50 feet away from the shot point. Aplin (1947) reported that 20

<table>
<thead>
<tr>
<th>Charge Size lbs.</th>
<th>Detonation Depth Feet</th>
<th>Radial Distance From Shot Point</th>
<th>Before Detonation</th>
<th>After Detonation</th>
<th>Alive</th>
<th>Dead</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/3</td>
<td>25'</td>
<td>needlefish sculpin lingcod</td>
<td></td>
<td></td>
<td>1 rockfish</td>
<td>2 sculpin 1 rockfish</td>
</tr>
<tr>
<td></td>
<td>50'</td>
<td></td>
<td></td>
<td></td>
<td>1 flatfish</td>
<td>7 sculpin 5 rockfish</td>
</tr>
<tr>
<td></td>
<td>75'</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10/20</td>
<td>25'</td>
<td>sculpin lingcod rockfish</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>50'</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>75'</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16½/20</td>
<td>25'</td>
<td>rockfish lingcod</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>50'</td>
<td>sculpin 1 flatfish 5 dogfish</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>75'</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25/32</td>
<td>25'</td>
<td>rockfish lingcod</td>
<td></td>
<td></td>
<td>1 salmon smolt (surface)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50'</td>
<td></td>
<td></td>
<td></td>
<td>3 sculpin</td>
<td></td>
</tr>
<tr>
<td></td>
<td>75'</td>
<td>1 lingcod 5 sculpin 1 crab</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50/40</td>
<td>25'</td>
<td>sculpin lingcod</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>50'</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>75'</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
pound charges of dynamite exploded four feet below the surface, at horizontal distances of 50 and 55 feet from caged fish, killed those with gas bladders but had no effect on gas-bladderless halibut and sculpins.

Of 11 dead fish accounted for, only one, a juvenile salmon, appeared on the surface. Two adult salmon, six rockfish and two sculpins were retrieved from the bottom at a depth of 10 fathoms. The last detonation, a 50 pound charge set to explode at 40 feet, had sufficient force to remove shellfish from rocks and split large boulders, but had no effect on gas-bladderless lingcod and sculpins located 50 to 100 feet away from the shot point. Thompson (1958) reported that 2,750,000 pounds of high explosive used to remove Ripple Rock, a navigation hazard in Canada, killed rockfish but did not kill lingcod located in cages ½ mile away. One live crab apparently unharmed was found within the 50–100 feet radius of the 50 pound explosion.

The decrease in lethality is related to a sharp dissipation of pressure as the distance away from the explosion increases (Hubbs and Rechnitz, 1952). The two dead sculpins (not identified as to species) which were within 25 feet of the shot point anchor were killed by a five pound charge set to explode at three feet from the surface. However, a 25 pound charge with a detonation depth of 32 feet did not kill two sculpins located within 25 feet of the shot point. This disparity may be attributed to the difficult observation conditions and the resultant inaccuracy in distance estimations.

Despite the paucity of the above data it is quite obvious that surface observations are not a reliable method for determining the total effect of a seismic explosion on fish because they do not account for subsurface mortality. A supporting view comes from Ferguson (1961) who noted that the number of fish which had been killed by seismic explosions and which had floated to the surface were not a reliable measure of charge lethality because of variations in fish abundance and distribution.

IV. Summary of Results

During the 1963 Shell Oil Seismic Program, 809 (7.6 percent) of a total of 10,667 detonations killed 59,277+ fish. Herring and rockfish represented 72.8 and 23.8 percent respectively of the total kill, with the remaining 4.2 percent consisting of 189+ adult salmon, 467+ juvenile salmon, and 1,732+ miscellaneous fishes. All fishes examined or observed possessed air bladders.

The total mortality of 59,277+ fish was regarded as minimal principally because estimates were based on surface observations only.

Light nitrate charges (5–25 pounds) have the capacity to kill fewer fish and less often than heavy charges (50–300 pounds). There was evidence that for a given charge size, an increased detonation depth results in an increased incidence of mortality. The occurrence of mortality resulting from light charges increased sharply when explosions were detonated in relatively shallow water (less than 34 fathoms).

A total of 10,676 charges of nitrate explosives were exploded at 9,638 shot points. Only 419 shot points (4.3 percent) showed evidence of fish mortality,
and seventy-five of these accounted for 86.2 percent of the total kill. Nine refraction shot points accounted for 75.3 percent of the total mortality. Refraction profile shooting patterns, which always involved detonation of heavy charges, killed the greatest numbers of fish and appear to be the greatest threat to fish populations.

Analysis of recordings from the Kelvin Hughes Ceres Fish Detection Unit demonstrated that the vertical scanner was the only functional unit which provided useful and accurate data concerning fish indications and their location. The horizontal and angle asdic scanners gave no satisfactory results. Recordings showed that herring schools were the most readily detected while rockfish were only occasionally detected. No observed salmon kills were correlated with indications on the recording tape. As the operator gains experience with the machine, sizeable fish indications on the recorder can be interpreted with sufficient confidence to recommend shot suspension.

Analysis of the Diving Assessment Program showed that of 11 dead or seriously damaged fish found during post-explosion examinations, only one was observed on the surface. The lethal effect of nitrate charges on fish populations sharply decreased with increasing distance from the shot point. Fish without gas bladders such as flatfish and lingcod were relatively unaffected by seismic explosions.

V. Conclusion

While supervision and control were the principal responsibilities of the Department’s observer staff, additional information was obtained in connection with the effects of underwater explosions on fish populations.

A total of 10,676 shots at 9,638 shot points exhibited an observed fish kill at 419 shot points. The total surface mortality amounted to 59,277+ fish. Herring and rockfish represented 72.2 and 23.8 percent of the total kill respectively with the remaining four percent consisting of 189+ adult salmon, 467+ juvenile salmon and 1,732+ miscellaneous fishes. Large charges (50–300 pounds) typical of refraction shooting killed more fish more frequently than the light charges (5–25 pounds) which were typical of reflection shooting. Increasing the charge detonation depth will increase the potential area of fish kill. In shallow water the horizontal lethal range of a seismic charge is greater than in deep water. Surface observations of fish mortality were not a reliable measure of charge lethality because they did not account for subsurface mortality. Only the vertical scanner on the fish detection unit was found useful in detecting the presence of fishes.

Considering the extent of the area explored and the number of shot points subjected to high velocity explosives, the resulting fish mortality may be considered relatively light (even when magnified by the unobserved mortality). Fishes of commercial value were not seriously affected by the 1963 seismic survey. However, it was obvious that nitrate explosives on several occasions killed large numbers of fish.

The fact that a high mortality to fish was not evident can probably be attributed to the conditions agreed to by the Company and the Department.
The excellent co-operation developed in this program resulted in the Company and the Department achieving their respective goals of oil exploration and maximum protection to the fishery resource.

Acknowledgments

The authors wish to gratefully acknowledge the assistance of R. E. McLaren, Chief Biologist and D. MacKinnon, Senior Biologist, Fish Culture Development Branch, Department of Fisheries, Pacific Area, in the planning of field procedures and editing this report. Constructive suggestions on editing from staff members R. N. Gordon, Senior Engineer, C. P. Ruggles, Senior Biologist, and M. E. Riske, 1964 Biologist Observer, were also appreciated.

Special acknowledgment is directed to the Exploration Division staff of the Shell Oil Company of Canada who provided technical details of company operations.

Grateful acknowledgment is extended to Assistant Observer J. M. Culp for his valuable field assistance and to Mrs. Anne Webb for her monumental patience throughout the typing of the manuscript.

Literature Cited


