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BONE DETECTION IN FISH BY X-RAY EXAMINATION

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This research has been carried out on a preliminary scale to determine whether X-rays can be used in the detection of bones in fish fillets and of bones and voids (air spaces) in fish blocks. The ultimate purpose was to develop a routine quality-control measure on a commercial scale.

EXPERIMENTAL PROCEDURES

Nine test samples were prepared in the following manner:

SAMPLE 1 - FROZEN FILLET BLOCK: Seven and one-half pounds of boneless haddock fillets were placed in a galvanized steel pan and frozen in a plate freezer producing a frozen block 9 by $11\frac{3}{8}$ by $1\frac{13}{16}$ inches. Varying thicknesses were produced on the block by cutting it in staircase fashion by means of a band saw (fig. 1). Fifteen steps were made in the block, each $\frac{1}{8}$ of an inch high and $\frac{1}{2}$-inch deep for the full width of the block. Bones were inserted into the side of the block in the middle of each step so that they were about $\frac{1}{2}$-inch apart and at varying depths of $\frac{1}{8}$ of an inch. Bones from two species of fish were used: from smelt (those lining the visceral cavity) and from haddock (those from the backbone in the tail region of the fish). The bones were inserted through the sides of the semithawed block by means of a wire probe. There was one bone for every $\frac{1}{8}$ of an inch in depth, or one bone on the first step, two on the second step, etc. (fig. 1). An attempt was made to space the bones in such a manner that they were not directly on top of one another when "viewed" from above the block. Actually this was not entirely possible, because of the difficulty in working with the semithawed fish block. The bones, therefore, were inserted at the indicated height but did not necessarily appear in the uniform arrangement shown in the diagram in figure 1. In order to avoid the difficulty, at the 11th to 15th steps some of the bones were inserted into the "face" of the block perpendicular to the edges of the steps. Sea smelt bones (0.35-0.45 mm. thick and averaging 12.7 mm. long) were used in the first five steps; haddock bones (0.70-0.90 mm. thick and averaging 12.7 mm. long) were used in the 6th to 15th steps.

SAMPLE 2 - HADDOCK SLABS: A second frozen boneless haddock block was prepared as described in sample 1. The frozen block was then cut into rectangular sections $2\frac{1}{2}$ by 3 by $\frac{1}{8}$ inches. These sections were used to build up fish slabs of varying thicknesses. Haddock bones (from the belly flap of scrod haddock) were inserted between each layer. The thickness of the bones was measured at their centers--the smaller thickness was recorded. The bone lengths were measured with a millimeter rule. The blocks were prepared with bones located at various points as illustrated (fig. 2). Each slab was about $\frac{1}{8}$ of an inch thick. Bones were placed between each slab where illustrated by small letters in figure 2.

SAMPLE 3 - HADDOCK SLABS: Trimmed-down portions of belly flaps taken from several sea smelt were cut into sections about $\frac{1}{2}$- to 1-inch square. These sections containing an array of bones were then inserted between rectangular slabs

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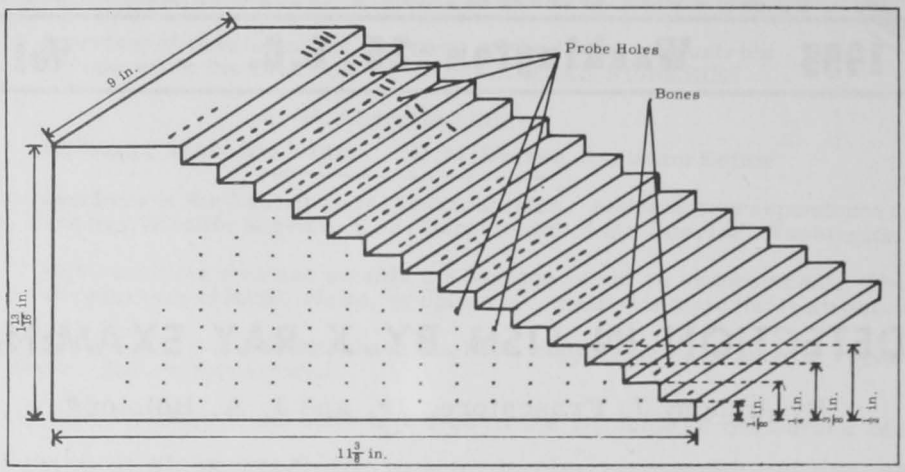


Fig. 1a - Three-dimensional view of fillet block cut in staircase fashion with 15 steps each $\frac{1}{8}$-inch high and $\frac{1}{8}$-inch deep for the full width of the block. Bones from smelt and haddock were inserted through the sides of the semi-thawed blocks by means of a wire probe--one bone was inserted for every $\frac{1}{8}$-inch of depth (one bone on the first or bottom step, two on the second step, etc.).

