A Commercial Tilapia, *Tilapia mossambica*, Hatchery for Hawaiian Skipjack Tuna, *Katsuwonus pelamis*, Fishery—Cost Analysis and Problematical Study

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ABSTRACT

The Hawaiian skipjack tuna fisherman spends a good part of his time catching nehu, *Stolephorus purpureus*, for bait instead of fishing. This paper considers pond-raised tilapia, *Tilapia mossambica*, as a possible alternative bait, and sets forth information about a commercial tilapia production plant. If the fishermen purchased tilapia and fished full time, their bait would cost less than it does now, since the current break-even cost to the fisherman of a bucket of nehu is determined to be $30.12, while the highest cost estimate for pond-reared tilapia is $17.56.

The catch rates for tuna when using nehu and tilapia as bait were studied, and found to be comparable. Tilapia still need extensive trials as a bait species, however, and tilapia data need further scrutiny.

Tilapia characteristics, both favorable and unfavorable, are discussed and should offer some insight into the problems and advantages of raising tilapia. The possibility of sharing the tilapia tanks with a compatible, marketable species, and thereby helping to defray expenses, are also discussed.

Fish diseases contracted during three different baitfish rearing studies are reviewed, along with their treatments.

INTRODUCTION

This paper sets forth information about a commercial tilapia, *Tilapia mossambica*, production plant, as far as what must be known and considered prior to the actual investment of cash. I investigated this subject as though this tilapia plant were being directed primarily to furnish tilapia for the local Hawaiian skipjack tuna, *Katsuwonus pelamis*, industry, although at the end of this paper I discuss possible alternative markets for tilapia and alternate uses of the production plant.

I began by studying the economic feasibility of such a production plant. Obviously, the figures used here will not apply in the future because of expected changes in price factors, but they provide a basis from which any interested individual or firm can derive information needed in considering such a commercial enterprise. I also discuss differences between the currently used baitfish, nehu, *Stolephorus purpureus*, and tilapia, and examine their relative efficiencies as skipjack tuna live bait.

I discuss the type of tank construction which has been used in the past and pointed out ways to facilitate such a plant's operation.

BACKGROUND

The Hawaiian skipjack tuna fishery is a live-bait fishery with an average annual ex-vessel value in excess of $2 million. Annual landings average over 4 million kg (9 million lb), but fluctuate between 2 and 7 million kg (5 and 16 million lb). This fluctuation is primarily due to:

1) availability of bait,
2) fragility of the bait, and
3) abundance and availability of the skipjack tuna.[2]

A possible solution to the problem of obtaining an adequate and dependable supply of baitfish would be for the fishermen to purchase bait, and to replace the time spent fishing for it ("baiting time") with time devoted entirely to fishing for aku ("fishing time"). This additional fishing time could increase the annual catch by as much as 66% and provide an increase in ex-vessel value of the catch by $1.9 million. This increase could occur with the existing fleet. Any growth of the fleet would result in an accompanying increase in ex-vessel value, since the skipjack tuna is underutilized (see footnote 2).

The problem then, is to estimate the indirect cost that the fisherman is incurring and the amount of skipjack tuna he is not catching because of the time he is spending baiting. This will give the estimated maximum cost per bucket that the fisherman should be willing to pay for bait. Obviously, this assumes that he will buy bait offered at a price that is less than the cost he is incurring by catching the bait himself. Past experience has shown this not to be the case. In the future, however, increasing

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[2]U.S. National Marine Fisheries Service. 1973. The tuna baitfish problem of Hawaii—an assessment and development of an action program. Unpubl. rep. prepared by Staff, Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812, 33 p.

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pressure may be exerted upon the fisherman to use his time more efficiently, abandoning the less efficient "traditional" ways that have hindered expansion of the commercial aku industry. This pressure could come from:

1) changing fleet composition, with more modern vessels in the *Anela*[3] class being added, permitting longer trips and travel to better fishing grounds during the off-season (October-April) and, at the same time, increasing the demand for live bait; and
2) increased world demand for high protein foods arising from a rapidly increasing population.

It is to the advantage of this study that the *Anela* has worked with different types of baitfish. This could serve to encourage other fishermen to use species other than the nehu.

