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REARING TILAPIA FOR TUNA BAIT

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ABSTRACT

The Hawaiian skipjack (*Katsuwonus pelamis*) fishery is often faced with an inadequate supply of live bait during the summer season when the skipjack are plentiful. The Bureau of Commercial Fisheries experimented with the hatchery rearing of *Tilapia mossambica* in 1958 and 1959 at Paia, Maui, to determine if tilapia could be produced economically to supplement the supply of naturally occurring bait fishes.

A description of the hatchery and its operation and the results obtained are presented. From the information gained it is believed that a larger and better designed hatchery than the one used in the study could produce bait economically and in adequate quantities.

REARING TILAPIA FOR TUNA BAIT

By Thomas S. Hida, *Fishery Research Biologist*, Joseph R. Harada, *Fishery Aid*, and Joseph E. King, *Fishery Research Biologist*

BUREAU OF COMMERCIAL FISHERIES

The pole-and-line live-bait fishery for skipjack (*Katsuwonus pelamis*) is the most important commercial fishery in the Hawaiian Islands. In 1959, the catch amounted to 12.4 million pounds, worth $1.5 million to the fishermen. Brock and Takata (1955) and Yamashita (1958) stated that a critical factor limiting this fishery is the shortage of live bait during the fishing season, which extends generally from May to October and usually reaches its peak in August. Yamashita (1958) has estimated that the Hawaiian live-bait fishery utilizes about 36,000 buckets (252,000 pounds) of bait annually. Much more than this amount could be used to advantage in most years, if it were available.

The principal bait fish is the nehu (*Stolephorus purpureus*), a small anchovy. The iao (*Pranesus insularum*), a silverside, is also used in some quantity. The nehu is a delicate fish that, even if handled carefully, will not survive in the bait wells of the sampans (fishing vessels) for more than a few days. It has not been considered feasible to attempt to rear the nehu artificially.

As one approach to solving the bait-fish problem, artificial baits of both edible and inedible materials have been tested with generally negative or inconclusive results (Tester et al., 1954).

In another approach to the problem, the staff of the Bureau of Commercial Fisheries Biological Laboratory at Honolulu, Hawaii, in recent years introduced a sardine (*Harengula vittata*) from the Marquesas Islands (Murphy, 1960) and the threadfin shad (*Dorosoma petenense*) from the United States. The introductions appear to be successful, but it is too early to predict if these fishes will become abundant enough to satisfy the needs of the fishery for additional bait supplies.

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A small stock of *Tilapia mossambica* was brought to Hawaii from Singapore in 1951 by the Hawaii Division of Fish and Game. The species is now well-established in ponds and reservoirs on all major islands of the Hawaiian group. The use of tilapia as skipjack bait was first tested by Brock and Takata (1955), who reported that tilapia were used to catch fish from schools that had been first chummed to the stern of the boat with nehu. King and Wilson (1957) further demonstrated that small tilapia had many characteristics of a good bait fish and judged it to be an adequate skipjack bait. They found tilapia to be a very hardy fish that tolerated a wide range of salinities and survived for indefinite periods in the bait wells of the sampans. It was their opinion, however, that large quantities of bait-size tilapia could not be produced effectively in reservoirs and natural ponds because of the difficulty of harvesting the young fish and because of the lack of control over cannibalism and predation.

In December 1957, a contract was signed with Maui Fisheries and Marine Products, Ltd., the Territorial Board of Agriculture and Forestry, and the Bureau of Commercial Fisheries, as principals, for operation of a hatchery at Paia, Maui, to determine the economic feasibility of producing young tilapia in a system of concrete tanks. Under the terms of the contract, Maui Fisheries was to bear the cost of land rental, the major capital improvements, and the water used; the Territory was to aid in fencing the area and provide other facilities and services; the Bureau of Commercial Fisheries agreed to provide a biologist to supervise operation of the plant, to furnish feed for the fish, and to supply miscellaneous equipment such as dipnets, screens, fish-sorting devices, and chemical supplies. While not parties to the formal contract, Hawaiian Tuna Packers, Ltd., and Hawaiian Commercial and Sugar Co., Inc., expressed

their interest in the project and willingness to cooperate. In February 1959, the same organizations signed another contract with almost identical conditions, except that the Bureau of Commercial Fisheries was to bear the additional cost of the water and electricity used in the plant.

A former horse and mule stable at Paia was selected for use as a tilapia hatchery and its reconditioning and conversion began early in December 1957, and was completed in all major respects in January 1958. A biologist was stationed at the hatchery from January through December, 1958, and from February through December, 1959.

This report describes the results obtained at the Paia hatchery during the 2 years of its operation. It is hoped that this review of the problems encountered, the methods employed, and the economic aspects of the operation will prove of value and interest to fishery scientists and to members of the tuna industries who are concerned with the problem of obtaining an adequate supply of live bait.

The production of bait-size tilapia under natural conditions in two types of ponds, located in the Honolulu area, is described in the appendix. In a brackish-water pond where many natural predators were present, production and survival of young fish were essentially zero. In a freshwater pond with few predators but prevalent cannibalism, bait-size fish were produced in limited quantities.

The interesting breeding habits of *T. mossambica* have been well described by Chen (1953) and other investigators. The adult male in breeding condition establishes a territory in which he digs a saucer-shaped depression, if the bottom is of sand or mud, or clears a circular area of algae, stones, or detritus, if the bottom is of hard clay or rock. He then maintains constant vigil over his "nest," chases away any other males that approach too closely, and attempts to herd females into the nest area. If a female can be encouraged to spawn, the eggs are extruded over the nest, fertilized by the male, and are immediately taken into the mouth by the female. The female then moves away or is chased away by the male. The male remains to guard the nest and to court other females. The eggs hatch in about 60 hours, but the female continues to carry the young in her mouth cavity for another 5 to 8 days. When the young are finally released by the female they form a tight little school near the surface of the water where they are easily dipnetted. If not dipnetted during their first day of freedom they sink to the bottom or middle layers of the tank where they are more difficult to capture.

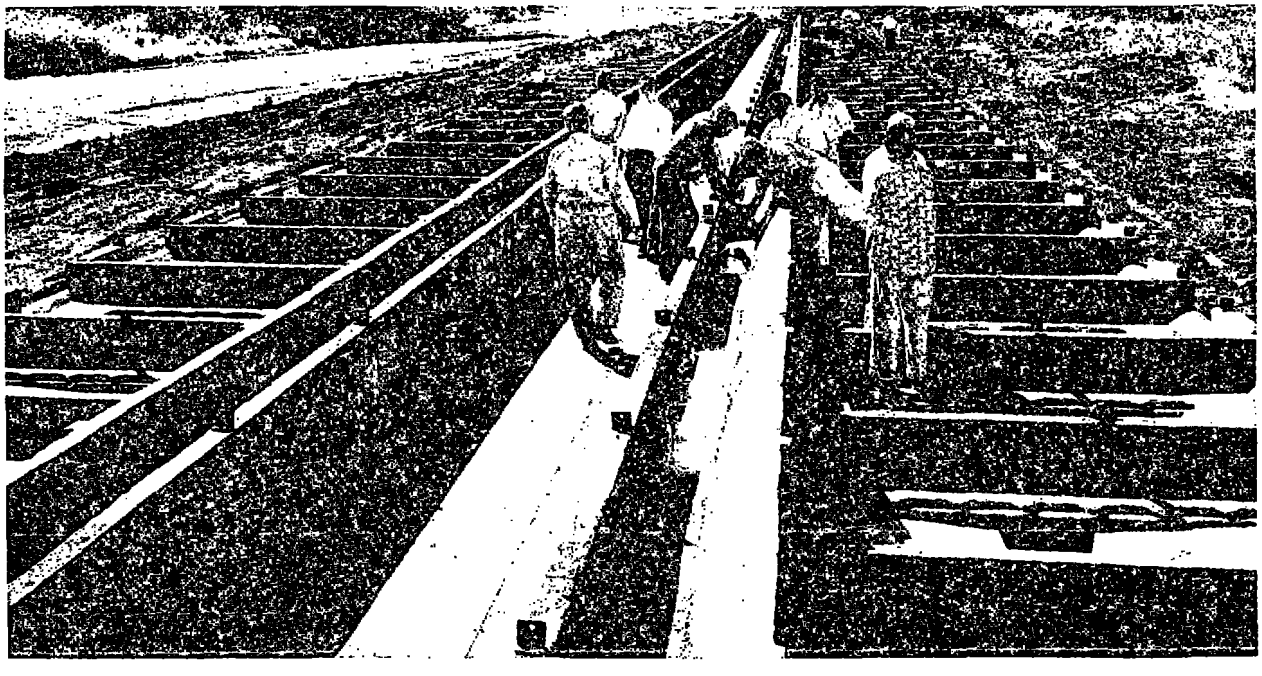

FIGURE 1.—Former stable at Paia, Maui, before being remodeled for use as a tilapia-rearing plant.

THE PAIA HATCHERY

DESCRIPTION OF FACILITIES

Tanks

The hatchery was situated near the sugar mill at Paia, Maui. The portion of the stable that was renovated consisted initially of a long, concrete-walled walkway with a narrow trough along each wall. On the outer side of each trough was a series of 45 individual stalls (fig. 1). To convert these structures into a tilapia-producing plant, the central walkway was walled at each end and partitioned in the middle to create two large brood tanks, A and B. The two narrow troughs and the 90 stalls were converted into fry tanks (fig. 2). Inflow pipes and drains were installed in all tanks. The dimensions of the various tanks are given in table 1.

A small building was moved onto the grounds and modified for storage of feed and equipment.