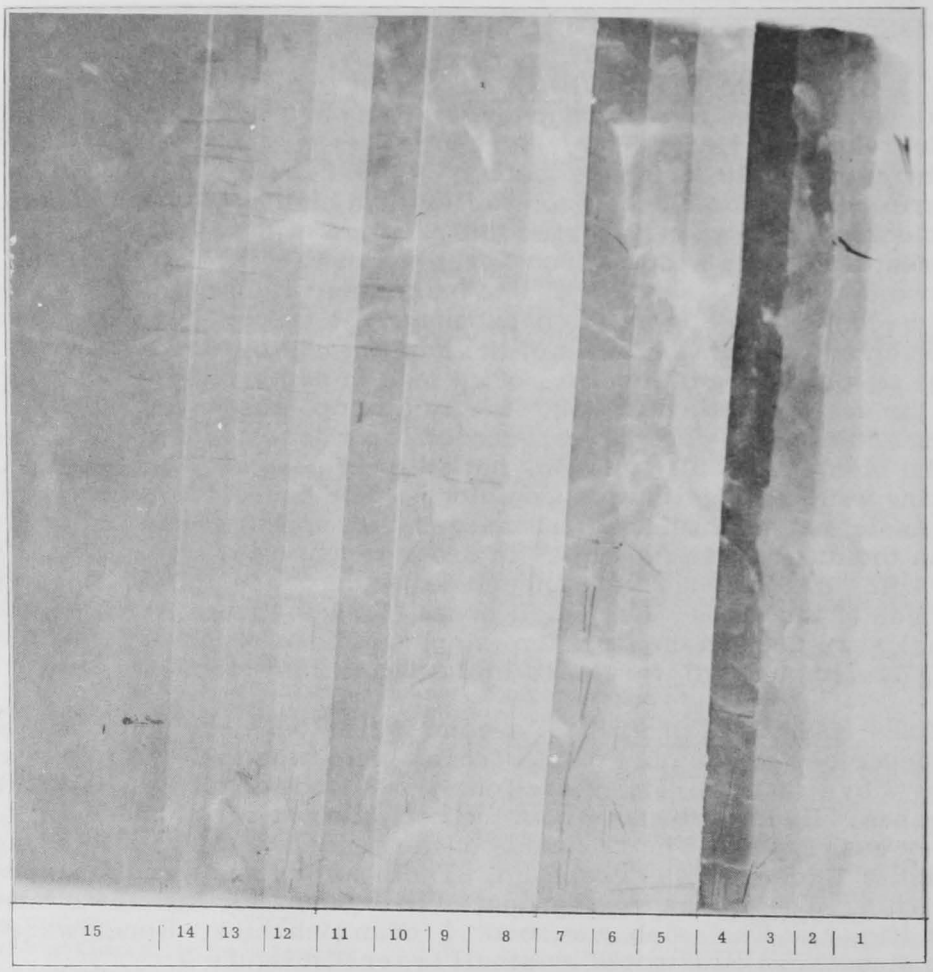
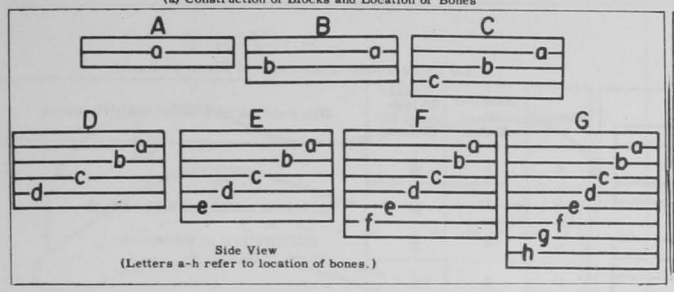


Fig. 1b - Radiograph of fillet block taken from the top view showing bones. Although the bones were inserted at indicated heights, the radiograph shows that they necessarily were not inserted in the uniform arrangement shown in the sketch above. Numbers show the steps as sketched above.

(a) Construction of Blocks and Location of Bones



(b) Dimensions of Blocks and Sizes of Bones

Sample	Number of Slabs	Total Thickness in Inches	Dimensions of Bones in Millimeters
A	2	$\frac{1}{4}$	a 39 x 0.54
B	3	$\frac{3}{8}$	a 44 x 0.69
			b 35 x 0.74
C	4	$\frac{1}{2}$	a 40 x 0.72
			b 136 x 0.56 c 134 x 0.70
D	5	$\frac{5}{8}$	a 38 x 0.57 c 38 x 0.61
			b 32 x 0.71 d 45 x 0.71
E	6	$\frac{15}{16}$	a 38 x 0.58 c 40 x 0.66
			b 41 x 0.68 d 31 x 0.68 e 43 x 0.62
F	7	$1\frac{1}{4}$	a 30 x 0.72 c 35 x 0.63 e 39 x 0.71
			b 34 x 0.63 d 39 x 0.66 f 37 x 0.74
G	9	$1\frac{1}{2}$	a 38 x 0.72 c 28 x 0.65 e 33 x 0.66 g 31 x 0.75
			b 39 x 0.72 d 42 x 0.62 f 36 x 0.56 h 44 x 0.65

Fig. 2a - Fillet blocks were built up by using slabs $2\frac{1}{2}$ by 3 by $\frac{1}{8}$ inches. Block A consists of two such slabs, Block B of 3 slabs, etc.