One additional point is that the crew size could be reduced without the need for added crew members to bait (see footnote 2).

I have employed the approach used by Shang and Iversen (1971) to determine the indirect cost of baitfish to the fishermen, relying heavily upon Hida et al. (1962) for their statistics. Previously unpublished data gathered by the State Fish and Game Division at the Honolulu Bait Station (HBS) were used in a present-day cost estimate for a commercial tilapia production facility.

AN ESTIMATE OF THE VALUE OF NEHU

A good cost estimate at today's market prices is of prime importance in considering a commercial tilapia production plant. The cost estimate obtained in this paper is derived from prices effective as of 1 January 1974.

To determine the cost of nehu, the same problems present themselves here as they did to Shang and Iversen (1971), those of a vertically integrated system for fishing. Since no market exists for bait, the cost of nehu has been determined indirectly.

I have described an operation similar to that set forth in Shang and Iversen (1971) with 1973 prices for fuel, ice, and total catch. Because final figures are not yet available for the total days fished and days baited, certain assumptions must be made. Using Shang and Iversen's table 2, but with the new prices substituted:

Cost of Fishing and Baiting Per Trip

	Fishing	Baiting
Hours of operation[a]	14	3-h day baiting 5-h traveling
Fuel consumption (gal/h)	12.5	5 gal/h during baiting 12.5 gal/h during traveling
Price of fuel per gallon	\$ 0.215	\$ 0.215
Price of ice	\$17.50	—
Total cost[b]	\$55.12[c]	\$16.66[d]

a. Fishing: 10-h scouting-fishing and 4-h traveling time (both ways).
Baiting: 5-h traveling—about 2 h to Pearl Harbor, 8 h to Kaneohe Bay (both ways).
b. Baiting trip uses less time than fishing trip and allows for more leisure time. The value of leisure time of fishermen is not incorporated in the calculation.
c. (14 × 12.5 × \$0.215) + \$17.50 = \$55.12.
d. (3 × 5 × \$0.215) + (5 × 12.5 × \$0.215) = \$16.66.

[3]The *Anela*, a 26.6-m steel vessel, joined the Hawaiian skipjack tuna fishing fleet in December 1971. Unlike the remainder of the skipjack tuna fleet (about 12 vessels), which consists of boats 17.8 to 24.5 m long with a bait-carrying capacity of only about 35 buckets, the *Anela* is capable of carrying 130 buckets. The *Anela* also has greater fish-carrying capacity and greater range, and represents a new look in the Hawaiian skipjack tuna fishery.

This shows that a fishing trip costs \$38.46 more than a baiting trip. This must be taken into account when one is talking of increasing fishing time and reducing baiting time.

Referring to Table 1 we can see that the total skipjack tuna catch (in metric tons) did not vary much between 1972 and 1973. Ths actual day-baiting effort and actual days fished were assumed to remain relatively constant for these 2 yr, since the 1973 data for these two areas were not yet available. Shown are the effects of reductions in baiting effort by the amounts of 25%, 50%, 75%, and 100%.

Table 2 shows the number of buckets of nehu caught during day and night baiting. Since the number of buckets of bait caught in 1971 and 1972 did not fluctuate appreciably, an average for these 2 yr was used to estimate the number of buckets of bait caught in 1973.

38,786 buckets
36,713 buckets
75,499 buckets

$$\frac{75{,}499 \text{ buckets}}{2} = 37{,}748 \text{ buckets of bait}$$

Using Shang and Iversen's (1971) formulas:

$$C_0 = \left(\frac{D_b}{D_f}\right)V - (D_b \cdot C_d) \text{ and}$$

$$B_t = B_0 + B_a$$

$$\text{where } B_a = \frac{Q_a}{Q_b} = Q_a \cdot \left(\frac{B_0}{Q_t}\right)$$

and taking the values from Tables 1 and 2, the net opportunity costs (C_0) and the total amount of bait required (B^t) (in buckets) were obtained. Dividing C_0 by B_t gives the break-even price of nehu.

$$C_0 = \$1{,}974{,}673{,}698$$
$$B_t = 65{,}671 \text{ buckets.}$$

The break-even price is \$30.12 per bucket of bait. (See p. 145, for calculations.)

