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DEVELOPMENT OF "HONEYCOMBING" IN HAWAIIAN SKIPJACK TUNA

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CONTENTS

BACKGROUND

The skipjack tuna (Katsuwonus pelamis) supports the most important fishery in the Hawaiian Islands--landings smount to about 10 million pounds annually. It is abundant during the summer months (May-September), when more than 75 percent of the annual catch is made. Besides the usual problems besetting any fish-

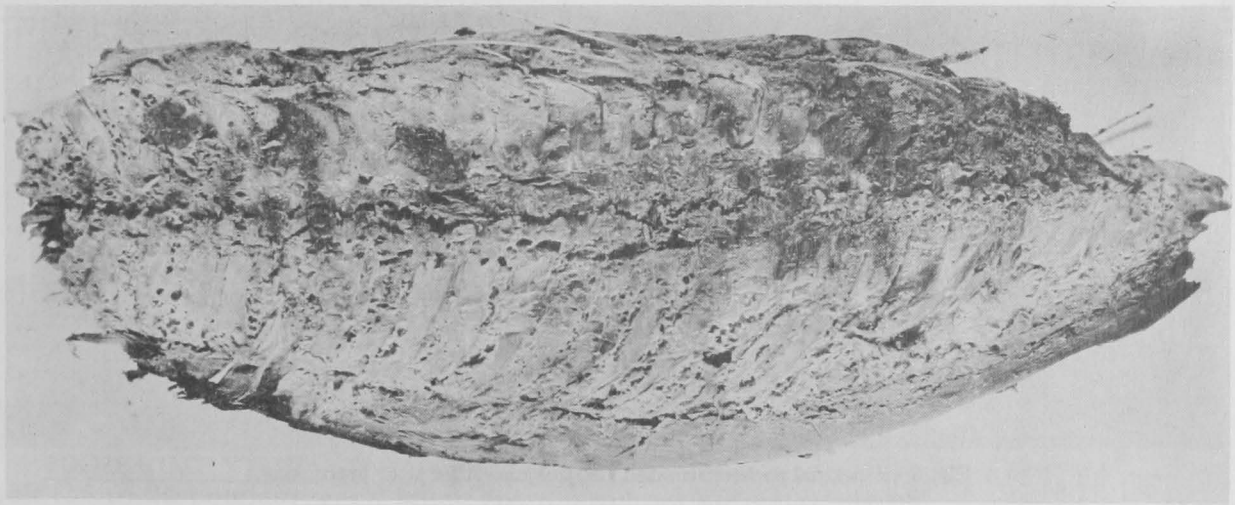

Fig. 1 - An extensively honeycombed skipjack tuna fillet after precooking.

ery, the industry is troubled from time to time with honeycombing, a pitted and cellular condition which appears in some of the fish during precooking, making the meat unsuitable for canning. During 1956 about 58,000 pounds of skipjack were so affected.

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Incidental to studies on skipjack distribution and abundance, the Service's Pacific Oceanic Fishery Investigations conducted several experiments to ascertain whether degree of sexual maturity, size of fish, or type and intensity of refrigeration were related to the appearance of honeycombing during precooking. These experiments suggest that honeycombing is independent of sexual maturity or fish size, but clearly show that it can be induced by holding the fish without refrigeration. Further, they suggest that slight variations in the holding temperature have a striking effect on the length of time required to induce honeycombing, small increases in temperature greatly accelerating the development of the condition. This is believed to be the key to the pronounced seasonality of the problem in Hawaii, where it is significant only during the summer months.

DESCRIPTION OF HONEYCOMBING

The term "honeycombing" is applied to the meat of cooked fish which is pitted and cellular in appearance. Figures 1 and 2 show an extreme case of this condition as it appears after precooking at the cannery. For comparison, the appearance

Fig. 2 - A closeup of a piece of honeycombed meat taken from the fish shown in figure 1.

of a normal, nonhoneycombed fish after precooking is shown in figure 3. There are various degrees of honeycombing; in some cases a slight trace may appear in the region of the nape, while in others the condition may be found throughout the entire