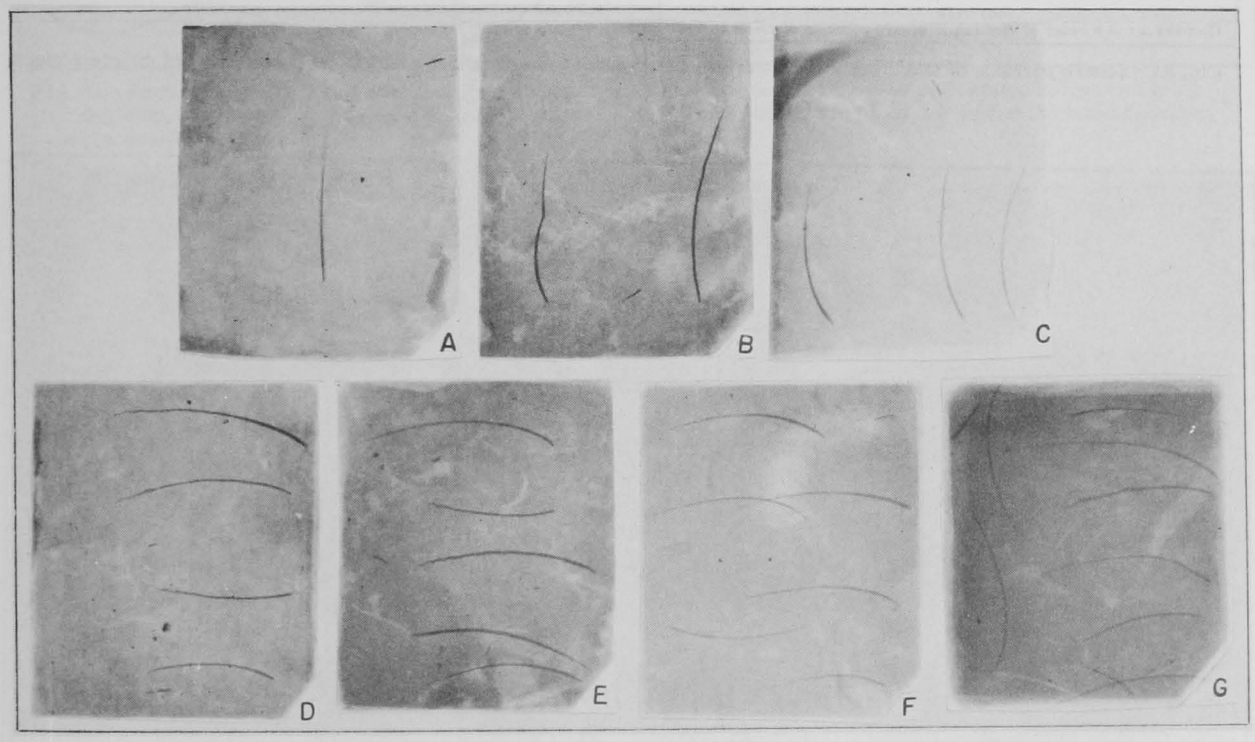


Fig. 2b - Radiograph shows the location of the bones as viewed from the top of the block.

previously prepared by the method used with sample 2. Bones were placed between each slab as indicated by small letters (fig. 3).

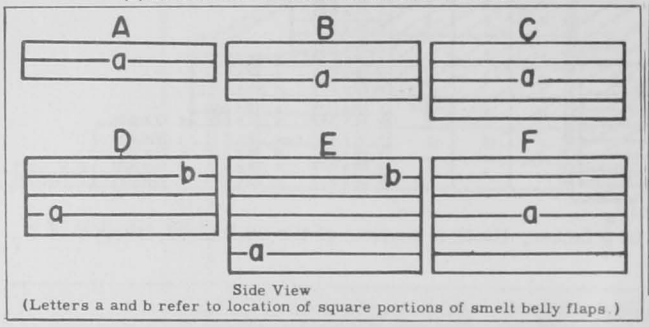
SAMPLE 4 - HADDOCK PORTIONS: An eviscerated scrod haddock weighing about 2,310 grams (fillets a and b of fig. 4) was split into two lengthwise portions leaving as many bones in as possible. A fillet (fillet c) was cut boneless and was placed over split portion a. The portions of fish arranged in this manner served as the test sample.

SAMPLE 5 - SMELT PORTIONS: A sea smelt was split into two lengthwise portions and arranged as shown in figure 5. Each portion weighed 160 grams, with the deepest thickness about $1\frac{1}{4}$ inches and the belly flap about $\frac{3}{8}$ of an inch.

SAMPLE 6 - OCEAN PERCH PORTIONS: Ocean perch were split lengthwise and three portions arranged as shown in figure 6.

SAMPLE 7 - WHITING BUTTERFLY PORTIONS: Three whiting were split butterfly fashion and arranged as shown in figure 7. The weight of each split butterfly

(a) Construction of Blocks and Location of Bones



Side View
(Letters a and b refer to location of square portions of smelt belly flaps.)

(b) Dimensions of Blocks and Sizes of Bones

Sample	Number of Slabs	Total Thickness in Inches	Dimensions of Bones in Millimeters
A	2	$\frac{5}{16}$	All bones averaged 0.35 to 0.45 millimeters in thickness.
B	3	$\frac{9}{16}$	
C	4	$\frac{5}{8}$	
D	4	$\frac{3}{4}$	
E	6	$1\frac{1}{4}$	
F	6	$1\frac{1}{4}$	

Fig. 3a - Square portions of smelt belly flaps were inserted between rectangular slabs to build up blocks of different sizes.