TABLE 1.—*Dimensions and capacities of fish tanks at the Paia hatchery*

Item	Type of tank			Total
	Brood	Fry trough	Fry	
Number of tanks	2	4	90	
Dimensions of tanks (ft.):				
Length	161	161	11	
Width	5.23	1.8	6.5	
Overall depth	2.25	1.58	1.08	
Depth of water (ft.)	2.0	1.33	1.0	
Capacity per tank:				
Cubic feet	1,684	385	71.5	2,140.5
Gallons	12,596	2,880	535	16,011
Surface area (sq. ft.):				
Per tank	84	290	71.5	
All tanks	1,684	1,160	6,435	9,279

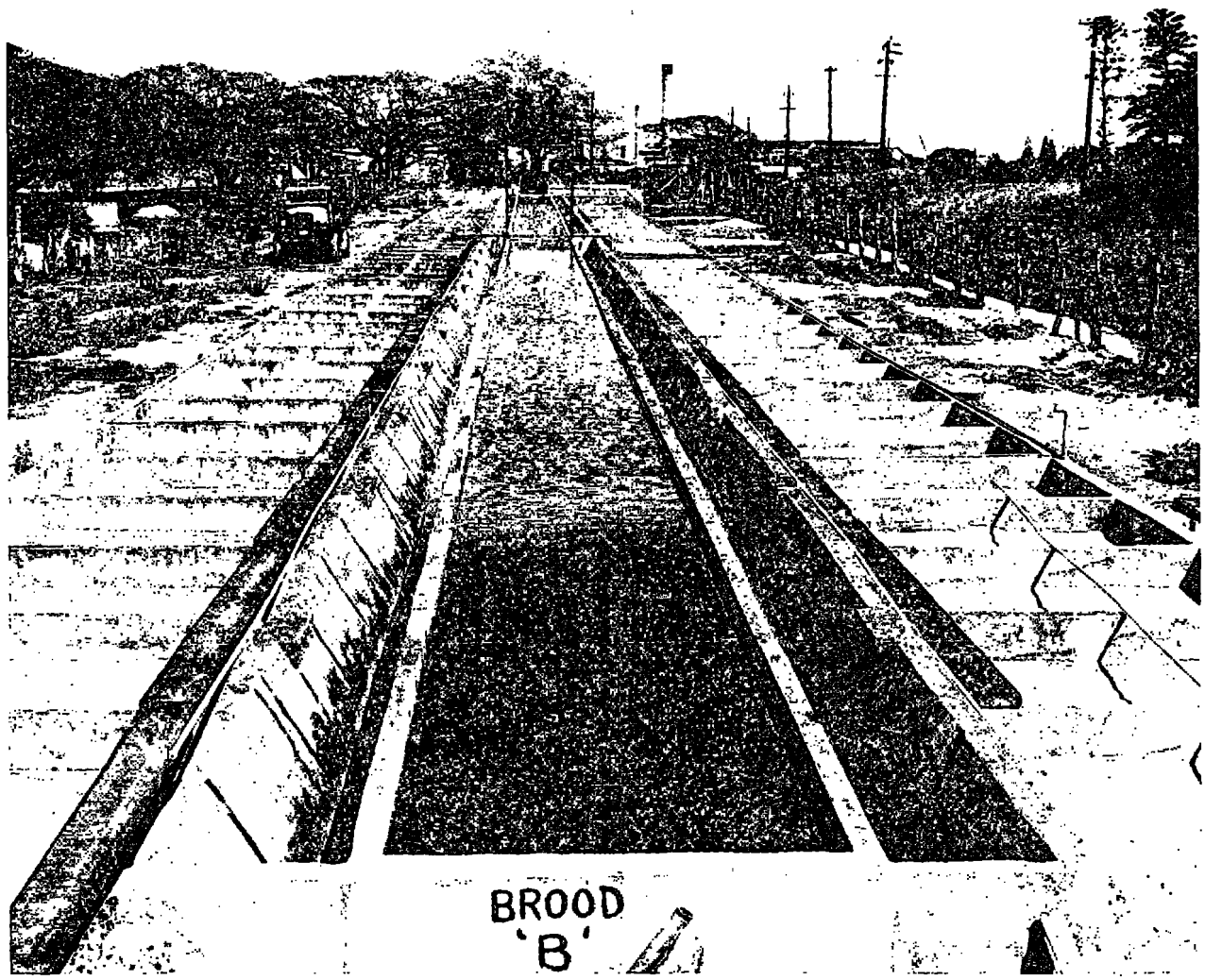

FIGURE 2.—Stable area at Paia, Maui, after being remodeled into a system of 2 brood tanks and 90 fry tanks for rearing tilapia.

Water Supply

The water used at the Paia plant came from wells located in the same general area. It was pumped to a storage tank at a higher elevation and returned by gravity flow to the tilapia plant, arriving there under considerable pressure. Analyses showed a salt content ranging from 60 to 80 grains per gallon. The water was suitable for irrigation but was not approved for human consumption. The brood tanks, as well as the fry tanks, had an independent water supply, and none of the water was recirculated in 1958. Early in 1959, a pump and sand filter box were installed and the water in brood-tank A was filtered and recirculated during the balance of the year.

The total amount of water used was 9,285,890 gallons in 1958 and 13,100,000 gallons in 1959. The amounts used and cost by months are given in tables 2 and 3 for the 2 years. The amounts used were greater in 1959 than in 1958 because (1) of the addition of 3 holding tanks, (2) a supply of bait-size fish was held over from the previous year, and (3) the peak in production was earlier in 1959 necessitating the use of more fry tanks throughout the year.

TABLE 2.—*Amount and cost of water used at the Paia hatchery, 1958*

Month	Gallons	Cost [1]	Average cost per month
January–April	[2] 1,792,303	$107.54	$26.88
May	385,752	23.15	23.15
June	634,878	38.09	38.09
July–August	2,239,367	134.36	67.18
September–October	2,540,700	152.44	76.22
November–December	1,692,890	101.57	50.78
Total	9,285,890	557.15	

[1] 6 cents per thousand gallons.
[2] Large volume because of fry-tank leakage.

TABLE 3.—*Amount and cost of water used at the Paia hatchery, 1959*

Month	Gallons	Cost [1]	Average cost per month
February–March	1,214,000	$72.84	$36.42
April–May	2,401,000	144.06	72.03
June–July	3,608,000	216.48	108.24
August–September	2,268,000	136.08	68.04
October–November	2,182,000	130.92	65.46
December	1,427,000	85.62	85.62
Total	13,100,000	786.00	

[1] 6 cents per thousand gallons.

Two air compressors and a system of air lines were installed in March 1959 to aerate the water in the brood tanks and increase its oxygen content during the hours of darkness, when the oxygen content usually reaches a very low level. In April 1959, a 120-foot lead-sheathed, soil-heating cable, rated at 3.65A–220V and capable of producing 800 watts, or 6.7 watts per foot, was installed in each brood tank with the objective of raising water temperatures and inducing early spawning. The amount and cost of electricity used in 1959 for the operation of the filter pump, the air compressors, and the heating cables are given in table 4.

TABLE 4.—*Amount and cost of electricity used at the Paia hatchery, 1959*

Date [1]	Pumps		Heating cables	
	KWH	Cost	KWH	Cost
Mar. 25–Apr. 16	788	$52.64		
Apr. 16–May 18	3,032	165.48		
May 18–June 16	2,158	123.75		
June 16–July 17	832	[2] 25.90	1,794	$32.02
July 17–Sept. 17	116	9.80		[3] 3.11
Sept. 17–Oct. 16	2	1.23		3.11
Total		378.80		38.24

[1] Mar. 27, filter pump placed in use; Apr. 10, heating cable and 1 aerator in use; Apr. 27, second aerator in use; July 1, heating cables turned off; Aug. 10, filter pump turned off.
[2] Heat and power put on separate meters June 13.
[3] Meter service charge.

ENVIRONMENTAL CONDITIONS

Temperature Variations

The monthly averages of maximum and minimum water temperatures in brood-tank A, as measured by a thermograph, are plotted in figures 3 and 4. The daily fluctuation in temperature ranged from 5° to 9° F. In 1958, the highest water temperature was recorded in September and the lowest in December. In 1959, the maximum occurred in July and the minimum in November.

Maximum air temperatures at the Paia station were higher from March through November in 1959 than in 1958 (fig. 5). The minima, on the other hand, were lower in 1959 than in 1958 for the summer months, May through August (fig. 6), but higher for the period February to April. As a result of the generally warmer air conditions during the spring months of 1959, we actually have no way to evaluate the effect of the heating cables on water temperature and spawning.

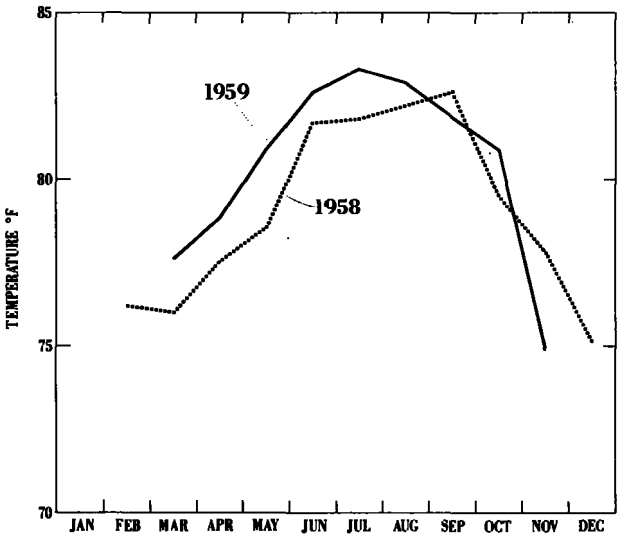

FIGURE 3.—Average monthly maximum water temperatures in brood-tank A in 1958 and 1959.

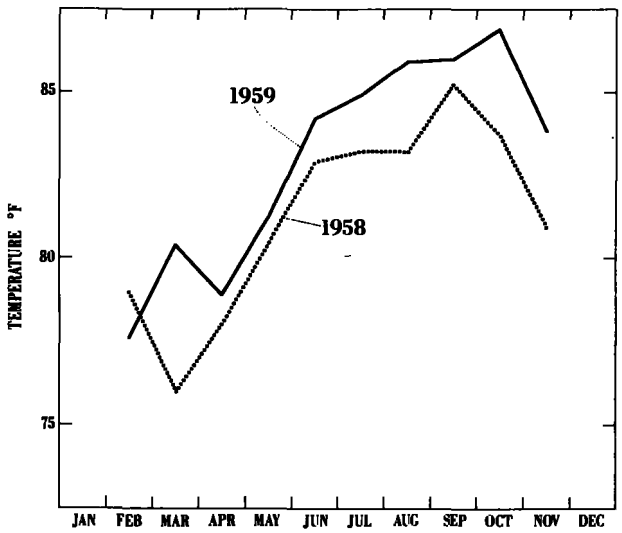

FIGURE 5.—Average monthly maximum air temperatures at Paia, Maui, in 1958 and 1959. (Data courtesy of Hawaiian Sugar Planters Association.)

The two years were generally similar in the amount of sunshine recorded at the Paia station (fig. 7). In the two months March and July, however, there was considerably more sunshine in 1959 than in 1958.

Oxygen Concentrations

1958.—Measurements of the concentration of dissolved oxygen in the brood tanks showed a marked diurnal variation (table 5). Oxygen values at about 8 a.m. were frequently less than 1.0 ml./l., and on a few occasions were less than 0.5 ml./l. These levels are dangerously low and conceivably could have had a detrimental effect on the survival of eggs and young.

On the basis of a 24-hour series of oxygen measurements made in tanks at the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, it would appear that our early morning and afternoon sampling times were close to the hours of minimum and maximum concentrations

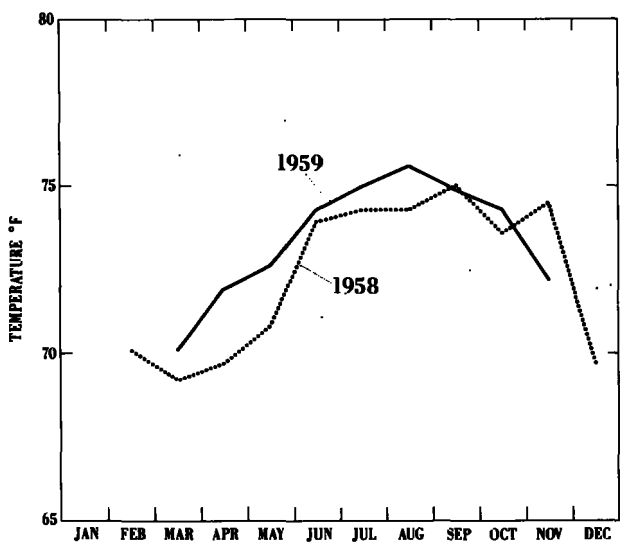

FIGURE 4.—Average monthly minimum water temperatures in brood-tank A in 1958 and 1959.