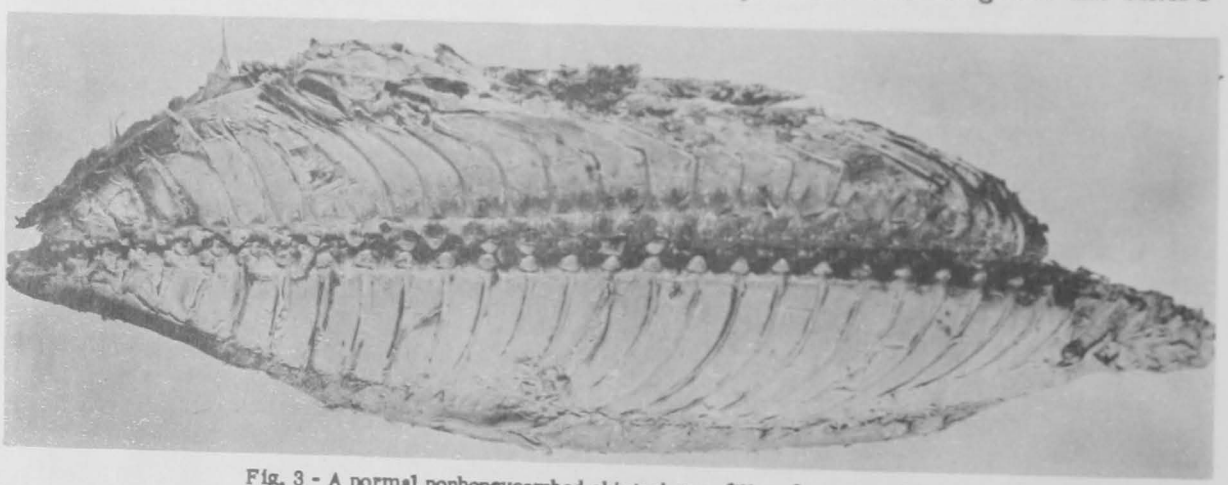

Fig. 3 - A normal nonhoneycombed skipjack tuna fillet after precooking.

body. During the course of the experiments discussed in this paper, it was observed that honeycombing starts at the nape and works posteriorly towards the caudal region. There were also some indications that it begins in the interior of the fish near the backbone and progresses outward.

Honeycombing should not be confused with another condition in the fish in which the meat has a texture variously described as "putty," "mushy," or "jellied." The latter condition is probably caused by sporozoan infection of the muscles as described for yellowfin tuna meat by Arai and Matsumoto (1953).

SEXUAL MATURITY

PROCEDURE: In order to study the relationship between honeycombing and sexual condition of the fish, 131 female skipjack were examined from a load of fish butchered and precooked on August 11, 1954. Ovaries were collected to determine the degree of ova maturity. When the fish were canned on August 12, they were examined for evidence of honeycombing.

RESULTS AND DISCUSSION: Of the 131 fish, ranging in weight from 14 to 18 pounds, 7 (5.3 percent) were honeycombed. The degree of maturity of these 7 as well as of 19 normal fish was estimated by measuring 10 eggs of the largest group in the ovaries (table 1). The mean size of the largest group of eggs in the ovaries was about the same for all ovaries examined. Furthermore, no gross differences were detected between the ovaries of honeycombed and normal fish; all appeared to be in the same stage of maturity. Hence, this experiment indicated no relationship between honeycombing and the sexual state of the fish.

Table 1 - Results of Ova Measurements Made to Determine Degree of Sexual Maturity of Normal and Honeycombed Female Skipjack Tuna

Honeycombed Fish		Normal Fish	
Fish Size (Dressed Weight)	Mean Ova Size	Fish Size (Dressed Weight)	Mean Ova Size
Lbs.	mm.	Lbs.	mm.
14	.587	-	.572
14 1/4	.590	-	.585
15 1/2	.574	14	.605
16	.565	14 1/4	.572
16	.594	15	.561
16 1/2	.574	15	.596
15 1/2	.608	15	.563
		15 1/2	.592
		16	.601
		16	.598
		16 1/2	.594
		16 1/2	.579
		16 1/2	.594
		17	.598
		17	.609
		17	.607
		17	.576
		17 1/2	.607
		17 1/2	.618
15.5	.585	Mean 16.1	.591

REFRIGERATION

Experiments designed to test the effect of refrigeration followed this general pattern: (1) a group of skipjack were taken from a school by live-bait fishing; (2) a portion of the group were frozen within an hour or two as controls; (3) the remainder received various experimental treatments prior to freezing.