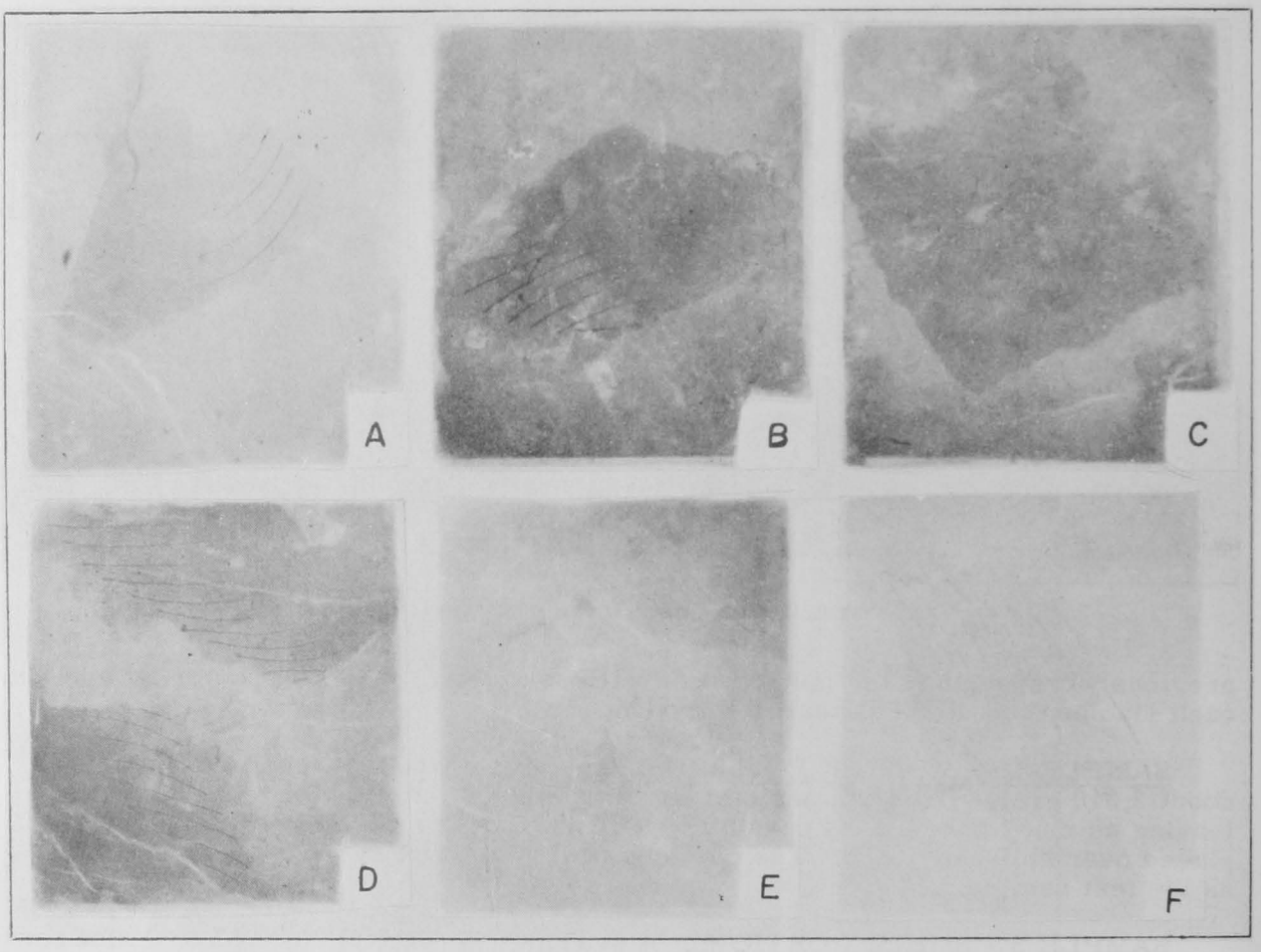


Fig. 3b - Radiograph shows location of bones in inserted smelt belly flaps as viewed from the top of each block. Note that Block C, the only exception, does not reveal the bones in the belly flap inserted between the third and fourth slab.

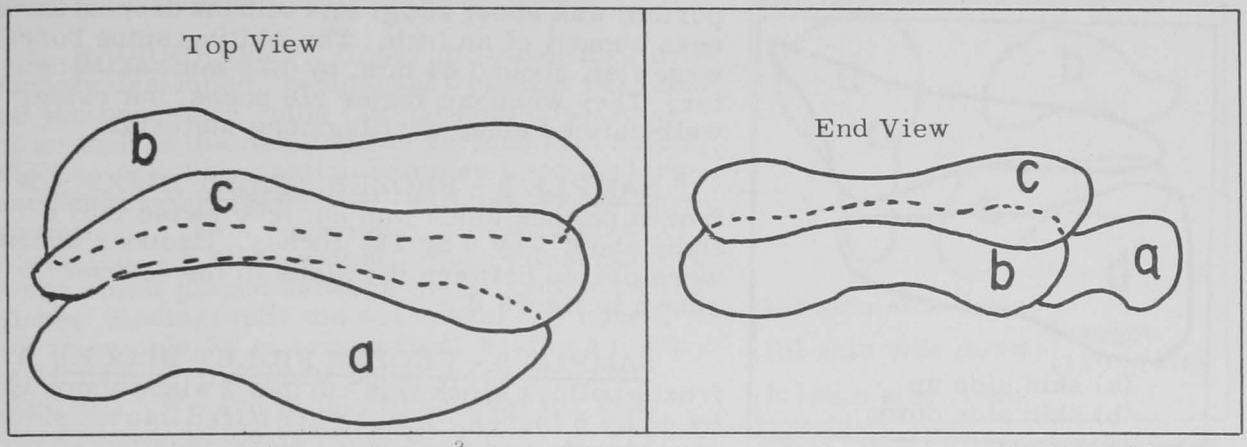


Fig. 4a - Portions a and b were each about $\frac{3}{4}$ of an inch thick--each one was cut from an eviscerated haddock weighing 2,310 grams, but leaving as many of the bones in as possible. Fillet c, which was about $1\frac{1}{8}$ inches thick and boneless, was placed over split portion a.

Fig. 4b - Top-view radiograph reveals the bones in split portions a and b. A portion with bones in and covered by a boneless fillet still clearly reveals the bones.

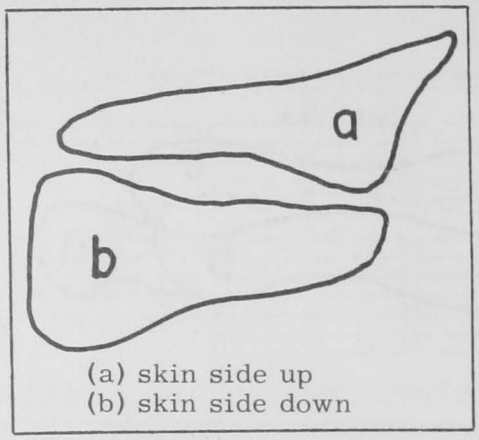


Fig. 5a - Shows the arrangement of split smelt portions.

portion was about 130 grams with the deepest thickness about $\frac{1}{2}$ of an inch. The whiting spine bones were flat, about 0.84 mm. by 0.25 mm. at the center. They were not major rib bones, but rather well-defined clear cartilaginous material.