Table 1.—The actual and projected catch and value of skipjack tuna derived by reducing day-baiting effort by 25%, 50%, 75%, and 100%, 1965-72.

Year	Actual day-baiting effort	Actual days fished	Skipjack catch	Value	Catch per day fished	Price per ton	Reduction in day baiting	Reduction in day-baiting effort	Projected days fished	Projected skipjack catch	Projected value	Increase in catch	Increase in value
	No. of days	*No. of days*	*Metric ton*	*Dollar*	*Metric ton*	*Dollar*	*Percent*	*No. of days*	*No. of days*	*Metric ton*	*Dollar*	*Percent*	*Dollar*
1965	838	2,400	7,328.96	2,013,861	3.05	274.78	25	210	2,610	7,960.50	2,187,386	9	175,525
1966	781	2,086	4,256.82	1,403,623	2.04	329.74	25	195	2,281	4,653.24	1,534,359	9	130,736
1967	736	2,010	3,646.80	1,263,116	1.81	346.36	25	184	2,194	3,971.14	1,375,444	9	112,328
1968	1,055	2,177	4,227.41	1,539,617	1.94	364.20	25	264	2,441	4,735.54	1,724,684	12	185,067
1969	864	1,743	2,704.94	1,245,204	1.55	460.34	25	216	1,959	3,036.45	1,397,799	12	152,595
1970	1,017	1,894	3,334.46	1,496,919	1.76	448.92	25	254	2,148	3,780.48	1,697,133	13	200,214
1971	1,334	2,013	6,051.39	2,752,710	3.01	454.89	25	334	2,347	7,064.47	3,213,557	17	460,847
1972	1,187	1,882	4,952.12	2,949,372	2.63	595.58	25	297	2,179	5,730.77	3,413,132	16	463,760
1973	1,187	1,882	4,877.00	3,203,246	2.59	656.84	25	297	2,179	5,643.61	3,706,949	16	503,540
1965	838	2,400	7,328.96	2,013,861	3.05	274.78	50	419	2,819	8,597.95	2,362,545	17	348,684
1966	781	2,086	4,256.82	1,403,623	2.04	329.74	50	390	2,476	5,051.04	1,665,530	19	261,907
1967	736	2,010	3,646.80	1,263,116	1.81	346.36	50	368	2,378	4,304.18	1,490,796	18	227,680
1968	1,055	2,177	4,227.41	1,539,617	1.94	364.20	50	528	2,705	5,247.70	1,911,212	24	371,595
1969	864	1,743	2,704.94	1,245,204	1.55	460.34	50	432	2,175	3,371.25	1,551,921	25	306,717
1970	1,017	1,894	3,334.46	1,496,919	1.76	448.92	50	508	2,402	4,227.52	1,897,818	27	400,899
1971	1,334	2,013	6,051.39	2,752,710	3.01	454.89	50	667	2,680	8,066.80	3,669,507	33	916,797
1972	1,187	1,882	4,952.12	2,949,372	2.63	595.58	50	594	2,476	6,511.88	3,878,345	31	928,973
1973	1,187	1,882	4,877.00	3,203,246	2.59	656.84	50	594	2,476	6,412.84	4,212,209	32	1,008,801
1965	838	2,400	7,328.96	2,013,861	3.05	274.78	75	628	3,028	9,235.40	2,537,703	26	523,842
1966	781	2,086	4,256.82	1,403,623	2.04	329.74	75	586	2,672	5,450.88	1,797,373	28	393,750
1967	736	2,010	3,646.80	1,263,116	1.81	346.36	75	552	2,562	4,637.22	1,688,876	27	425,760
1968	1,055	2,177	4,227.41	1,539,617	1.94	364.20	75	791	2,967	5,755.98	2,096,328	36	556,711
1969	864	1,743	2,704.94	1,245,204	1.55	460.34	75	648	2,391	3,706.05	1,706,043	37	460,839
1970	1,017	1,894	3,334.46	1,496,919	1.76	448.92	75	763	2,657	4,676.32	2,099,294	40	602,375
1971	1,334	2,013	6,051.39	2,752,710	3.01	454.89	75	1,000	3,013	9,069.13	4,125,456	50	1,372,746
1972	1,187	1,882	4,952.12	2,949,372	2.63	595.58	75	890	2,772	7,290.36	4,341,993	47	1,392,621
1973	1,187	1,882	4,877.00	3,203,246	2.59	656.84	75	890	2,772	7,179.48	4,715,770	47	1,512,361
1965	838	2,400	7,328.96	2,013,861	3.05	274.78	100	838	3,238	9,875.90	2,713,700	35	699,839
1966	781	2,086	4,256.82	1,403,623	2.04	329.74	100	781	2,867	5,848.68	1,928,544	37	524,921
1967	736	2,010	3,646.80	1,263,116	1.81	346.36	100	736	2,746	4,970.26	1,721,499	36	458,383
1968	1,055	2,177	4,227.41	1,539,617	1.94	364.20	100	1,055	3,232	6,270.08	2,283,563	48	743,946
1969	864	1,743	2,704.94	1,245,204	1.55	460.34	100	864	2,607	4,040.85	1,860,165	49	614,961
1970	1,017	1,894	3,334.46	1,496,919	1.76	448.92	100	1,017	2,911	5,123.36	2,299,979	54	803,060
1971	1,334	2,013	6,051.39	2,752,710	3.01	454.89	100	1,334	3,347	10,074.47	4,582,776	66	1,830,066
1972	1,187	1,882	4,952.12	2,949,372	2.63	595.58	100	1,187	3,069	8,071.47	4,807,206	63	1,857,834
1973	1,187	1,882	4,877.00	3,203,246	2.59	656.84	100	1,187	3,069	7,948.71	5,221,031	64	2,041,268