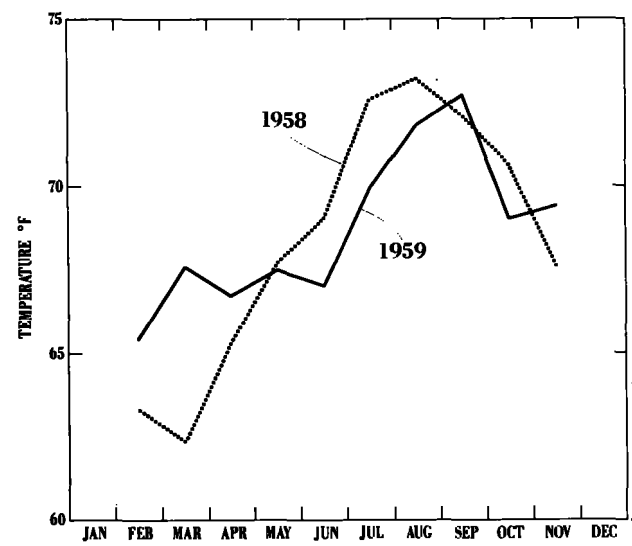

FIGURE 6.—Average monthly minimum air temperatures at Paia, Maui, in 1958 and 1959. (Data courtesy of Hawaiian Sugar Planters Association.)

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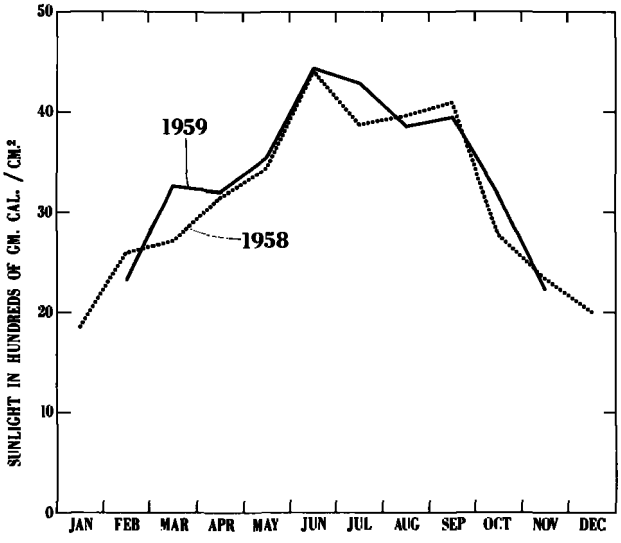

FIGURE 7.—Average monthly sunlight recorded at Paia, Maui, in 1958 and 1959. (Data courtesy of Hawaiian Sugar Planters Association.)

of dissolved oxygen. The low (morning) values averaged 1.11 ml./l. for tank A and 0.99 ml./l. for tank B. The high (afternoon) values averaged 6.62 ml./l. for tank A and 5.12 ml./l. for tank B. This marked diurnal variation resulted, we believe, from oxygen being utilized during the hours of darkness by both algae and fish and being restored during daylight hours by photosynthesis. The difference in tilapia production between the two tanks may possibly have been related to the higher oxygen concentration that prevailed in tank A.

On March 4 and 5, detailed sampling was carried out to determine the differences in oxygen concentration at different positions and at different depths in the brood tanks in relation to inflow and outlet and direction of the prevailing winds. The results are given in table 6. There were no major differences between the two tanks in the afternoon. Early in the morning the oxygen concentrations were slightly less in tank B than in tank A. Concentrations of oxygen were higher at the surface than those midway in the tank, which in turn were usually higher than those near the bottom of the tanks. Concentrations were higher near the inflow end of the tanks than near the outlet, as might be expected.

TABLE 5.—*Concentrations (ml./l.) of dissolved oxygen in selected tanks, measured in morning and afternoon, 1958*

[Samples drawn about 12 in. below surface approximately midway in tank]

Date	Time	Tank A	Tank B	Fry tank No. 90	Remarks
Feb. 12	0830	0.68	0.93	------	
12	1430	6.25	6.98	------	
19	0815	2.68	.39	------	
19	1230	6.36	2.42	------	
26	0830	1.32	1.26	------	
26	1300	5.80	5.49	------	
Mar. 12	0815	.54	.62	4.58	
12	1330	4.49	1.52	4.98	
14	0815	.69	.55	------	Inflow about 4 gal./min.
19	0815	1.44	1.01	4.99	
19	1300	8.49	5.65	6.17	
26	0810	1.30	.65	4.63	
26	1300	8.04	5.05	6.14	
Apr. 2	0815	1.20	.68	4.96	
2	1305	6.77	5.11	6.35	
9	0815	1.26	.82	4.45	
9	1315	7.05	5.55	6.08	
16	0750	1.08	.71	4.20	
16	1300	6.97	5.44	6.71	
23	0750	.86	.60	4.57	
23	1300	5.95	4.78	6.98	
30	0745	.59	.58	3.52	
30	1300	4.62	5.53	6.39	
May 7	0750	.66	.33	3.88	
7	1300	5.64	2.94	6.50	
14	0745	.84	.86	2.68	
14	1300	7.27	6.59	5.61	
21	0745	1.26	1.15	2.55	
21	1320	*9.05	*8.56	5.59	*Water depth 15 in.; sample 3 in. below surface.
28	0630	.40	.49	------	
28	0700	.61	.39	------	
28	0740	.95	1.06	------	
June 5	0620	.35	.50	3.58	Tank A =2 gal./min. inflow. Tank B=1 gal./min. inflow.
11	0630	.19	.26	------	
13	0630	.63	.59	------	About 10,000 gal. water passed through each tank overnight.
18	1625	2.64	1.58	------	
25	0630	.52	1.73	------	
July 3	0705	.39	.75	------	
10	0715	1.06	1.08	------	
17	0735	.65	.90	------	
25	0745	.92	.80	------	
Aug. 1	0800	1.24	.78	------	
6	0800	.87	1.05	------	
15	0750	.75	.65	------	
29	0715	.69	1.06	------	
Sept. 4	0750	.89	1.44	------	Inflow of tank B about twice that of A.
12	0725	.66	.76	------	
19	0800	1.36	2.05	------	No water entered brood tanks for past 4 days.
26	0715	.85	1.01	------	
Oct. 3	0800	2.65	1.76	------	
10	0815	4.01	2.01	------	
17	0725	3.96	3.84	------	
24	0735	2.12	1.12	------	
31	0725	2.38	1.63	------	
Nov. 7	0715	.64	.72	------	
14	0725	.64	.52	------	
20	0800	1.29	2.18	------	
26	0805	.83	1.09	------	
Dec. 12	0755	.64	.69	------	Water level lowered in brood tanks; level restored with fresh water Dec. 2-3.
17	0825	.33	.77	------	
26	0745	.49	.52	------	
30	0730	.36	.39	------	

A number of measurements (table 5) taken in one of the fry tanks indicates that oxygen concentrations there were favorable at all times. The high values are related, no doubt, to the shallow depth of the tanks, the high surface area to volume ratio, and the presence of algae.

TABLE 6.—*Concentrations (ml./l.) of dissolved oxygen at different depths and positions in brood tanks, 1958*

Sampling time and depth	Outlet end (NE.)	Middle	Inflow end (SW.)
TANK A [1]			
0815 hours:			
Surface	0.53	0.70	0.76
Midway	.52	.47	.70
Bottom	.42	.40	.66
1330 hours:			
Surface	2.54	3.31	3.46
Midway	2.39	3.29	2.99
Bottom	2.43	3.26	2.97
TANK B [2]			
0830 hours:			
Surface	.73	.51	.34
Midway	.69	.47	.32
Bottom	.67	.48	.18
1315 hours:			
Surface	4.17	3.50	2.99
Midway	3.50	3.42	2.33
Bottom	3.49	3.47	2.18

[1] Sampled March 4.
[2] Sampled March 5.

1959.—In 1959, in contrast with 1958, oxygen concentrations in the brood tanks were usually favorable following installation of the aeration system, with very few readings below 1 milliliter per liter and with the average above 3 ml./l. The very low levels in concentrations of oxygen in some of the fry tanks, however, may have been caused by retention of fish for long periods of time in a single tank with inadequate flushing. The oxygen concentrations in the brood tanks and in selected fry tanks are given in table 7.

TABLE 7.—*Measurements (ml./l.) of dissolved oxygen in selected tanks, taken about midday, 1959*

Sampling date	Brood A	Brood B	Tap	Fry tank No.—						
				76	73	90	86	67	82	66
Mar. 5	4.62	1.29	5.31	----	----	----	----	----	----	----
13	2.39	1.82	6.26	0.53	----	----	----	----	----	----
17	.83	1.18	4.85	----	1.18	----	----	----	----	----
24	1.50	.95	5.97	.77	.71	----	----	----	----	----
31	2.11	2.42	5.21	.45	.60	----	----	----	----	----
Apr. 7	3.35	1.77	1.03	.42	1.56	----	----	----	----	----
14	2.05	.89	4.99	.16	.58	----	----	----	----	----
21	5.36	2.64	5.84	----	.33	1.72	----	----	----	----
28	2.04	1.27	4.53	----	.83	2.44	----	----	----	----
May 5	3.92	5.18	5.26	----	1.53	1.78	----	----	----	----
12	4.01	5.36	5.33	----	.23	3.41	----	----	----	----
29	5.89	6.59	5.56	----	----	3.65	----	----	----	----
June 5	5.91	7.17	5.61	----	----	----	----	6.81	----	----
9	5.38	6.18	5.70	----	----	----	----	3.40	----	----
25	5.48	2.80	5.23	----	----	----	5.71	----	----	----
July 7	5.63	5.33	5.25	----	----	----	4.58	----	----	----
14	5.11	4.64	5.76	----	----	----	5.04	----	----	----
22	4.97	3.64	5.46	----	----	----	2.98	----	----	----
28	5.79	4.51	5.40	----	----	----	2.80	----	----	----
Aug. 5	3.47	4.07	3.85	----	----	----	2.75	----	----	----
12	5.66	4.75	5.62	----	----	----	2.92	----	----	----
19	3.56	3.35	4.97	----	----	----	3.78	----	----	----
25	4.27	4.97	5.51	----	----	----	3.54	----	----	----
Sept. 11	5.62	4.03	5.69	----	----	----	----	3.71	5.80	----
22	4.39	4.34	4.87	----	----	----	----	3.19	6.16	----
29	2.56	2.49	5.08	----	----	----	----	2.24	2.70	----
Oct. 8	2.52	2.09	5.08	----	----	----	----	----	3.96	4.68
16	1.61	4.90	5.60	----	----	----	----	----	3.22	2.38
21	.55	6.18	7.20	----	----	----	----	----	5.52	4.56
28	5.08	4.14	5.40	----	----	----	----	----	5.08	4.32
Nov. 5	1.89	4.97	5.60	----	----	----	----	----	2.24	3.64
13	3.71	1.54	5.81	----	----	----	----	----	3.64	2.94
17	2.42	5.69	6.94	----	----	----	----	----	5.30	5.54
24	1.92	5.16	5.85	----	----	----	----	----	3.41	3.48
Dec. 1	4.39	5.04	5.90	----	----	----	----	----	3.38	2.81
Average concentration	3.70	3.81	5.36	.47	.84	2.60	3.79	3.87	4.20	3.82

Other Chemical Determinations

Several chemical determinations were made in 1959 in addition to the oxygen measurements. Data on hydrogen ion concentration (pH), and carbon dioxide (CO_2), bicarbonate (HCO_3^-), and normal carbonate ($CO_3^=$) concentrations are presented in table 8. The slight differences in the pH concentrations in the two brood tanks were judged to be negligible. The CO_2, $CO_3^=$, and HCO_3^- concentrations are approximations, since it was difficult to determine the end points when the water samples were dirty brown to deep green in color, as was frequently the case.