SAMPLE 8 - FROZEN FILLET BLOCK: A frozen pollock block was cut lengthwise into 2 slabs about 1 by 9 by $11\frac{3}{8}$ inches. Haddock bones were placed between the slabs in the manner shown in figure 8.

SAMPLE 9 - FROZEN FILLET BLOCK: A frozen pollock block was cut into 2 slabs about $1\frac{3}{4}$ by $4\frac{1}{2}$ by 6 inches. Holes were bored into the sides at each cut, and the 2 slabs were reunited as in the original block (fig. 9). Standard size drills were used to produce holes (or voids) of the desired uniform diameter.

RADIOGRAPHIC AND FLUOROSCOPIC EXAMINATION: Radiographs were made of each of the 9 samples with a portable medical diagnostic X-ray machine (top performance 85 kv. at 25 ma.) using Dupont film, medical no. 508 double-coated. Exposures were at 60 kv., 10 ma., at a distance of 30 inches for 5 seconds on the blocks and slabs, and for 3 seconds on the portions. The film was then developed at 68° F. for 3 minutes in General Electric Super-Mix Developer.

Fluoroscopic examinations were made while the equipment was operating at 60 kv. and 5 ma., and in two cases where indicated at 60 kv. and 10 ma.

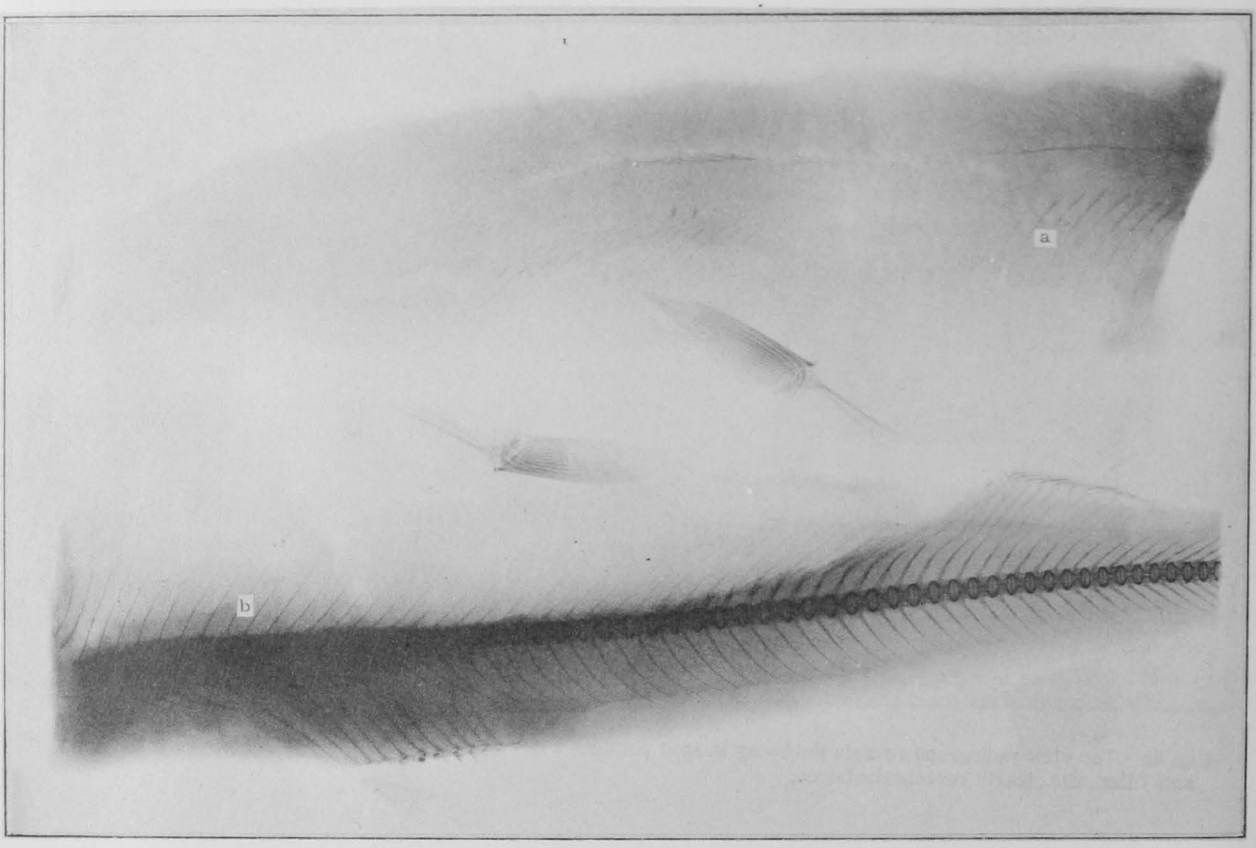


Fig. 5b - Radiograph shows the bones in a smelt split into two lengthwise portions.

DISCUSSION OF RESULTS

RADIOGRAPHY: Under the conditions previously described, radiographs clearly revealed all the bones and voids (air spaces) down to $\frac{1}{16}$ of an inch in diameter in the various fish fillets, blocks, and slab-section samples up to the largest depth used ($1\frac{13}{16}$ inches), with one exception--sample 3C. This subsample, $\frac{5}{8}$ of an inch thick, consisted of 4 slabs with a 7-bone rib section of a sea smelt placed between the second and third slabs. Radiographs did not reveal any bones, yet in sample 3F of this series, having a depth of $1\frac{1}{4}$ inches, the smelt bones were apparent (fig. 3F). We are unable to account for this discrepancy in the results.