Table 2.—Catch, baiting effort, and catch per effort in the fishery for nehu in Hawaiian waters, 1965-72. Percentages of the catch and the effort expended, by day and night baiting operations, are given in parentheses. (Note: The total catch from both day- and night-baiting operations for each year is not the same as that shown in Table 1 because some catch reports failed to designate when the catches were made.) (U.S. NMFS, 1973, see text footnote 2.)

	Catch		Baiting effort		Catch per effort	
Year	Day	Night	Day	Night	Day	Night
	Buckets	*Buckets*			*Buckets*	*Buckets*
1965	19,972 (58)	14,251 (42)	838 (37)	1,424 (63)	23.8	10.0
1966	20,696 (67)	10,242 (33)	781 (44)	1,011 (56)	26.5	10.1
1967	22,336 (71)	9,187 (29)	736 (45)	913 (55)	30.4	10.1
1968	30,148 (86)	4,911 (14)	1,055 (66)	544 (34)	28.6	9.0
1969	25,535 (86)	4,164 (14)	864 (70)	374 (30)	29.6	11.1
1970	30,332 (92)	2,724 (8)	1,017 (78)	290 (22)	29.8	9.4
1971	38,786 (93)	2,776 (7)	1,334 (82)	288 (18)	29.1	9.6
1972	36,713 (94)	2,187 (6)	1,187 (85)	206 (15)	30.9	10.6

Average for 1971 and 1972 = 37,748 + 2,482 = 40,230 buckets = B

$$Q_b = \frac{(4{,}877 \text{ tons of tuna caught 1973})\ (2{,}204.6 \text{ lb/t})}{40{,}230 \text{ buckets}}$$

$$= \frac{10{,}751{,}129 \text{ lb}}{40{,}230} = 267 \text{ lb of tuna/bucket of bait.}$$

This is the price that the fisherman indirectly pays per bucket of baitfish caught. If a baitfish could be offered at a price less than this, the fisherman should, in principle, be willing to buy it since it would be more economical to do so than to catch his own.

COST ESTIMATE FOR CONSTRUCTION OF A COMMERCIAL TILAPIA PRODUCTION PLANT

HBS was run by the State Division of Fish and Game. Construction was finished in March 1962 and rearing of tilapia commenced immediately thereafter. Termination of this pilot project occurred in July 1965 because of the lack of demand by the commercial fisherman in spite of a plentiful supply of skipjack tuna that year.