TABLE 8.—*Chemical determinations made on brood tanks, 1959*

Date	Tank A				Tank B			
	pH	CO_2 (p.p.m.)	CO_3 (p.p.m.)	HCO_3 (p.p.m.)	pH	CO_2 (p.p.m.)	CO_3 (p.p.m.)	HCO_3 (p.p.m.)
Mar. 5	8.8	------	------	------	7.9	------	------	------
13	7.6	------	------	------	8.8	------	------	------
17	7.7	------	------	------	7.8	------	------	------
24	8.8	------	------	------	8.8	------	------	------
31	8.8	------	------	------	8.5	------	------	------
Apr. 7	8.3	------	------	------	8.2	------	------	------
14	7.6	------	------	------	7.2	------	------	------
21	7.9	------	------	------	7.4	------	------	------
28	7.9	------	------	------	7.3	------	------	------
May 5	7.6	------	------	------	8.0	------	------	------
12	8.2	4.26	22	142	8.6	2.18	5	35
29	8.6	------	------	------	8.2	------	------	------
June 5	7.8	------	------	------	8.1	------	------	------
9	7.8	4.0	0	102	7.8	1.7	0	97
25	7.9	10.5	0	14.5	8.6	8.0	0	17.5
July 7	7.9	9.0	0	130	8.4	4.0	0	63
14	7.9	13.0	0	111	8.8	0	15	65
22	7.8	4.5	0	88.5	8.4	4.0	0	42.5
30	8.2	4.0	0	105	8.0	5.0	0	65
Aug. 5	7.6	10.5	0	94	7.6	12.5	0	90
12	8.2	5.6	0	94	8.8	4.0	0	77
19	7.8	12.0	------	135	7.8	9.5	0	88
25	9.0	2.5	0	110	8.8	7.0	0	90
Sept. 11	7.6	10.0	0	83	7.4	9.0	0	69
22	7.6	12.5	0	91	7.4	9.5	0	100
29	7.3	15.2	0	81	7.2	15.1	0	71
Oct. 8	7.6	11.5	0	84	7.3	11.0	0	73
16	7.5	12.0	0	86	7.4	6.0	0	52
21	7.2	10.0	0	99	7.4	7.0	0	66
28	7.4	7.5	0	70	7.2	9.5	0	81
Nov. 5	7.2	10.0	0	86	7.4	15.0	0	55
13	7.2	7.0	0	54	7.2	10.0	0	68
17	7.2	6.5	0	73	7.2	4.0	0	39
24	7.2	8.0	0	74	7.5	4.5	0	38
Dec. 1	7.2	11.0	0	70	7.4	8.0	0	60
Maximum	9.0	15.2	------	142	8.8	15.1	------	100
Minimum	7.2	2.5	------	14.5	7.2	0	------	17.5

OPERATION OF THE HATCHERY

STOCKING THE BROOD TANKS

The brood stock for stocking the tanks was supplied by Hawaiian Tuna Packers, Ltd. The crew of the sampan *Amberjack* seined the fish on January 10, 1958, from reservoir No. 6, at Ewa, Oahu. The fish were acclimatized to sea water in the bait wells of the sampan and transported to Maui on January 11–12. Some mortalities occurred during the acclimatization and as a result of handling, but about 5,000 fish weighing 1,200 pounds survived. A total of 2,000 adults (500 males and 1,500 females), weighing 625 pounds, were stocked in the two brood tanks, each tank receiving 250 males (0.34 lb. average weight) and 750 females (0.30 lb. average weight). The remainder of the fish were retained to replace stock that died.

In the days that followed, dead fish were removed from the tanks and replaced with a like number of the appropriate sex. Deaths were numerous during the first week after stocking, but were practically zero by the end of the second week. The total mortality from January 13 to 31 was 705 fish (549 females and 156 males). The mortality rate was about the same for the sexes.

The adult fish were stocked in 1958 at a concentration of 1 male per 3.37 square feet of bottom area. Uchida and King (1962) had found that production was favorable in tanks where the area allotted per male was about 3 square feet. Although in their initial experiments Uchida and King used a 2♀ :1♂ sex ratio with successful results, it was anticipated that better production might be obtained by increasing the ratio to 3♀ :1♂, so we used this latter ratio.

Although the area was fenced and posted, vandals entered the hatchery on September 25 and 27, 1958, removing an unknown number of adult fish. As we did not wish to disturb the fish further, we postponed taking a census until December 2–3, 1958, when production had declined. A census on these dates showed that brood-tank A contained 689 females and 216 males, a loss of 61 females and 34 males since stocking. Brood-tank B contained 736 females and 251 males, a loss of 14 females and a gain of 1 male (this apparent gain may have been due to miscount or to recruitment of a juvenile that escaped capture and grew to adulthood).

In later experiments in 1958, Uchida and King found that the best production of fry was observed in tanks with a 3♀ :1♂ ratio and with about 4 square feet of bottom area per male. Therefore, in 1959 we stocked each brood tank with 600 females and 200 males, with each male being allotted 4.21 square feet of bottom area. A census taken on December 7–8, 1959, showed that tank A contained 604 females and 228 males, a gain of 4 females and 28 males. Brood-tank B contained 668 females and 252 males, an increase of 68 females and 62 males. These increases were due, we believe, to recruitment of juveniles that had escaped capture early in the year and had grown to maturity. The males averaged 30.5 centimeters (12 in.) in length and 1.0 pound in weight, while the females averaged 22.9 cm. (9 in.) in length and 0.5 pound in weight when the brood stock was counted in December 1959.

FEEDING SCHEDULES

Adults

In 1958, the brood stock was usually fed twice daily except on Sundays. The fish were fed once every Sunday until June and were not fed on Sundays thereafter. The daily ration for the total brood stock ranged from 5 to 12 pounds, depending on how readily the fish were feeding. An average daily ration of 4 pounds of Purina trout chow (developer) per 1,000 adults seemed to satisfy the needs of the fish during their most productive period. The kinds of feed used in 1958, with the price per pound, are shown in table 9. In January to March, 1958, the adults were fed a millrun-fish meal mixture (4:1 ratio). In April, the feed in one brood tank (B) was changed to rabbit ration (pelletized), a better quality feed. The change in feed did not result in an increase in fry production. The rabbit ration was supplemented in July with Purina trout chow and in August through December 1958 the fish in both brood tanks were given Purina feed.

In 1959, the brood stock was fed twice daily, except on Sundays, from February through October, and once daily from November through December. They were fed once on Sundays until May and were not fed thereafter on Sunday. Their daily ration was 3 to 6 pounds of Purina developer or large fingerling feed. The kinds, costs, and amounts of feed used in 1959 are shown in table 10.

TABLE 9.—*Amount (in pounds) and cost of feeds supplied tilapia brood stocks, 1958*

Month	Fish-meal	Millrun	Clark's crumbles	Middlings	Fresh liver	Rabbit ration	Purina trout chow	Purina small fingerling	Total amount	Total cost
January	17.5	71.3	19.5	76.7					185.0	$12.64
February	26.5	106.0	32.5						165.0	14.08
March	40.6	162.4							203.0	8.12
April	26.8	111.2			1.8	67.0			206.8	10.58
May	27.2	108.8				148.0			284.0	14.32
June	21.0	84.0				105.0			210.0	10.50
July	20.4	81.6				57.0	45.0		204.0	13.35
August	3.0	12.0					165.0		180.0	22.05
September							153.0		153.0	19.89
October							161.0		161.0	20.93
November							120.0	52.0	172.0	22.36
December								178.0	178.0	23.14
Total amount (lb.)	183.0	737.3	52.0	76.7	1.8	377.0	644.0	230.0	2,301.8	
Average cost per pound	$0.08	$0.03	$0.27	$0.05	$0.60	$0.06	$0.13	$0.13		
Total cost	14.64	22.12	14.04	3.84	1.08	22.62	83.72	29.80		191.96

TABLE 10.—*Amount (in pounds) and cost of feeds supplied tilapia brood stocks, 1959*

Month	Purina developer	Purina large fingerling	Total amount	Total cost
March	168.10		168.10	$21.85
April	100.00	34.50	134.50	17.48
May	29.25	88.75	118.00	15.34
June		117.00	117.00	15.21
July		142.50	142.50	18.53
August		163.75	163.75	21.29
September		132.00	132.00	17.16
October		132.00	132.00	17.16
November		96.00	96.00	12.48
December		16.00	16.00	2.08
Total amount (lb.)	297.35	922.50	1,219.85	
Average cost per pound	$0.13	$0.13		
Total cost	38.66	119.92		158.58

The adults generally fed avidly when production of young was low but not when production was high.

Young

The young fish were usually fed three times daily in 1958, except on Sundays, with the amounts varying with the number and age of the young. Our intention was to give the fry all the feed they could consume in order to obtain maximum growth. Toward the end of summer, with about 500,000 young in the tanks, 45 pounds of feed were supplied daily.

Until they were 2–3 weeks of age, the very young fish paid little attention to the feed offered them, feeding principally on green algae obtained from the walls of the tanks. The kinds, amounts, and costs of feed supplied the young fish in 1958 are listed in table 11. Until July, the young fish were fed primarily on Clark's trout feed and a wheat middlings-fish meal mixture (4:1 ratio). Starting in July this was supplemented with Purina trout feed. The use of Clark's feed was discontinued in September.

The young fish were usually fed twice daily in 1959 with rations similar to those in 1958. The very young to 3-week-old fish were fed on either Purina starter or a middlings–fish-meal mixture (4:1 ratio). The 3- to 10-week-old fish were fed on Purina fry feed. The 10-week-old and older fish were fed a mixture of millrun-fish meal (4:1 ratio). The kinds, amount, and cost of various feeds given the young in 1959 are listed in table 12.