EXPERIMENT NO. 1--Crushed Ice vs. Freezing: On July 25, 1954, 66 skipjack (16 to 24 pounds) were taken from a school 60 miles off the southwest coast of the island of Hawaii: 26 were dry frozen within an hour of capture; 1 1/2 hours later the remaining 40 were packed in crushed ice in an unrefrigerated brine well.

The iced fish were repacked the next day, since the ice melted rapidly and many of the fish on the bottom were immersed in water. In order to control this excessive melting, partial refrigeration was resorted to on the morning of July 27,

approximately 45 hours after the start of the experiment. The brine tank temperature was lowered to 40° F. in order to reduce the rate of melting and was occasionally lowered further to 20° F. in order to refreeze the melted ice. Unfortunately, this resulted in freezing the fish, so this experiment in essence tests immediate freezing against 45 hours in crushed ice.

More fish were added to the freezer from another school fished on July 28, bringing the total of dry-frozen fish to 40. These were almost the same size as the first group (15-24 pounds).

The 80 skipjack (40 dry-frozen and 40 "iced") were delivered to the cannery on August 1, a week after the beginning of the experiment. The two groups of fish were butchered and precooked on August 2 in two separate cartloads. They were examined and packed on August 3.

Results and Discussion: All except two fish were in excellent condition. These two, both from the "iced" group, were rejected, one for a very slight trace of probable honeycombing near the nape and the other for a slightly "mushy" texture. The defects in both cases were detected only after the most critical examination.

This experiment indicates no significant difference in the condition of fish frozen immediately after capture and those held in crushed ice for a period of 45 hours prior to freezing.

EXPERIMENT NO. 2--Freezing vs. Holding at Sea-Water Temperature: On August 16, 1954, 80 skipjack (15-32 pounds) were taken 20 miles north of the island of Molokai: 40, selected at random, were frozen within 1½ hours of capture; the remaining 40 fish were held in unrefrigerated circulating sea water for 14 hours (15 hours from capture) before they were frozen. The sea-water temperature during this period ranged between 78.0° F. and 79.0° F. and averaged 78.4° F. This is the type of storage generally used by commercial fishermen in Hawaii for cannery deliveries. The length of time fish are held in sea water prior to delivery at the cannery, where they are held in brine at 32° F., depends on the location of the catch and other operational factors.

Table 2 - Results of Experiment Testing the Condition After Precooking of Fish Frozen Shortly After Capture and Fish Held in Sea Water for 14 Hours Before Freezing

	Dry Frozen Immediately			Held in Sea Water 14 Hours 1/		
	Number Rejected 2/	Number Accepted	Total 3/	Number Rejected 2/	Number Accepted	Total 3/
Males	0	18	18	20	3	23
Females	1	19	20	14	1	15
Total	1	37	38	34	4	38

1/ These fish were on deck for 1 hour before being stowed. Temperature of sea water ranged from 78.0° F. to 79.02° F., averaging 78.4° F. during the experiment.
2/ Rejected because of honeycombing.
3/ Only 38 of the 40 fish in each lot were followed through the cannery. Identification tags were lost on the remaining 4 fish.

Just prior to freezing, the unrefrigerated fish were somewhat soft, but none emitted any "off" odor nor showed noticeable signs of decomposition. The two groups of fish (40 dry-frozen and 40 held in sea water) were delivered to the cannery on August 30, 1954, and were butchered and precooked on August 31 and canned on September 1.

Results and Discussion: Of the 38 frozen fish followed through the cannery, only 1 (2.6 percent) was found to be honeycombed; of 38 that had been held in sea water, 34 (89.5 percent) were honeycombed (table 2). Size and sex distributions of the two groups were similar (tables 2 and 3). The stomachs of both groups

were generally well filled, and many contained partly digested young skipjack, suggesting that their immediate precapture histories were essentially identical.