The total construction costs (1962 prices) for the 10 brood tank, 44 fry-holding tank facility, and a small residence are shown below.

CONSTRUCTION

A.	Contract work items		$119,070.00
B.	Design engineering		
	1. Field survey	—	
	2. Subsurface inspection	—	
	3. Office engineering	$8,248.08	
	4. Consultant services	350.00	
	5. Blueprinting	263.17	
	6. Miscellaneous	132.70	
	Subtotal		8,993.95
C.	Construction engineering		
	1. Field survey	—	
	2. Material	113.44	
	3. Office engineering	—	
	4. Inspection	1,607.09	
	5. Miscellaneous	5.98	
	Subtotal		1,726.51
Total construction costs			$129,790.46

(Source: State Division of Fish and Game.)

As noted in the above figures, there were several areas which were completed at no cost to HBS, but which would have to be taken into account in the construction of such a plant by a private firm or individual. Consequently, a rounded figure of $130,000 is probably somewhat low.

HBS found after some time that this plant should have had an additional 16 fry tanks to handle the fry properly. This would have made a total of 10 brood tanks and 60 fry tanks. Assuming no difference between the cost of a brood and a fry tank, this would have increased construction costs by 23%. Since the $130,000 figure includes the residence, I used section A as the construction cost of the tanks, rounding this figure to $120,000.

$$\frac{(10 + 44) \text{ tanks}}{(10 + 60) \text{ tanks}} = 0.77 \text{ or } 77\% \text{ of the ideal facility actually constructed}$$

$$(\$120{,}000)/\ 77\% = \$155{,}844 \text{ would have been the cost of the ideal facility.}$$

Consequently, the construction cost for the complete 10 brood and 60 fry tank facility would have been approximately $166,000.

The increase in construction costs between 1962 and January 1974 was 64.4%.

$$(164.4\%)\ (\$166{,}000) = \$272.904.$$

The figure, therefore, for such a facility built as of 1 January 1974, would be approximately $273,000.

A commercial tilapia production plant requires about 2 acres of land. At $3.00/sq ft, this would cost $261,360, and land cost plus construction cost would total $534,360 (Tables 3, 4).

Table 3.—Total annual expense incurred raising tilapia on chicken feed; cost per bucket of bait-sized tilapia.

Total production and operating expenses (chicken feed)	$46,585.00	
Total construction and land costs (@ $3.00/sq ft) (2 acres)		$534,360.00
Total + 10% interest on construction and land costs (payable in 12 yr)	49,047.00	588,566.00
Annual total	$95,632.00	
Total fry production in pounds	51,082	
Cost per pound of bait (no profit)	1.87	
Cost per bucket (@ 7 lb/bucket)	13.09	
Cost per bucket (@ 10% profit)	14.40	
Cost per bucket (@ 20% profit)	15.71	

Table 4.—Total annual expense incurred raising tilapia on trout feed; cost per bucket of bait-sized tilapia.

Total production and operating expenses (trout feed)	$57,585.00	
Total construction and land costs (@ $3.00/sq ft) (2 acres)		$534,360.00
Total + 10% interest on construction and land costs (payable in 12 yr)	49,047.00	588,566.00
Annual total	$106,632.00	
Total fry production in pounds	51,082	
Cost per pound of bait (no profit)	2.09	
Cost per bucket (@ 7 lb/bucket)	14.63	
Cost per bucket (@ 10% profit)	16.09	
Cost per bucket (@ 20% profit)	17.56	

OPERATING EXPENSES

Utility Costs

Electricity.—HBS paid an average of $375 per month for power. This would cover only 77% of the electricity costs of a 70-tank facility.

$$(\$375)/77\% = \$487.01.$$

The cost per kilowatt hour in 1962 was $0.03125.

$$\frac{\$487.01}{\$0.03125} \simeq 15{,}600 \text{ kwh/month.}$$

The cost per kilowatt hour for 1 January 1974 was $0.03351.

$$(\$0.03351)\ (15{,}600 \text{ kwh}) \simeq \$523.00.$$

Water.—The maximum rate of water usage at HBS was 40 gal/min (Table 5). Again (40 gal/min)/77% = 51.94 gal/min for the ideal case. This volume of water requires a code 06 m, with a monthly base charge at January 1974 rates of $7.50 (Board of Water Supply, Water Service Rate Schedule, effective 23 December 1970).