We did not attempt to record the amount of feed supplied to the fish in each fry tank because the tanks were too numerous and the fish varied among tanks from newly hatched fry to bait-size fish. At each feeding the fish were given the maximum amount that they would consume, based on past observations. The total weight of feed given the young at each feeding was recorded. With experience gained during the 2 years of operation, we were able to set up a feeding schedule that appeared adequate for favorable growth. The schedule outlined here is suitable for a tank 6.5 × 11 feet containing approximately 6,500 young. The amounts specified should be given 2 or 3 times daily as follows:

First and second weeks, 0.3 ounces per feeding; third week, 0.8 oz.; fourth and fifth weeks, 1.3 oz.; sixth and seventh weeks, 2.5 oz.; eighth week and older, 5.9 oz. per feeding. With three feedings a day, 6 days a week for 12 weeks, 43.3 pounds of feed were required to produce about 18 pounds of bait-size fish, or 2.4 pounds of feed per pound

TABLE 11.—*Amount (in pounds) and cost of feeds supplied tilapia fry, 1958*

Month	Clark's crumbles	Fish-meal	Mid-dlings	Rabbit ration	Beef liver	Fresh skipjack	Purina fry feed	Purina small finger-ling	Purina trout chow	Total amount	Cost
March	0.1	0.3	1.2							1.6	$0.11
April	3.0	.7	3.2	0.3	0.1					7.3	1.10
May	7.6	1.6	6.3	4.3						19.8	2.75
June	33.3	8.3	33.2	3.0						77.8	11.50
July	60.3	38.1	156.2	.3		14.0	68.5			337.4	36.06
August	26.0	109.0	436.0				33.0	156.5		760.5	62.18
September	23.0	181.5	726.0						22.0	952.5	59.89
October		130.8	523.2				61.0	74.0		789.0	54.17
November		82.0	328.0				190.0	76.0		676.0	57.54
December		55.0	230.0				392.0	181.0		858.0	90.39
Total amount (lb.)	153.3	607.3	2,443.3	7.9	0.1	14.0	744.5	487.5	22.0	4,479.9	
Average cost per pound	$0.27	$0.08	$0.05	$0.06	$0.60	Free	$0.13	$0.13	$0.13		
Total cost	41.39	8.58	122.16	.47	.06		96.79	63.38	2.86		375.69

TABLE 12.—*Amount (in pounds) and cost of feeds supplied tilapia fry, 1959*

Month	Mill-run	Wheat mid-dlings	Purina starter	Purina fry	Fish meal	Total amount	Total cost
March	25.65	[1] 225.72				251.37	$12.06
April	147.80	30.69	12.63	71.15		262.27	16.86
May	59.18	48.90	48.90	177.68		334.66	33.68
June		46.20	9.40	560.00		615.60	76.33
July		258.50	75.00	268.00	51.00	652.50	61.59
August		352.00	8.00	280.00	103.00	743.00	63.28
September			9.00	398.00		407.00	52.91
October			7.25	420.00		427.25	55.54
November			5.75	474.00		479.75	62.37
December			1.00	88.00		89.00	11.57
Total weight	232.63	962.01	176.93	2,736.83	154.00	4,262.40	
Average cost per pound	$0.03	$0.05	$0.13	$0.13	$0.08		
Total cost	6.98	48.10	23.00	355.79	12.32		446.19

[1] High quantities fed bait-size fish carried over from 1958.

of bait-size fish. These amounts do not include natural foods occurring in the ponds, such as green algae and mosquito and midge larvae, which were consumed in some quantity by the young fish.

COLLECTING THE FRY

Once production had started, a diligent effort was made each day to remove all the young that could be captured by dipnetting. A sorting device consisting of a large net mounted behind a frame with grating of aluminum tubing, which was to be pulled through the brood tanks, was tried but did not prove feasible. The device was effective in catching young fish but was judged impractical because of the problem of removing the young from the net and from the detritus that was also collected. Since the young schooled near the surface of the water, dipnetting with a square-framed, 20 × 20-inch net "walked" along the walls of the brood tanks was a simple and satisfactory method of collection (fig. 8). The young were transferred from the dipnet to a bucket and then counted and released into the fry tanks. Each fry tank was stocked with about 6,500 young, or 91 young per square foot of surface area. Some effort was made to put fry of the same size into each tank to reduce cannibalism. The few young that escaped the daily dipnetting were removed at intervals of 3 to 4 months when we seined the ends of the brood tanks where the juveniles tended to congregate.

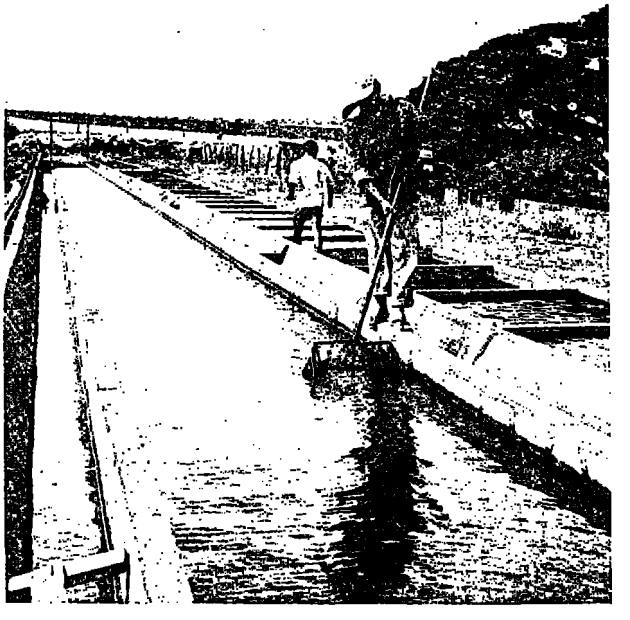

FIGURE 8.—Dipnetting tilapia fry.

TABLE 13.—*Monthly production of young tilapia in brood-tanks A and B, 1958*

Month	Number of young			Number of young per female			Young produced per square foot of area		
	Tank A	Tank B	Total	Tank A [1]	Tank B [2]	Average	Tank A	Tank B	Average
January									
February	698	240	938	0.9	0.3	0.6	0.8	0.3	0.6
March	8,640	11,550	20,190	11.5	15.4	13.4	10.3	13.7	12.0
April	15,626	5,003	20,629	20.8	6.7	13.8	18.6	5.9	12.2
May	21,006	10,162	31,168	28.0	13.5	20.8	24.9	12.1	18.5
June	122,427	40,444	162,871	163.2	53.9	108.6	145.4	48.0	96.7
July	151,570	108,227	259,797	202.1	144.3	173.2	180.0	128.5	154.2
August	119,296	80,453	199,749	159.1	107.3	133.2	141.7	95.5	118.6
September	128,999	39,113	168,112	172.0	52.2	112.1	153.2	46.5	99.8
October	97,053	35,055	132,108	140.9	47.6	94.2	115.3	41.6	78.4
November	23,682	33,657	57,339	34.4	45.7	40.0	28.1	40.0	34.0
December	15,072	6,103	21,175	21.9	8.3	15.1	17.9	7.2	12.6
Total	704,069	370,007	1,074,076	954.8	495.2	725.0	836.2	439.3	637.6

[1] Tank A contained 759 females during the January–September period and 689 females during October–December.
[2] Tank B contained 750 females during January–September period and 736 females during October–December.

PRODUCTION OF YOUNG

The monthly fry production is given in table 13 for 1958 and in table 14 for 1959. These data are based on gross production and do not indicate losses from disease, cannibalism, or other factors. There was marked seasonal variation with the peak production in 1958 occurring in July and in 1959 in May.

There was an important difference in the production of the two brood tanks in 1958 that may have been related to the position of the inlets and drains, the direction of the prevailing winds, and the resultant circulation of the water within the tanks. Tank A, with the drain on the upwind side, was generally cleaner and more productive than tank B, which had the drain on the downwind side. In 1959 a drain was installed on the upwind end of tank B and the water was somewhat cleaner than in the previous year.

Production was higher in 1959 than in 1958 and there was little difference between the two tanks. Factors operating in 1959 which may have contributed to the higher production that year were—

1. Improved drainage in brood-tank B.
2. Larger bottom area (4.21 sq. ft. versus 3.37 in 1958) allotted to each male.
3. Aeration of the brood tanks.
4. Water filtered and recirculated in brood-tank A.
5. Slightly higher water temperatures. Since both brood tanks were heated slightly and there were no control tanks, it is difficult to evaluate the results. We can state, however, that water temperatures rose following installation of the heating cables (figs. 4 and 5) and that production increased over that of the previous year.
6. Increased oxygen content in brood tanks.
7. Higher grade of feed fed adults.

TABLE 14.—*Monthly production of young tilapia in brood-tanks A and B, 1959*

Month	Number of young			Number of young per female [1]			Young produced per square foot of area		
	Tank A	Tank B	Total	Tank A	Tank B	Average	Tank A	Tank B	Average
January									
February	1,706	0	1,706	2.8	0	1.4	2.0	0	1.0
March	7,396	20,280	27,676	12.3	33.8	23.0	8.8	24.1	16.4
April	112,167	138,215	250,382	186.9	230.4	208.6	133.2	164.1	148.7
May	164,671	129,179	293,850	274.5	215.3	244.9	195.6	153.4	174.5
June	96,135	55,851	151,986	160.2	93.1	126.6	114.2	66.3	90.2
July	59,331	64,151	123,482	98.9	106.9	102.9	70.5	76.2	73.4
August	71,929	53,241	125,170	119.9	88.7	104.3	85.4	63.2	74.3
September	116,781	91,493	208,274	194.6	152.5	173.6	138.7	108.7	123.7
October	52,259	11,908	64,167	87.1	19.8	53.4	62.1	14.1	38.1
November	38,471	5,745	44,216	64.1	9.6	36.8	45.7	6.8	26.2
December	2,477	348	2,825	4.1	0.6	2.4	2.9	0.4	1.6
Total	723,323	570,411	1,293,734	1,205.4	950.7	1,077.9	859.1	677.3	768.1

[1] Based on 600 females in each brood tank throughout the year.

8. Better physical condition of brood stock than in 1958, when they were captured and transported from Oahu to Maui.

9. Larger size of brood fish, which may have been responsible for the larger number of young produced per female (Chen, 1953; Vaas and Hofstede, 1952).

In 1958, newly released fry were observed in February, 1 month after the initial stocking of the adults. Production remained at a low level, however, from February to May. Heavy production started in June and continued through October. In 1958, the highest number of young collected in any one day was 29,800 fry on July 8th. The average production per female for the year was 725 fry.

In 1959, production was at a low level in February and March, but remained high from April through September. The largest day's collection of fry in 1959 was 40,877 fry on May 19th. The average production per female for the year was 1,078 fry.