This experiment coincided with the peak of the skipjack season, and at the time honeycombing was quite common in the commercial catch, which is held in sea

Table 3 - Size of Fish in the Experiment Testing the Condition After Precooking of Fish Frozen Shortly After Capture and Fish Held in Sea Water for 14 Hours Before Freezing

	Size Groups (cm.) 1/					Not Recorded	Total
	67-70	71-74	75-78	79-82	83-84		
Fish frozen...	5	27	3	2	0	1	38
Fish held in sea water...	9	14	9	5	1	0	38

1/ The fish ranged in size from 67 to 84 cm. in total length or approximately 15 to 32 pounds each in weight.

water from the time of capture until delivery at the cannery. The results of this single experiment did not in themselves answer the question of whether or not the skipjack are at this season somehow inherently more susceptible to honeycombing than at other times. They did, however, strongly suggest that the phenomenon could, at this season, be produced to a high degree in one batch of fish and almost completely prevented in another batch of similar fish simply by regulating the temperature at which the fish were held after capture.

EXPERIMENT NO. 3--Varying Time in Sea Water vs. Immediate Freezing: On May 25, 1955, 82 skipjack averaging 7 pounds and ranging from about 5 to 11 pounds in weight were taken a few miles off Oahu. The control group of 32 fish selected at random was frozen within 1 hour after capture. The remaining 50 fish were put in unrefrigerated circulating sea water, and at 5-hour intervals groups of 10 fish were transferred from the sea water to the freezer, the last group being transferred after 25 hours in sea water (26 hours from time of capture). The temperature of the sea water during the 25 hours ranged between 74.7° F. and 75.6° F. and averaged 75.3° F. On May 28, 1955, the 82 experimental fish were delivered frozen and held frozen until June 8 when they were air-thawed; they were precooked on June 9, and examined on June 10.

Results and Discussion: The results (table 4) were in general consistent with those obtained in experiment No. 2. The control group of 32 fish was completely

Table 4 - Results of Experiment No. 3

Group	Number of Fish	Hours in Sea Water 1/	Cannery Results		Remarks 2/
			Number Honeycombed	Percentage Honeycombed	
A	32	0	0	0.0	Completely acceptable
B	10	5	0	0.0	Do.
C	10	10	0	0.0	Do.
D	10	15	0	0.0	Do.
E	10	20	10	100.0	Degree of honeycombing about 80 percent in each fish
F	10	25	10	100.0	Degree of honeycombing about 95 percent in each fish

1/ All fish were on deck for 1 hour before being stowed. Sea-water temperature, 74.7° F. - 75.6° F., averaging 75.3° F.
2/ Observations by a cannery representative.

acceptable with no trace of honeycombing, but the experimental groups gave varying results. There was no honeycombing in those held from 5 to 15 hours (6-16 hours from capture) in sea water, but the 20- and 25-hour groups (21-26 hours from capture) were all honeycombed. In the previous experiment fish held in seawater for 14 hours developed honeycombing, while in this instance the 15-hour group did not. The significant differences between the two experiments were: (1) the first experiment was conducted in August and the second in May; (2) the sea-water temperature averaged 78.4° F. in August and 75.3° F. in May; (3) the fish used were smaller in May; (4) the fleet was experiencing honeycombing in August but not in May. In view of these differences, the results appear to indicate that honeycombing is a seasonal phenomenon only in that it is related to seasonal changes in the sea-water temperature, and that it can probably be produced in Hawaiian skipjack at any season if the fish are kept at high enough temperatures for a long enough time.

EXPERIMENT NO. 4--Varying Time in Sea Water vs. Immediate Freezing: Following the same design as in the previous experiment, this trial used 90 fish averaging 28 pounds (25 to 34 pounds) each taken a few miles off the northwest coast of Oahu on June 9, 1955: 40 fish (Group A) were placed in the freezer within 1½ hours of capture; the remaining 50 fish were held in circulating sea water for varying lengths of time up to 25 hours (27 hours from capture). The sea-water temperature during the 25-hour interval ranged between 75.0° F. and 76.5° F., averaging 75.8° F.

The following observations were made at the time of transfer of fish from sea water to the freezer.

Group	Hours In Sea Water	Remarks
B	10	Fish with slight off-odor but quite firm
C	15	Do.
D	20	Fish with ripe odor; meat somewhat softer
E	25	Fish with ripe odor; soft meat; deteriorating

Unfortunately, as the ship's freezer was overcrowded, the fish did not freeze properly, and when they were delivered to the cannery's freezer on June 10, 28 hours after the start of the experiment, only a few of the control group were completely frozen. On June 14 the fish were removed from the cannery freezer to thaw. It was found at this time that four fish had lost their tags. These fish had been tied together in pairs with a single label, and since two groups of 10 were exactly two short, it was known that the four unlabeled fish had come from only two groups. By comparing the general condition of the two pairs of unidentified fish with the two groups, it was possible to make probable assignments. Pair X was in condition comparable to the remaining 8 fish of group C, and pair Y to group D (see table 5).