The average number of gallons of freshwater used per month would be 1,112,879 gal (Table 5) with the 23% increase included or 2,225,758 gal bimonthly. Bimonthly rates apply with a code 06 m.

Table 5.—Quantity of water used during one year of raising tilapia at Honolulu Bait Station.

Month	Gallons of fresh water
January	84,000
February	21,000
March	105,000
April	735,000
May	1,344,000
June	1,743,000
July	1,491,000
August	812,000
September	1,407,000
October	1,218,000
November	987,000
December	336,000
Total	10,283,000

$$\frac{10{,}283{,}000}{(12)\ (77\%)} = 1{,}112{,}879 \text{ gal/mo}$$

Using the maximum amount of water used in June, we can calculate the number of gallons per day and hour and minute:

$$\frac{1{,}743 \text{ gal/mo}}{30 \text{ days}} = 58{,}100 \text{ gal/day}$$

$$\frac{58{,}100 \text{ gal/day}}{24 \text{ h/day}} = 2{,}400 \text{ gal/h}$$

$$\frac{2{,}400 \text{ gal/h}}{60 \text{ min/h}} = 40 \text{ gal/min.}$$

First 100,000 gal @ $0.37/1,000 gal	=	$ 37.00
Next 700,000 gal @ $0.30/1,000 gal	=	210.00
Next 2,000,000 gal @ $0.22/1,000 gal for 1,425,758 gal	≃	314.00
Total bimonthly water costs		$560.00

Sewer charges.—Although there are no sewer charges at this time, I feel that they should be included since they will probably have to be taken into consideration for any future plant operation. Proposed charges are substantial: $0.40/1,000 gal of freshwater used. For 1,112,879 gal/mo (Table 6), the cost would be approximately $445/mo.

Table 6.—Monthly and annual total operating expenses of tilapia rearing facility.

Operating expenses	Monthly	Annual
Utility costs:		
Electricity	$ 523.00	$ 6,276.00
Water	287.50	3,450.00
Sewer charges	445.00	5,340.00
Labor	2,125.00	25,500.00
Maintenance	68.25	819.00
Miscellaneous	100.00	1,200.00
Total	$3,548.75	$42,585.00

Labor

A facility such as this would require at least three persons for maintenance and operation. They would have the responsibilities of cleaning the tanks, handling the paper work, feeding the tilapia, and supervising the loading of the bait aboard fishing vessels. The annual wages of two employees with a GS-2 level and a supervisor with a GS-7 level would give a fairly accurate salary assessment. Current salaries run:

2 GS-2 @ $6,800	=	$13,600 annually
1 GS-7	=	11,900 annually
Total		$25,500 annually

Maintenance and Repair

Cost of maintenance and repair should run approximately 6% of the total construction cost of $273,000. Prorated over a 20-yr period, this equals $819/yr.

Miscellaneous Expenses

Approximately $1,200 a year should cover such items as office supplies and equipment. See Table 6 for total operating expenses.

PRODUCTION AND PRODUCTION COSTS

Brackish water breeding at HBS resulted in a threefold increase over that of the freshwater control. HBS estimates (the numbers were not as carefully controlled as the Hida et al. project) agreed closely with the Hida et al. (1962) report. The production at Paia, Maui, was 1,033 bait-size fish per female per year (Hida et al. 1962). Production with brackish water would have been 3 × 1,033 = 3,099 fry. With 3,000 females, the estimated annual production at HBS would have been 3,000 × 3,099 = 9,297,000 bait-size fish. With 182 bait-size fish equal to 1 lb (Brock and Takata 1955), the production for such a facility would be:

$$\frac{9,297,000}{182} = 51,082 \text{ lb of baitfish per year}$$

and

$$\frac{51,082 \text{ lb}}{7 \text{ lb/bucket}} = 7,297 \text{ buckets/yr.}$$

Feed requirements would run about 50,000 lb/yr. Chicken feed is currently about $0.08/lb and trout feed is approximately $0.30/lb. This gives:

Chicken feed = $4,000 annually or $334/mo
Trout feed = $15,000 annually or $1,250/mo.