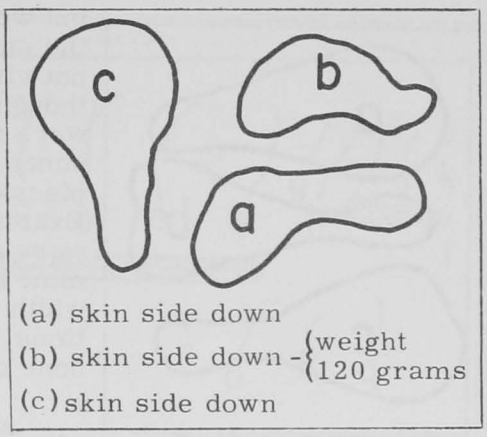
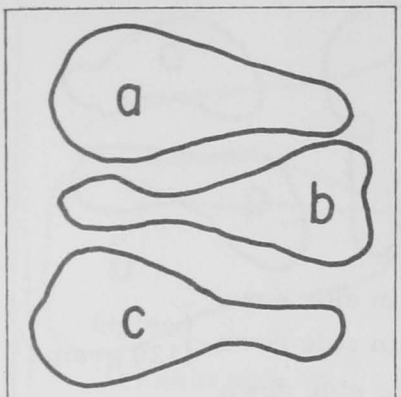


Fig. 6a - Shows the arrangement of split ocean perch portions.

FLUOROSCOPY: As was expected, fluoroscopic examinations did not reveal all the bones as clearly as did the radiographs. Furthermore, in the haddock block (fig. 1) and the slab sections (fig. 3) at 60 kv. and 5 or 10 ma., not a single smelt bone was visible, not even in the $\frac{1}{8}$-inch section (first step) of sample 1. Bones of the haddock portions (fig. 4) were plainly visible,

Fig. 6b - Radiograph clearly reveals the bones in the split ocean perch portions.



(a) skin side down
(b) skin side up
(c) skin side down

Fig. 7a - Shows arrangement of split whiting butterfly portions.

but were less visible in the double layer of portions. In the smelt portions (fig. 5) skin side up, the bones were not visible, but skin side down the bones were visible--though the belly-flap bones and the pectoral-fin bones were not. In the ocean perch portions in general, all bones were clearly visible, with the exception of 2 bone pieces in one portion (fig. 6b upper left-hand corner). Examination of this portion showed these 2 bone pieces were actually 9 mm. long by 0.52 mm. thick and 14.5 mm. long by 0.58 mm. thick and were no different in width than other bones in the fish. In the whiting portions, fluoroscopy revealed a diffuse mass in which none of the bones were visible except the spinal column.

All the voids up to $\frac{5}{32}$ of an inch in diameter were visible. Those smaller were not.

SUMMARY

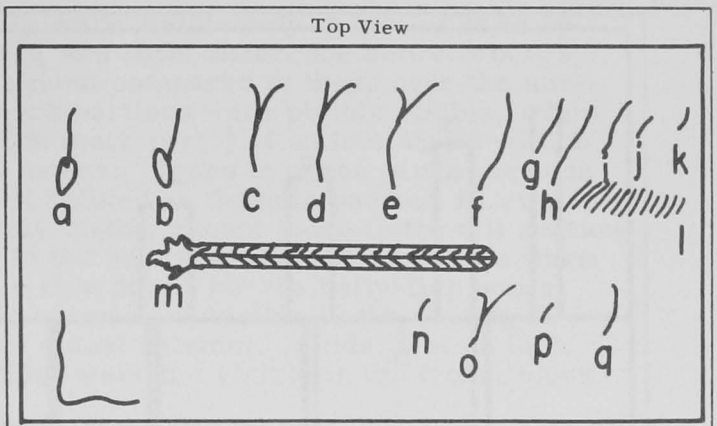
Use of a portable medical diagnostic X-ray apparatus under the conditions specified indicated the following:

1. Radiography revealed essentially all the bones present in split portions of haddock, ocean perch, whiting, and smelt; voids

Fig. 7b - Radiograph clearly reveals the bones in the split whiting butterfly portions.

(air spaces) down to $\frac{1}{16}$ of an inch in diameter placed in the center of frozen haddock blocks up to $1\frac{13}{16}$ inches thick were also revealed.

2. Fluoroscopy revealed at 60 kv. and 10 ma. all the haddock bones, but none of the smelt bones placed in haddock slabs up to a thickness of $1\frac{13}{16}$ inches. At 60 kv. and 5 ma., the haddock bones were clearly visible in the slab thickness of $\frac{15}{16}$ of an inch, but at a greater slab thickness of $1\frac{1}{2}$ inches, all bones were dull and barely visible.



Length of Bones (in inches)

(a) $2\frac{5}{8}$	(d) $1\frac{1}{4}$	(g) $1\frac{5}{8}$	(l) 12 bones and 1 cartilage	(p) $\frac{7}{8}$
(b) $2\frac{3}{8}$	(e) $1\frac{1}{2}$	(h) 2	(m) spinal column section	
(c) $1\frac{1}{32}$	(f) 2	(j) $\frac{3}{4}$	(n) $\frac{3}{8}$	

(Letters a to q refer to bone segments and the dimensions of bones i, k, l, m, o, and q are not known.)

Fig. 8a - Frozen block of pollock fillets showing location of bones.