Table 5 - Results of Experiment No. 4

Group	Number of Fish	Hours in Sea Water 1/	Cannery Results		Remarks 2/
			Number Honeycombed	Percentage Honeycombed	
A	40	0	0	0.0	One fish with a "putty" texture
B	10	5	1	10.0	One fish with "very faint trace of what could be the start of honeycombing"
C (X)	8 2 (?)	10 10 (?)	1 1	20.0	Two fish with "slight trace of what could be start of honeycombing" at nape--only at the surface
D (Y)	8 2 (?)	15 15 (?)	8 2	100.0	All honeycombed; degree of honeycombing 5, 10, 10, 10, 20, 20, 20, 20, 20, and 50 percent, all at nape
E	10	20	10	100.0	All honeycombed; degree of honeycombing 20, 20, 20, 20, 25, 40, 40, 45, 45, and 80 percent. All at anterior portion of body, none in caudal region
F	10	25	10	100.0	All honeycombed; degree of honeycombing 10, 20, 40, 50, 55, 55, 55, 80, 80, and 90 percent. Only caudal region unaffected

1/ All fish were on deck for 2 hours before being stowed. Sea-water temperature, 75.0° F.-76.5° F., averaging 75.8° F.
2/ Observations by a cannery representative.
(?) Indicates probable assignment of fish in the group as discussed in text.

Results and Discussion: There was a definite progression in the degree of honeycombing with the length of time the fish were kept in sea water (table 5).

Generally, the fish held in sea water for 15 hours or more were badly honeycombed; however, there were a few fish in the other groups which had possible traces of the condition. It may be relevant to reiterate here that in this experiment the fish did not freeze properly until they had been transferred to the cannery's freezer, 28 hours after the start of the experiment. This may have been the reason for the development of some honeycombing in the groups refrigerated after only 5 and 10 hours in sea water.

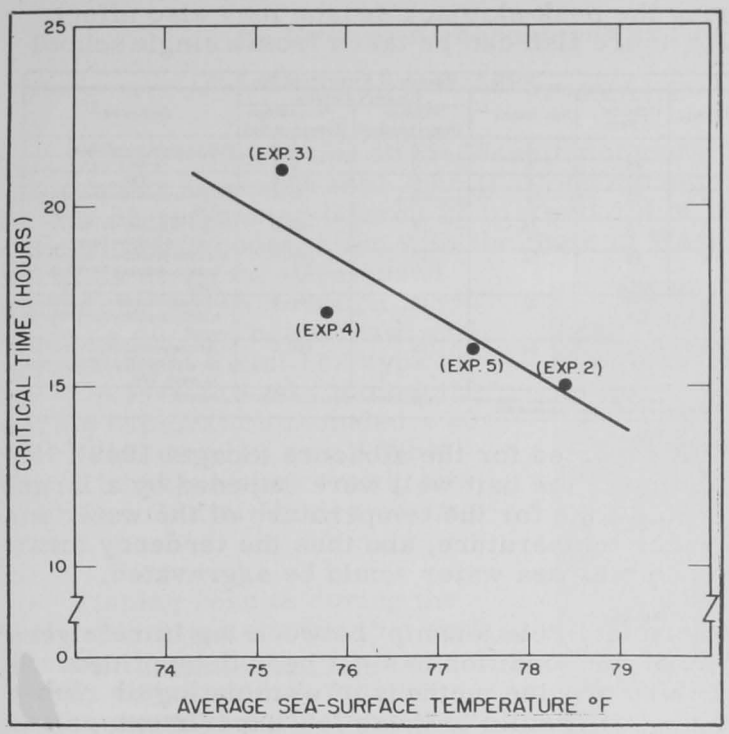

Fig. 4 - The relationship between average sea-water temperature and the length of time fish were held before honeycombing developed. (The sea-water temperature is the average surface temperature for the period in which the fish were held in sea water. Temperatures were obtained from bucket thermometer and thermograph readings. The "critical time," which is the time required to induce honeycombing in 90 percent of the fish, includes the time the fish were on deck prior to treatment.
Note: The critical time was not definitely established in experiment No. 2 since only one group of fish was held in sea water.)