The above data are given in Tables 3 and 4 and show the cost per bucket at 10% and 20% profits with these two types of feed. Since three persons could also operate a 20/120 plant, the cost per bucket should remain the same even after doubling this 70-tank facility. The price may even decrease. Depending upon the finances of the individual or firm, then, the size of the tilapia plant could theoretically be expanded to fill the entire fleet's live-bait needs, though I presently regard tilapia as only a supplemental baitfish.

Using the figures from Table 2 to obtain the number of buckets of bait caught, and my calculations of tilapia production, it is seen that this 10/60 commercial plant would provide 19% of the total day baitfish requirement for the present skipjack tuna fleet. If this plant were increased in size and production to, say, 25% of the total bait needs of the fleet, the projected value of its production can be seen in Table 1.

Effectiveness of Tilapia as Baitfish

I have so far assumed that tilapia would be as acceptable to the skipjack tuna fisherman as the currently used live bait, nehu. There are several points overlooked by such an assumption. First, the number of pounds of skipjack tuna caught per pound of bait used might differ between tilapia and nehu. Secondly, tilapia exhibit different swimming characteristics from nehu. Thirdly, the hooks currently used are shiny and somewhat similar in appearance to nehu; tilapia are darker in coloration and present a greater contrast to the hooks than do nehu.

The total mortality of nehu in the baitwells of the Hawaiian skipjack tuna fleet has been calculated by Yoshida et al. (1977) and found to average 21.7% from 1960 through 1972. For the period from 1954 through 1972 (Table 7), I obtained a mean value of 50.25 lb of tuna caught per pound of nehu used (see Calculations, p. 145). Nehu may be more efficient than this during the peak fishing season (May-September) and less so during the other months.

For comparison, I took information from all the literature which mentioned use of tilapia as skipjack tuna bait (Table 8). I converted the number of skipjack tuna taken with tilapia into pounds, using 18 lb as the average weight for tuna caught between May and September (King and Wilson 1957). From Shomura's (1964)

Table 7.—Annual catches of skipjack tuna and live bait from 1954 through 1972.

Year	Metric tons of skipjack	Buckets of nehu
1954	6,360.13	43,737
1955	4,397.43	49,712
1956	5,049.58	40,864
1957	2,780.66	30,638
1958	3,100.15	33,303
1959	5,630.65	37,637
1960	3,338.46	22,849
1961	4,941.66	37,092
1962	4,270.81	34,256
1963	3,673.86	32,670
1964	4,093.10	30,606
1965	7,328.96	36,352
1966	4,256.82	31,603
1967	3,646.80	31,832
1968	4,227.41	35,535
1969	2,704.94	30,096
1970	3,334.46	33,596
1971	6,051.39	42,098
1972	4,952.12	38,970
Total	84,139.39	675,446

Table 8.—Summary of number of tests conducted with tilapia as a live bait for pole-and-line fishing for skipjack tuna.