MORTALITY OF YOUNG

Many factors contributed to the loss of young fish. Some of the observed mortalities were due to handling, disease, and to structural failures such as tank leaks. Many sources of attrition such as predation by black-crowned night herons, dragonfly nymphs, and adult tilapia, and cannibalism among the fry themselves, were known to exist but difficult to estimate. Table 15 provides monthly figures for the dead fish that were collected and counted. In 1958, such losses totaled 48,806, or 4.5 percent of the gross production. The unobserved mortalities for 1958 amounted to 82,400,[1] or 7.7 percent of the gross production. The estimated total mortality was 131,200 or 12.2 percent. Losses in 1959 totaled 99,209, or 7.7 percent of the gross production. The unobserved mortalities for 1959 amounted to 71,800, or 5.6 percent, for a total mortality of 171,000, or 13.2 percent.

As far as we could determine, the brood tanks remained disease free in 1958. In 1959, a minor outbreak of the protozoan *Trichodina* caused some loss of very young fry before the infected individuals were removed. In the young fish, the major disease problems resulted from infections of *Trichodina*, which were controlled by treatment with 0.5 p.p.m. copper sulphate or 3 p.p.m. potassium permanganate. A condition diagnosed as acute catarrhal enteritis, as described by Davis (1956), was the cause of high mortality rates in a few of the tanks. Losses from disease were minimized by the fact that each of the 90 fry tanks had an independent water supply and did not drain into any of the other tanks. Except in brood-tank A, none of the water used was recirculated in 1959. This may not have been the most economical use of water, but it did prevent infections from spreading from one tank to another.

On the few occasions in 1958 when the water supply was interrupted by breaks in the line, there were particularly serious outbreaks of disease. Such water shortages did not occur in 1959. Chemical treatment followed by a thorough flushing with fresh water usually brought an end to the losses in 2 or 3 days. Highest mortality rates occurred when the fish were 1 to 3 weeks old. Once past their 4th week, tilapia seemed to be immune to the usual disorders.

Early detection and treatment of disease were necessary to keep losses at a low level. Treatment with 3 p.p.m. potassium permanganate was effective for fish 0–2 weeks old infected with *Trichodina*, and 0.5 p.p.m. copper sulphate was effective for fish 3 weeks old and older. Treatment was applied usually between the hours of 9 a.m. to 3 p.m., when the oxygen content of the water in the fry tanks was highest, so that the young would have an adequate oxygen supply during treatment.

TABLE 15.—*Observed mortalities of young tilapia, by months, 1958 and 1959*

Month	1958		1959	
	Brood tanks	Fry tanks	Brood tanks	Fry tanks
January				
February	221	9		
March	271	4,006	148	[1] 391
April	8	2,317	974	[2] 53,586
May	48	3,004	423	20,186
June	95	323	227	4,577
July	105	6,872	86	471
August	33	4,412	130	2,269
September	124	[3] 15,119	170	2,300
October	26	[4] 8,521	0	6,996
November	26	1,464	422	5,853
December	0	1,802		
Total	957	47,849	2,580	96,629

[1] 233 lost from fry-tank leakage.
[2] 4,170 lost from fry-tank leakage; 35,373 died after treatment with pyridylmercuric acetate.
[3] 6,555 were lost when a hole opened in the bottom of a fry tank, draining the tank.
[4] 5,967 were lost in the same manner as in footnote 3.

[1] Method of calculating this figure explained in section dealing with the production of bait-size fish.

Fish afflicted with the condition diagnosed as acute catarrhal enteritis were supplied with an increased flow of fresh water, since there is no known treatment.

In 1959, each newly filled tank was given a prophylactic treatment of 3 p.p.m. potassium permanganate or 0.5 p.p.m. copper sulphate before the fry were added. This procedure seemed to be effective in checking *Trichodina* outbreaks. Although we have no measure of the effect of wind-blown dust and debris on the disease problem, we believe that the causative organisms of some of the infections could have been introduced through the excessive amounts of road dust that occasionally contaminated the tanks. Early detection of disease was often difficult because of rain or strong winds that prevented our observing the condition of the fish.

DUTIES OF THE HATCHERY OPERATOR

When operated on an experimental basis, the Paia plant required one person full time; on a commercial basis we estimate that the work load would not have been too great for one man half time.

The daily tasks and time required to perform them were as follows:

1. Dipnetting the young—½ hour to 2 hours.
2. Counting the young—½ hour to 3 hours.
3. Feeding adult fish twice a day—¼ hour.
4. Feeding young three times a day—¼ to ½ hour.
5. Removing the dead fish—10 minutes to 3 hours.
6. Checking inflow and drain pipes—¼ to ½ hour.

Some irregularly occurring tasks were as follows:

1. Treating sick fish: weighing chemicals, applying treatment, checking results, flushing out tanks with fresh water—½ hour to 4 hours.
2. Transferring young from fry tanks to holding tanks—2 men ½ day a week during productive season.
3. Cleaning fry tanks—½ day a week.
4. Constructing equipment, mending nets, et cetera—2 hours a week.
5. Measuring oxygen concentrations—1 hour if done once a week.
6. Caring for grounds—1 day every 4 weeks with power mower.
7. Trucking bait-size fish to docksite—truck driver and helper, 1 day a week during productive season.
8. Acclimatizing bait fish—Old method: 1 day a week during productive season. New method: 4 hours a week during productive season.

PRODUCTION OF BAIT-SIZE TILAPIA

1958 PRODUCTION

By the end of December 1958, an estimated 412,530 bait-size (1.5 to 2.5 in.) tilapia, weighing 1,429 pounds (204 buckets[2]), had been removed from the hatchery. Of this amount, 189,237 fish weighing 630 pounds (90 buckets) were delivered to Maui Fisheries and Marine Products, Ltd.; the rest were used in experimental fishing from the Bureau of Commercial Fisheries research vessels *Hugh M. Smith* and *Charles H. Gilbert*. On January 8, 1959, an estimated 146,346 fish weighing 531 pounds (76 buckets) were received aboard the *Smith* and the *Gilbert*. The average individual weight of fish in each of the delivered lots, estimated by subsampling, ranged from 1.17 grams (39 mm. or 1.5 in. length) to 2.18 g. (49 mm. or 1.9 in. length). The overall average weight was 1.59 g. (44 mm. or 1.7 in. length).

If we subtract from the estimated total production (1,074,076) the number of fish delivered (558,876) up to January 8, 1959, and the observed mortality (48,806), we obtain a remainder of 466,394 fish, the theoretical balance on hand. Following the January 8th delivery to the *Smith* and *Gilbert*, 64 fry tanks each containing an estimated 6,000 young fish approaching bait size remained at the Paia plant. This stock of 384,000 fish, barring accident, should equal 190 buckets of bait by the end of February. The difference between 466,394 and 384,000 equals 82,394 or the unobserved losses resulting from cannibalism, predation by night herons and dragonfly nymphs, and from other causes. In terms of buckets, the total production, therefore, amounted to 470 buckets. In terms of production per unit area, the 1958 production was equal to 9,200 pounds (4.6 tons) of fish per acre per year, based on the 280 buckets actually used, or 15,400 pounds (7.7 tons) per acre per year, based on the estimated total production.

[2] One bucket equals 7 pounds of fish.

1959 PRODUCTION

By the end of December 1959, an estimated 767,071 bait-size (1.5 to 2.1 in.) tilapia weighing 2,489 pounds (356 buckets) had been removed from the hatchery. Of this amount 508,364 fish weighing 1,415 pounds (202 buckets) were delivered to Maui Fisheries and Marine Products, Ltd. A few buckets of fish were supplied to the Hawaii Division of Fish and Game for experimental purposes. The rest were used from the *Smith* and *Gilbert*. The average individual weight of fish in each of the delivered lots, estimated by subsampling, ranged from 0.92 g. (37 mm. or 1.5 in. length) to 2.67 g. (52 mm. or 2.1 in. length). The average of all lots was 1.49 g. (43 mm. or 1.7 in. length). Of the total bait delivered, 159,504 fish or 971 pounds were carried over from the 1958 production.

The total production for 1959 was 1,293,734 fry. If we subtract the observed mortalities (99,209) and fish delivered (607,567) from the total production, we have a remainder of 586,958 fish. An estimated 514,900 fry remained in the hatchery as of December 8, 1959. The difference between 586,958 and 514,900 is 72,058 fish, representing the unobserved losses from cannibalism, predation by night herons and dragonfly nymphs, and other causes. In February 1960, 257 buckets of bait should have been available at the hatchery. The total bait delivered during 1959 was 1,517.9 pounds (216.8 buckets), and the production was equal to 7,110 pounds (3.6 tons) per acre per year on an area basis, or 15,600 pounds (7.8 tons) per acre per year based on the total estimated production. Production in numbers of young was higher in 1959 than in 1958, but production in buckets of bait was about the same in the two years, since the average size of the fish was smaller in 1959. The smaller average size in 1959 may have resulted from the less-frequent feeding and greater stocking densities.

There are numerous reports dealing with the pond culture of tilapia. Chen (1953) reported an annual production of 270 pounds per acre in the rice paddies of Taiwan, and Pongsuwana (1956) reported annual productions in excess of 5 tons per acre in Thailand. Swingle (1960) reported annual productions of 2,291 and 9,685 pounds per acre in Alabama from stocking rates of 4,000 and 20,000 fingerlings per acre, respectively, basing the production on 365 growing days a year.

ACCLIMATIZATION TO SEA WATER

The bait-size tilapia were hauled by truck from the Paia hatchery to a docksite area, either to Maalaea Harbor or to Kahului Harbor. Two means were used to transport the fish: (1) 50-gallon drums, each with a carrying capacity of 1 to 1.5 buckets of fish, and (2) a special truck bearing a 500-gallon steel tank having a carrying capacity of about 10 buckets of bait.

The acclimatization to sea water was carried out either in large wooden tanks equipped with running fresh and salt water, located at Maalaea Harbor (fig. 9), or in the bait wells of the sampans and the Bureau of Commercial Fisheries vessels. In each instance, the acclimatization was accomplished in 8 to 12 hours and with little loss of fish, except for one unfortunate experience when an entire lot of 129 pounds (27,000 fish) died. Mortality in this case was probably the result of a combination of factors: the rate of change from fresh water to sea water was too rapid; there was insufficient fresh water available to permit proper acclimatization and the maintenance of suitable oxygen concentrations; the vessel, lying at the dock in Maalaea Harbor and, being held against the dock by the wind, was generally motionless, so there was little circulation of water through holes in the bottom of the bait wells. The loss was regrettable but taught us several things about the requirements and limitations of the fish that must be considered during the acclimatization process.