This experiment, both in terms of results and design, closely resembled the preceding test, except that the fish were larger (28 pounds versus 7 pounds) and the sea water was slightly warmer. At the time of the experiment (June) the commercial fleet was not experiencing honeycombing.

EXPERIMENT NO. 5--Varying Time in Sea Water vs. Immediate Freezing: The final experiment in the series was conducted on 80 skipjack taken 19 miles off the west coast of Hawaii on August 17, 1955. These fish averaged $4\frac{1}{2}$ pounds in weight and ranged from about $3\frac{1}{2}$ to 5 pounds. The control group of 10 fish was frozen within 1 hour of capture and the remaining 70 were held in circulating sea water for lengths of time varying from 6 to 24 hours (7 to 25 hours from capture) and then frozen. The sea-water temperature in the brine well containing the fish ranged between 76.2° F. and 80.0° F., averaging 77.4° F. The 80 fish were delivered to the cannery's freezer on August 26, 1955, precooked on August 31, and examined on September 1.

Results and Discussion: The results (table 6) were essentially similar to those obtained in the previous experiments. Some honeycombing was evident in fish kept unrefrigerated for 13 hours, but the bulk of the honeycombing occurred in groups left unrefrigerated for 16 hours or longer. Here again the results clearly indicated a progression in the degree of honeycombing with the length of time the fish were held in unrefrigerated sea water.

SUMMARY

The results of these experiments are remarkably consistent in showing that honeycombing develops in Hawaiian skipjack held without refrigeration, independent of sexual maturity or size of the fish. The seasonality of occurrence observed in the commercial landings (the condition is usually noticed during the summer) is not at all apparent in the experimental results, as honeycombing resulted from delayed refrigeration in experiments performed at different times of the year. It appears that the rate of honeycombing is more rapid at higher sea-water temperatures (fig. 4), and since the months of highest water temperatures in Hawaii coincide with the peak

skipjack season and peak "honeycombing season," it may be inferred that there is a close relationship between water temperature and honeycombing.

The relative fishing success during the peak skipjack season may also affect the onset of honeycombing. Generally, more fish can be taken from a single school during the peak than during the off-season. This may mean that larger numbers of fish are put into the bait well at one time, possibly causing an appreciable rise in the temperature of the sea water, because the body temperature of skipjack immediately after capture is generally higher than the water temperature (Uda 1941). Furthermore, it is believed that the skipjack undergoes an initial increase in temperature for several hours after landing, similar to that reported for the albacore (Scagel 1949). If, under these circumstances, the circulation in the bait well were impeded by a large quantity of fish, it would take considerable time for the temperature of the water in the well to revert to the normal sea-water temperature, and thus the tendency for honeycombing to develop in the warm summer sea water would be aggravated.

Table 6 - Results of Experiment No. 5

Group	Number of Fish	Sea Water 1/	Cannery Results		Remarks 2/
			Number Honeycombed	Percentage Honeycombed	
A	10	0	0	0.0	All in good condition
B	10	6	0	0.0	Do.
C	10	9	0	0.0	Do.
D	10	12	3	30.0	Slight traces on these three fish
E	10	15	9	90.0	Slight to minor on these fish--all at the nape
F	10	18	10	100.0	All honeycombed; degree of honeycombing 20-75 percent
G	10	21	10	100.0	All honeycombed; degree of honeycombing 95-100 percent
H	10	24	10	100.0	All honeycombed; degree of honeycombing 100 percent in each fish

1/ All fish were on deck 1 hour before being stowed. Sea-water temperature, 76.2° F.-80.6° F., averaging 77.4° F.
2/ Observations by a cannery representative.

Although it has been shown that there is a relationship between lag in refrigeration and honeycombing, the basic cause of the condition has not been determined. Further experiments are necessary before precise methods of eliminating or reducing the condition can be prescribed. The results of these few experiments, however, do suggest that in Hawaii a modest amount of refrigeration on the boats would postpone the development of honeycombing long enough to permit delivery of the fish in good condition to the canneries' chill tanks. It might suffice to handle the catch in crushed ice, or simply to add a little ice to the sea water in which the fish are held aboard the boats.

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