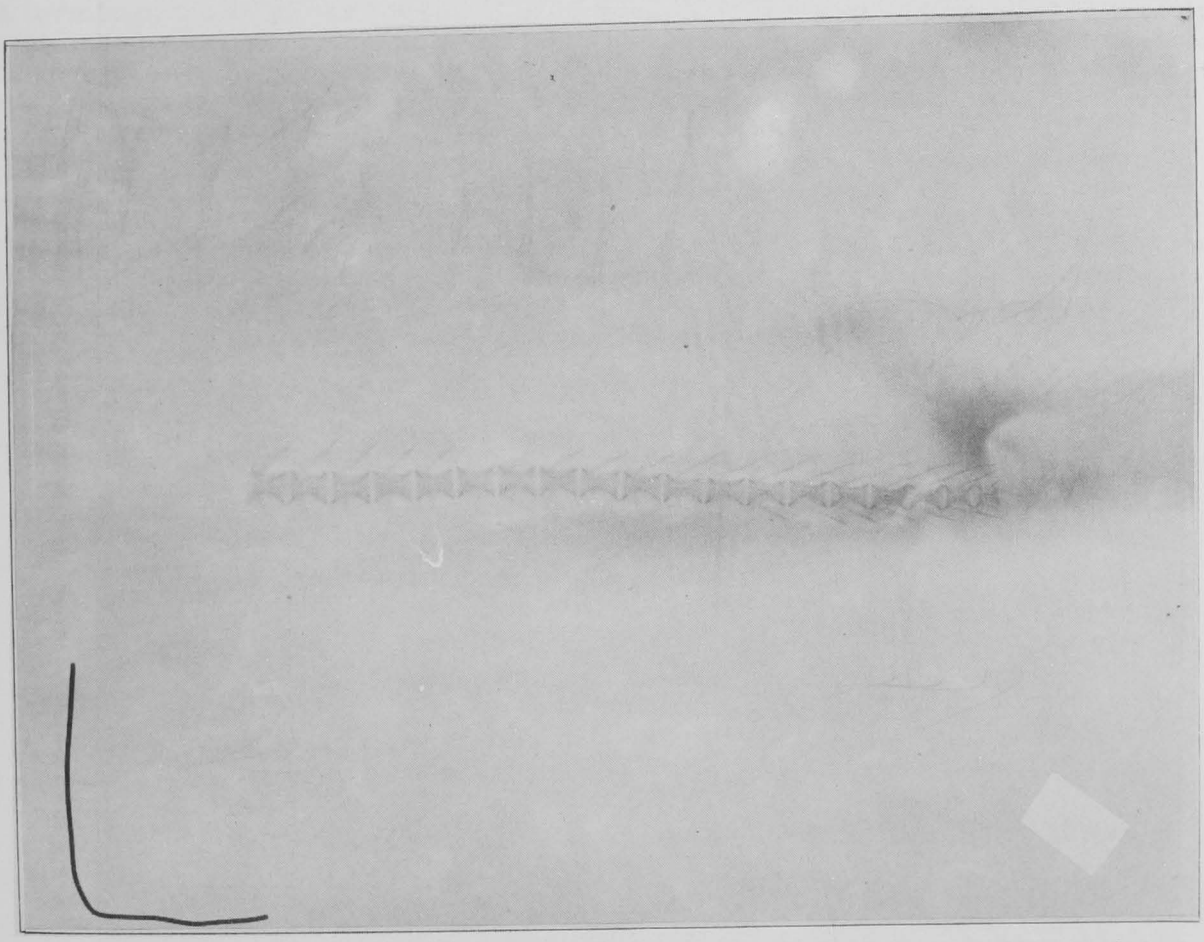


Fig. 8b - Radiograph indicates that nearly all the bones were clearly visible. A frozen pollock block was cut lengthwise into 2 slabs and bones were placed between the slabs in the manner shown.