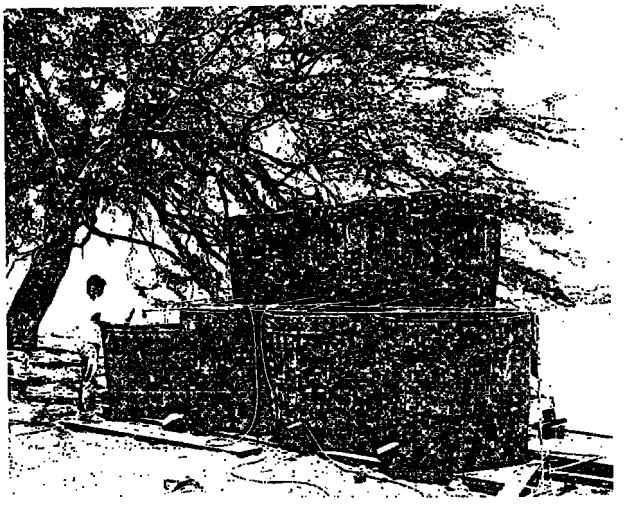

FIGURE 9.—Tilapia acclimatization tanks at Maalaea Harbor, Maui.

In 1959, Maui Fisheries and Marine Products, Ltd., built a concrete and hollow-tile tank, 10 feet × 30 feet × 3 feet deep, at Maalaea Harbor, which was capable of holding about 30 buckets of fish. The fish were acclimatized in this tank by introducing them directly into water with a salinity of approximately 17 °/₀₀ and leaving them at this salinity for at least 12 hours before introducing them into sea water (35 °/₀₀) in the bait wells of the sampans. This method, developed by the Hawaii Division of Fish and Game in 1959 (unpublished data), was easy to follow and usually resulted in few losses. One great advantage was that no one needed to monitor the salinity and regulate continually the flow of salt and fresh water, as was required for the method employed in 1958. The water in the acclimatization tank was aerated by a small compressor, with a few airstones distributed over the bottom of the tank.

UTILIZATION OF BAIT

The results of fishing operations utilizing tilapia produced at the Paia hatchery along with the naturally occurring bait fishes, nehu and iao, are presented in table 16. The amount of bait used was estimated by the fishermen. An observer accompanied the vessels on most of the trips and recorded the catch rates with the different types of baits used.

We calculated an average catch of 49 pounds of skipjack per pound of tilapia used in 1958, as compared with 48 pounds of skipjack per pound of nehu and 68 pounds of skipjack per pound of iao. In 1959, the average catch amounted to 53 pounds of skipjack per pound of tilapia, and 64 pounds of skipjack per pound of nehu. Iao was used on one trip with a catch of 49 pounds of skipjack per pound of iao. Although most of the catches were made using nehu and tilapia alternately, some schools were fished entirely with tilapia with fairly good results. On September 5, 1959, the *Sailfish* caught 5,600 pounds of 20-pound skipjack using 90 pounds of tilapia, or 62.2 pounds of skipjack per pound of tilapia.

These results indicated that tilapia could be used to advantage to supplement the supplies of nehu. The fishermen commented on the fact that tilapia were slow swimmers, and necessitated reducing the speed of the sampans during the chumming and fishing operations. Also, they noted that the tilapia were very hardy and performed well when large wild schools of skipjack were encountered, and that they were particularly good bait for large skipjack of 18 to 25 pounds.

TABLE 16.—*Tilapia as skipjack bait compared with nehu and iao, 1958 and 1959*

Vessel and date	Bait taken aboard (lb.)			Bait used (lb.)			Skipjack catch (lb.)		Catch rate					
									Number of skipjack per pound of bait used			Pounds of skipjack per pound of bait used		
	Nehu	Tilapia	Iao	Nehu	Tilapia	Iao	Total weight	Average weight of fish	Nehu	Tilapia	Iao	Nehu	Tilapia	Iao
1958:														
Amberjack: July 22	117	54		117	32		4,110	8.1	3.8	2.0		30.7	16.2	
Olympic:														
Aug. 25	99	54		99	45		9,000	22.1	3.1	2.2		68.8	48.6	
Aug. 30		72	50		40	45	4,500	17.6		3.0	3.0		53	52
Sept. 4	45	32	72	45	32	54	9,000	14.0	3.2	5.7	6.0	44.4	79.2	83.3
Average									3.4	3.2	4.5	48.0	49.2	67.6
1959:														
Tradewind:														
July 8	36	18		34	2		6,708	12.0	16.5	0.4		198.0	4.8	
July 10	270	27		180	18		9,100	16.0	3.1	0.3		50.0	5.0	
Sooty Tern: July 10	300	60		276	12		18,030	15.0	4.3	0.2		65.0	2.5	
Sailfish:														
July 30	234	108		90	18		5,600	18.3	3.1	1.5		56.7	27.5	
July 31	144	90		144	81		6,943	13.3	3.1	1.0		40.9	13.0	
Buccaneer:														
Aug. 10	324	117		63	14		4,429	25.6	1.4	6.1		37.0	156.2	
Aug. 11	261	104		238	22		10,114	16.8	1.9	6.3		32.5	105.3	
Aug. 12	22	81		22	63		5,120	16.0	2.5	4.2		39.8	67.0	
Sailfish:														
Aug. 27	90	108		90	108		15,000	(1)	(1)	(1)		55.5	92.5	
Sept. 5		90			90		5,600	20.0		3.1			62.2	
Olympic: Sept. 7		90	81		90	81	9,500	22.0		2.3	2.2		50.0	49.4
Average									4.5	2.5	2.2	63.9	53.3	49.4

[1] No records.

SUMMARY OF PRODUCTION COSTS

The major elements in the cost of producing a pound or a bucket of bait-size tilapia in each of the two years of the operation are described in the sections that follow and are summarized in table 17.

TABLE 17.—*Summary of production costs, 1958 and 1959*

Item	1958	1959
Capital improvements	$4,353.24	$900.00
Annual cost, amortized on a 10-year basis	435.32	525.32
Interest on capital investments	261.19	315.19
Operating expenses	1,814.82	2,507.79
Total cost	2,511.33	3,348.30
Number of fry produced	1,074,076	1,293,734
Production of bait-size fish:		
Number of buckets	470	474
Number of pounds	3,290	3,318
Cost per pound	$0.76	$1.01
Cost per 7-pound bucket	$5.34	$7.06

1958 OPERATIONS

An accounting of the major expenses incurred in setting up and operating the plant at Paia during the first year, not including the salary of a biologist, follows.

In addition to the operating expenses incurred in 1958, it was necessary to supply feed and water for approximately 2 months in 1959 to the young fish that were held over from 1958.

Capital improvements:[1]	
Initial renovation of the plant	$2,233.24
Other construction and improvements	1,500.00
Barbed-wire fencing	90.00
Bait-hauling tank	100.00
Bait acclimatization facilities	380.00
Bait-barge acquisition and repair	50.00
Total	4,353.24
Operating expenses:	
1958:	
Feed—for adult fish	$191.96
Feed—for young fish	375.69
Water	557.17
Hauling bait fish to docksite	90.00
Maintenance and care of grounds	150.00
Annual lease on plant area	240.00
Subtotal	1,604.82
1959:	
Feed—for young fish	$60.00
Water—for fry tanks	50.00
Hauling bait fish to docksite	100.00
Subtotal	210.00
Total	1,814.82

[1] Borne by Maui Fisheries and Marine Products, Ltd.

It is customary to amortize the cost of capital improvements over a reasonable period of time. We suggest amortizing the costs over a 10-year period in this instance, rather than charging the full amount against the quantity of bait produced the first year. Also, it is usual business procedure to include in the cost analysis a figure representing income that might be derived from a reasonable interest rate on the capital cost of the original construction; i.e., income which might have been realized had the money been invested. A 6-percent return on the amount of the capital improvements ($4,353.26) would equal $261.19.

Total costs:	
Capital improvements	$435.32
Interest	261.19
Operating expenses:	
Jan.–Dec., 1958	1,604.82
Jan.–Feb., 1959	210.00
Total	2,511.33

The cost therefore, of producing bait in 1958 was $0.76 per pound when based on the total estimated production of 470 buckets and an expense of $2,511.33, or $5.34 per 7-pound bucket.

As mentioned before, there is no allowance in these figures for the salary of the biologist in charge of the plant. If we assume that the plant could be operated on a commercial basis with one man working half time at a salary of approximately $2,000 per year, the total cost would be $4,511.33 and the cost of producing bait would be $9.59 per 7-pound bucket, or $1.37 per pound. These costs are reasonable, but we must consider the fact that most of the concrete structure of the hatchery was already in and that building a new hatchery would have increased the costs much more.

As mentioned before, the skipjack fishermen expressed high approval of the effectiveness of tilapia in catching the larger skipjack. In fishing for these larger skipjack the fishermen preferred using tilapia 5 to 6 cm. (2.0 to 2.4 in.) in length. Young tilapia between 3.8 and 6.4 cm. (1.5 and 2.5 in.) are generally suitable, however, as skipjack bait. A 3.8-cm. fish weighs 1.0 g., whereas a 5.1-cm. (2 in.) fish weighs 2.5 g., and a 6.4-cm. fish weighs 4.4 g. The bait fish delivered by the Paia plant in 1958 averaged 1.59 g. in weight and approximately 4.4 cm. (1.7 in.) in length. Whether tilapia are harvested at 4.4 cm. with approximately 2,285 fish to the bucket, or at 5.1 cm.

with 1,274 per bucket, is an important consideration in calculating the commercial feasibility of such a bait-rearing project. If the growth rate could be increased, the fishermen's preference for the larger size would have less importance to the producer—the cost of holding the fish to the larger size being compensated for by the more rapid rate of growth.

1959 OPERATIONS

The major expenses, not including the salary of the biologist, incurred at the Paia plant in 1959 are listed below.

In addition to the operating expenses incurred in 1959, it was necessary to supply feed and water for approximately 1 month in 1960 to the young fish that were held over in order for them to reach bait size.

Capital improvements: [1]	
Acclimatization tank	$600.00
Filter tank	300.00
Total	900.00
Operating expenses:	
1959:	
Feed—for adult fish	158.57
Feed—for young fish	446.18
Water	786.00
Electricity	417.04
Maintenance and care of grounds	150.00
Annual lease on plant area	240.00
Hauling bait fish to docksite	90.00
Subtotal	2,287.79
1960:	
Feed—for young fish	$60.00
Water	60.00
Hauling bait fish to docksite	100.00
Subtotal	220.00
Total	2,507.79

[1] Borne by Maui Fisheries and Marine Products, Ltd.

It would seem logical to amortize the cost of capital improvements in 1959 over a 10-year period and to charge a 6-percent interest rate on the total capital investment, which is now $5,253.24.

Total costs:	
Capital improvements	$525.32
Interest	315.19
Operating expenses, 1959	2,287.79
Operating expenses, 1960	220.00
Total	3,348.30

The cost of producing bait in 1959 was $1.01 per pound, or $7.06 per 7-pound bucket, when based on the total estimated production of 474 buckets and expenses of $3,348.30. The higher production cost per pound of bait in 1959 than in 1958 was due principally to greater expenditures for water, electricity, and feed.

If we assume that the plant could be operated on a commercial basis with one man working half time at an annual salary of approximately $2,000, the cost of producing bait-size fish then becomes $11.28 per bucket, or $1.61 per pound.

The 2-year operation of the Paia plant was successful with respect to the number of young fish produced per female. It was not judged economically successful, however, principally because the plant was too small. It is our belief that a plant designed on a commercial scale for volume production and with more efficient use of labor could be operated profitably.