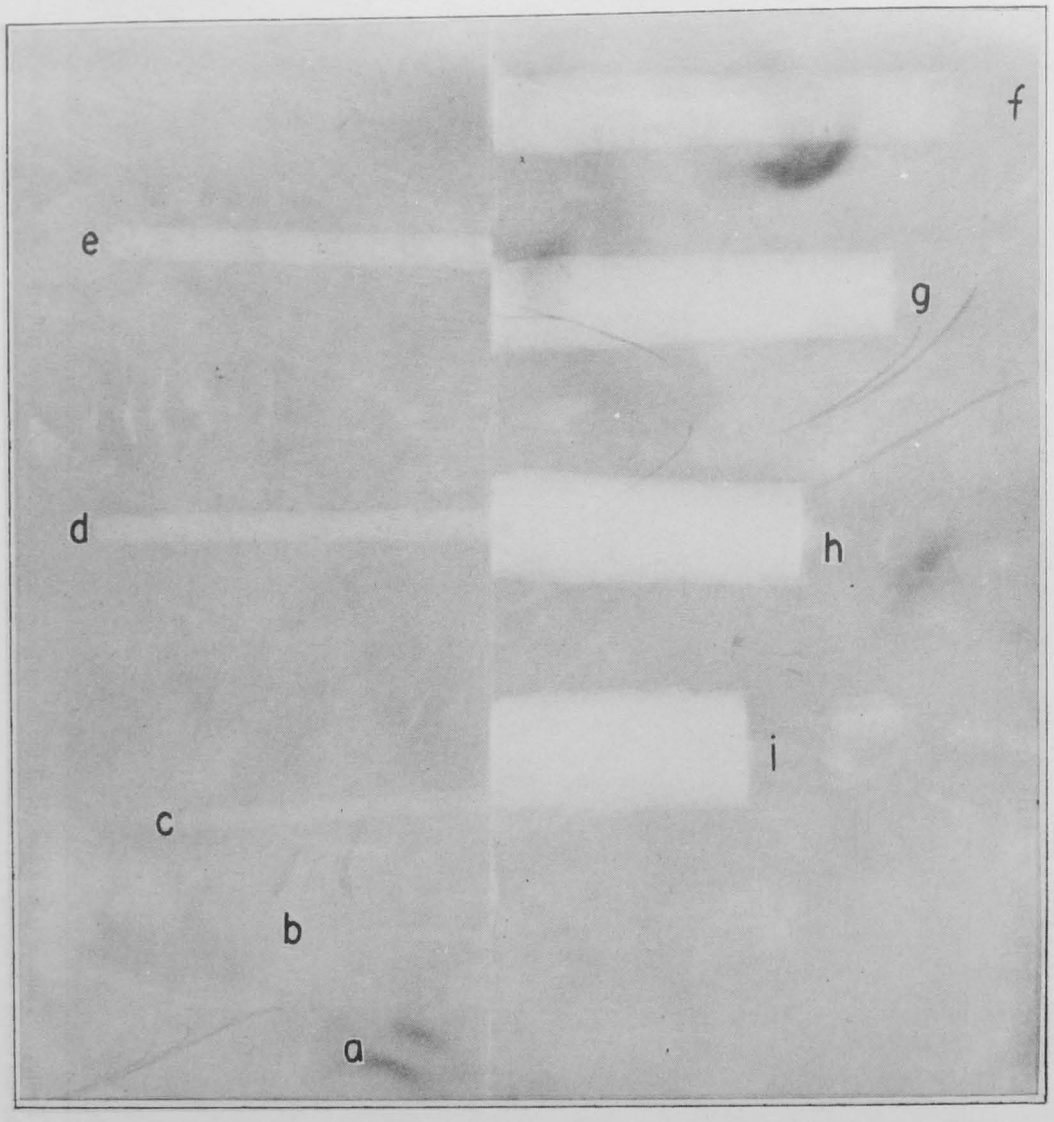
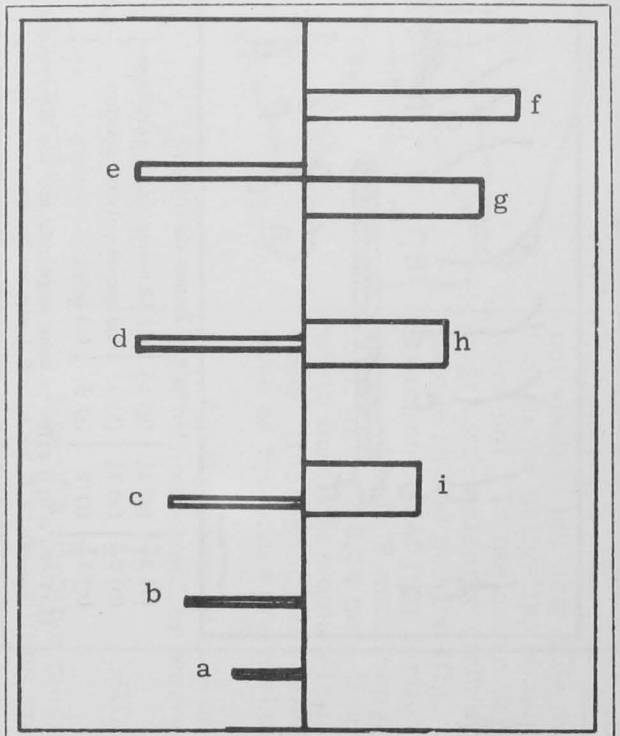


Fig. 9b - Top-view radiograph clearly shows all voids or air spaces except "a."



Diameter of Voids (in inches)

(a) $\frac{1}{16}$ x 1	(d) $\frac{7}{32}$ x $2\frac{3}{8}$	(g) $\frac{5}{8}$ x $2\frac{1}{2}$
(b) $\frac{3}{32}$ x $1\frac{11}{32}$	(e) $\frac{1}{4}$ x $2\frac{3}{8}$	(h) $\frac{3}{4}$ x 2
(c) $\frac{5}{32}$ x $1\frac{7}{8}$	(f) $\frac{1}{2}$ x 3	(i) $\frac{7}{8}$ x $1\frac{5}{8}$

Fig. 9a - A frozen pollock block was cut into 2 slabs. Holes were bored into the two sides at each cut and the 2 slabs were reunited as in the original block.

In haddock blocks they were visible only in blocks up to $1\frac{1}{8}$ inches thick, and there was little difference between bones located deeper in the meat compared to those near the surface. Bones in haddock portions were plainly visible, even in a doubled-up portion (each part $\frac{3}{4}$ of an inch thick) with a total thickness of $1\frac{1}{2}$ inches. Bones in ocean perch portions did not appear as well defined as those in haddock fillets, although all were clearly visible except those in the tail section. The large rib bones in the smelt portions were visible when they were placed skin side down, but the belly-flap bones were not visible. No bones were visible in the whiting fillets (except the small spinal column). Voids $\frac{3}{32}$ of an inch in diameter and smaller were not visible in the frozen block.

RECOMMENDATIONS

The X-ray equipment used was designed for diagnostic purposes only and was therefore limited in capacity and not necessarily suitable for the purpose of detecting bones and air spaces in fish and fish blocks. The results of these preliminary tests, nevertheless, seemed rather encouraging even with the use of this particular equipment. The radiographs were entirely satisfactory for detecting bones and air voids in the commercial species of fish used. It is unlikely, however, that radiographs will find practical application with the fillet or frozen-block industries as a routine quality-control measure. Fluoroscopy could be applied readily, provided it furnished the required degree of accuracy and a reasonable degree of ease of operation. It is recommended, therefore, that further tests with greater capacity and more versatile X-ray fluoroscopic instruments be encouraged to develop equipment and procedures which can be used commercially for the detection of bones in fish fillets and bones and air spaces in frozen fish blocks.

ACKNOWLEDGMENT

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