APPLICATION OF RESULTS

ESTIMATED COMMERCIAL PRODUCTION COSTS

It is hazardous to project these preliminary data, but it is our opinion that a commercial plant much larger than the Paia hatchery could produce bait-size tilapia at a cost of about $1.00 a pound, which should bring the price of bait within the reach of tuna fishermen.

This projection is based on a plant with 16,000 square feet of brood-tank space and 40,000 square feet of fry-tank space, which is the size of plant that the Hawaii Division of Fish and Game plans to build with an appropriation of $130,000 granted for the purpose by the 30th Territorial Legislature. Such a hatchery could be stocked with 12,000 females and 4,000 males. Using the best production figures from the Paia hatchery, an average of about 1,000 young per female per year obtained in 1959, the total annual production should be about 12,000,000 young. If the fish were delivered as bait at a size when 2,000 constitute a 7-pound bucket, the hatchery should produce 6,000 buckets of bait annually. If the capital improvements were amortized over a period of 10 years, they would be prorated at $13,000 per year.

Operation of the plant would require 2 men working full time, at a cost of about $10,000 a

year for salaries. This estimated labor cost is higher than the estimate given for the Paia hatchery because of the larger scope of the operation. Feed would cost approximately $15,000 annually. Utilities, mostly electricity and water, would cost about $3,000 a year. Another $1,000 would be needed for miscellaneous equipment and for bait-hauling expenses. The annual operating cost would thus be approximately $29,000, with an additional $13,000 for capital improvements, or a total of $42,000. With the anticipated production of 6,000 buckets of bait, the cost per bucket would be $7.00, or $1.00 per pound. Land costs are not included in our estimates since the planned location of the hatchery is on State-owned land.

Brock and Takata (1955) estimated that the break-even value of nehu to the Hawaiian skipjack fishermen was roughly $4.23 per pound at the peak of the season. Therefore, if the cost of commercially produced bait were higher than $4.23, the fishermen would fare better by catching their own bait; and if the cost of a substitute bait were lower they would be better off to buy their bait.

ESTIMATED VALUE TO FISHERMEN

From the estimates of bait-production costs given in the previous section,we can estimate the potential value of tilapia to the commercial tuna fisherman. Hawaiian skipjack vessels ordinarily use 20 to 30 buckets of bait per trip when natural bait is in good supply. Let us assume that a boat purchases 30 buckets of tilapia at a cost of $7.00 a bucket and in 1-day's fishing catches 10,000 pounds of skipjack (as calculated from our average conversion rate in 1958 and 1959) worth $1,000 to the fishermen. If we deduct $210 for the cost of the bait, $15 for the crew's food, $25 for fuel and ice, for a total of $250, we have $750 remaining. The crew's share, or 63 percent, equals $472.50 for the day's operation. Based on an average crew per vessel of 10 men, the day's share for each crew member is $47.25.

We do not visualize that tilapia or any artificial bait substitute will entirely replace the nehu in the Hawaiian skipjack fishery. King and Wilson (1957) have estimated, however, that if the average fishing time for a sampan could be increased from the present 15 days a month to a possible 20 days a month through the use of tilapia or other supplemental bait, the total annual skipjack catch for Hawaii might be increased by 3 million to 4 million pounds. It is probable that the number of fishing days could be increased to well over 25 days a month if the entire bait needs or sufficient supplemental bait were supplied by a large tilapia hatchery. Such an increase in days fished in a month might conceivably increase the total annual skipjack landings for Hawaii by more than 6 million pounds.

CONCLUSIONS AND RECOMMENDATIONS

Location of the Plant

The site was characterized by strong, gusty winds, above average rainfall for the island of Maui, and a high rate of cloud cover. Although the wind aided in circulating the water, it also brought large quantities of dust and debris into the tanks. We concluded that a sheltered area on the drier and warmer leeward side of the island would have provided a more favorable site.

Arrangement of the Plant

The general arrangement was satisfactory but could have been improved in a few respects.

a. Both brood tanks should have been equipped with drains on their upwind end where the detritus collected. (The drains were installed in 1959.)

b. Aeration during the hours of darkness would help keep the oxygen level fairly high. (An aeration system was in operation in 1959.)

c. Fry tanks should have been built with a sump or catch basin to facilitate removal of fry. Considerable time was expended in seining the fish from the tanks, which were difficult to drain.

d. The plant had a ratio of brood-tank area to fry-tank area of 1 : 3.8. A ratio of 1 : 5 would have permitted less crowded conditions within the fry tanks and probably would have induced faster growth in the young fish.

Fish Feed

a. Fish 2 to 3 weeks of age fed well on a middlings–fish meal mixture and Purina starter feed; between 4 weeks and 3 months of age they readily accepted the Purina fry feed and always seemed to be hungry even with three feedings a day. At all ages, they fed on the algae in the tanks.

b. The particle size of the Purina small fingerling feed seemed to be too large for the 2- to 3-month-old tilapia.

c. The adults preferred Purina trout chow (developer), but appeared to remain in satisfactory condition on a millrun–fish meal mixture (4:1

ratio), or on rabbit ration. The adults fed extensively on the filamentous algae growing on the tank walls.

Fry Growth

a. Each of the fry tanks, which had an area of 71.5 sq. ft., yielded about 3 buckets of bait-size fish in 10–12 weeks when stocked with 5,000 to 7,000 fry.

b. We predict that by providing more space per fish, bait-size fish could be produced in 8 weeks.

Production Costs

a. In the first year of operation (1958), the Paia plant produced approximately 470 buckets of bait-size tilapia at a cost of $0.76 per pound, not including the salary of the supervising scientist. If the plant had been operated on a commercial basis, employing one caretaker half-time, we estimate that the total production cost including labor would have been $1.37 per pound.

b. In the second year of operation (1959), the Paia plant produced approximately 474 buckets of bait-size tilapia at a cost of $1.01 per pound, not including the salary of the supervising scientist. If the plant had been operated on a commercial scale, employing one caretaker half-time, we estimate that the total cost including labor would have been $1.61 per pound. The higher average cost in 1959 was due to larger expenditures for water, electricity, and fish food than in 1958.

c. Better plant design with a proportionately greater amount of fry-tank space would have resulted, we believe, in faster growth of the young fish and, therefore, lower production costs.

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APPENDIX

POND CULTURE OF TILAPIA

In 1956 and 1957, personnel of Hawaiian Tuna Packers, Ltd., and of the Bureau of Commercial Fisheries seined bait-size tilapia from two ponds adjacent to Honolulu and used the fish in experimental live-bait fishing for skipjack. One of the ponds, Kuliouou Pond, is a naturally occurring body of brackish water; the other, Ewa Pond No. 6, is an artificially created body of fresh water.

The number of adult tilapia in each pond was estimated from the frequency of capture of finclipped fish (appendix table 1). The quantity of young fish removed from each location in relation to the number of adults and size of the area provide some comparison with the production obtained in the brood tanks at the Paia, Maui, hatchery.

The natural food supply of the tilapia was supplemented in each pond during the study period by a daily feeding of rice bran.

Kuliouou Pond

This brackish-water pond is about 3 acres in extent and has a salinity of about 20 °/₀₀. King and Wilson (1957) obtained 105 pounds of bait-size tilapia from this pond on one seining trip in 1956. In 1957 a more detailed study of the pond was initiated to obtain an estimate of the size of the brood stock and the extent of production of young fish. Appendix table 1 gives the population estimates and summary of the fish removed.

Kuliouou Pond failed to yield any bait-size tilapia in four seining trips in 1957. The catch made on three of these trips is shown in appendix table 1. The adult population, estimated at the end of the experiment, was about 1,400 pounds. On each occasion, nests were observed on the bottom of the pond and evidence of spawning (females carrying ova or young in the mouth) was noted. The pond contained a large number of predators, which with the cannibalistic traits of the tilapia, practically eliminated all young fish.

Ewa Pond No. 6

This fresh-water pond, with few predators other than crayfish, was a much better source of bait-size tilapia. During 1956, King and Wilson (1957) obtained 436 pounds of bait-size tilapia in five seining trips to this pond. Nine seining trips in 1957 yielded 882 pounds of bait-size fish. The catch obtained on six of these trips is given in appendix table 1. The average catch of bait per trip was slightly higher in 1957 than in 1956.

Using the mark (fin clipping) and recovery method, the adult tilapia population in Ewa Pond No. 6 was estimated to be about 6,000 pounds when sampled in April and again in July 1957. The annual production of bait-size fish was, therefore, approximately 147 pounds per 1,000 pounds of adults. In the Paia, Maui, hatchery (this report) a brood stock weighing about 800 pounds produced about 3,300 pounds of bait-size fish per year, or 4,125 pounds of bait per 1,000 pounds of adults.

Although the adult tilapia population in this pond was fed rice bran daily, cannibalism probably reduced the amount of bait available. As reported by King and Wilson (1957), it was difficult to harvest the crop of young fish. Seining requires a rather large crew and is not efficient because of the tendency of the fish to burrow in the mud or hide in the spawning beds. Therefore, we believe that, in all respects, the large-scale production of bait-size tilapia is more practicable by the tank-culture method than by the uncontrolled pond-culture method.

APPENDIX TABLE 1.—*Seining results and population estimates, Kuliouou and Ewa Ponds, 1957*

Item	Kuliouou Pond			Ewa Pond No. 6					
	Mar. 26	May 1	July 10	Mar. 1	Mar. 8	Apr. 18	May 10	July 11	July 12
Number of hauls	10	10	6	1	1	2	5	4	4
Bait-size fish caught (lb.)[1]				6		83	56	106	107
Small to medium fish:[2]									
Caught and removed (lb.)	129	347.5	414	27	81				
Caught and returned (lb.)					138	188			126
Unmarked large fish:[3]									
Caught and removed (lb.)				741	[4] 1,184	300	308	38	177
Caught and returned (lb.)		62.5	66.5	[5] 1,202		412			355
Recovery and return of marked medium and large fish:[6]									
Number of males	18	50	43	124	408	502	[7]	[7]	189
Number of females	15	167	113	95	738	268	[7]	[7]	148
Total weight (lb.)	7	48	49.5	48	296	226			159
Estimated adult population (lb.)	[8] 1,081	1,360	1,384	9,188	7,781	5,910			6,189
Total, less adults removed (lb.)				8,447	6,597	5,610			6,012
95-percent confidence limits:[9]									
l_1 (lb.)	305	1,115	1,115	6,703	7,029	5,287			5,417
l_2 (lb.)	1,440	1,790	1,737	12,172	8,634	6,634			7,109

[1] Less than 3 inches long.
[2] 3 to 8 inches long.
[3] Greater than 8 inches.
[4] Large females, totaling 464 pounds, were marked and transferred to the Kuliouou Pond from this haul.
[5] Captured unmarked; marked and returned.
[6] Greater than 6 inches.
[7] Catch not examined for marked fish.
[8] Including 464 pounds of fish (large females) added March 8 from Ewa Pond No. 6.
[9] Following Chapman (1948).

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