Date	Vessel	No. schools chummed w/tilapia	Scheme employed	No. buckets nehu	No. skip-jack[1]	Pounds skipjack caught	No. skipjack per bucket nehu	Pounds skipjack per pound nehu	No. buckets tilapia	No. skipjack per bucket tilapia	Pounds skipjack per pound tilapia
6/15/54	*Makua*	1	Attract with nehu, then chum with tilapia and nehu alternately.[2]	—	11 (small)	—	—	—	5	—	2.5 (assume 2 lb)
8/ 4/54	*Darling Dot*	2	Attract with nehu, then chum with nehu and tilapia.[2]	20	[3]313	8,184	—	—	2	—	104
9/21/54	*Buccaneer*	1	Attract with nehu, then chum with nehu initially then with tilapia alone.[2]	30	—	3,860	—	—	2	—	—
6/21/56	*Orion*	3	One school of three chummed first with tilapia. Nehu and tilapia may have been used in some.[4]	30	911/59	—	30.2	—	5	11.8	30.4
6/26/56	*Orion*	3	All three schools chummed first with tilapia.[4]	30	627/275	—	31.4	—	12	22.9	[5]59
7/11/56	*C. H. Gilbert*	6	Five schools chummed first with tilapia, others with nehu.[4]	—	56/—	—	3.5	—	—	—	—
7/12/56	*C. H. Gilbert*	2	Both schools chummed with tilapia only.[4]	2	—	—	—	—	2	—	—
7/26/56	*Marlin*	2	One school chummed first with tilapia, others with nehu.[4]	14	86/31	—	6.1	—	4	7.8	[5]20
7/27/56	*Marlin*	1	Chummed first with nehu, then tilapia.[4]	10	72/93	—	7.2	—	5	18.6	[5]48
8/10/56	*Buccaneer*	4	All four schools chummed first with tilapia, two others chummed first with nehu.[4]	5	12/1	—	2.4	—	4	0.1	—
9/22/56	*Buccaneer*	2	Both schools chummed only with tilapia.[4]	—	—	—	—	—	2	—	—
7/22/58	*Amberjack*	—	Tilapia and nehu used at discretion of fishermen. Estimate of buckets used derived from pounds used.[6]	17	—	4,110	26.6	30.7	5	14.0	16.2
8/25/58	*Olympic*	—	Same as above	14	—	9,000	21.7	68.8	6.5	15.4	48.6
8/30/58	*Olympic*	—	Same as above	—	—	4,500	—	—	6	21.0	53
9/ 4/58	*Olympic*	—	Same as above	6.4	—	9,000	22.4	44.4	4.6	40	79.2
7/ 8/59	*Tradewind*	—	Same as above	5	—	6,708	11.6	198.0	< 1	2.1	4.8
7/10/59	*Tradewind*	—	Same as above	26	—	9,100	21.7	35	2.6	2.1	5.0
7/10/59	*Sooty Tern*	—	Same as above	39.5	—	18,030	30	65	1.7	1.4	2.5
7/30/59	*Sailfish*	—	Same as above	12.8	—	5,600	31.7	56.7	2.6	10.5	27.5
7/31/59	*Sailfish*	—	Same as above	20.6	—	6,943	1.7	40.9	11.6	7.0	13.0
8/10/59	*Buccaneer*	—	Same as above	9	—	4,429	9.8	37.0	2	42.7	156.2
8/11/59	*Buccaneer*	—	Same as above	34	—	10,114	131.3	32.5	3	44.0	105.3
8/12/59	*Buccaneer*	—	Same as above	3	—	5,120	17.5	39.8	9	29.4	67.0
8/27/59	*Sailfish*	—	Same as above	13	—	15,000	—	55.5	15.4	—	92.5
9/ 5/59	*Sailfish*	—	Same as above	—	—	5,600	—	—	13	21.7	62.2
9/ 7/59	*Olympic*	—	Same as above	—	—	9,500	—	—	13	16.1	50.0
1952-62	*C. H. Gilbert*	6	Nehu and tilapia altered every 2 min.[7]	—	—	—	—	—	—	—	—
5/62-8/62	*Broadbill*	73	Used as live bait for pole-and-line fishing in connection with monofilament gill netting. Tests not designed to test tilapia as skipjack bait.[8]	—	—	—	—	—	—	—	57

[1]Number of skipjack tuna caught with nehu/number of skipjack tuna caught with tilapia.
[2]Source of data—Brock and Takata 1955.
[3]At approximately 19 lb per tuna.
[4]Source of data—King and Wilson 1957.
[5]Assume 18 lb per skipjack tuna due to time of year.
[6]Source of data—Hida et al. 1962.
[7]Source of data—Yuen 1969.
[8]Source of data—Shomura 1964.

data, I obtained a value of 57 lb of tuna per pound of bait. The average for the five papers consulted was 53 lb of skipjack tuna caught per pound of tilapia used. This agrees with Hida et al. (1962) at least in part because the large quantity of data that they contributed caused this final figure to be skewed in their direction.

I feel that this 53-lb figure may not be real, because, as can be seen in Table 8, the ratio between the amount of nehu used and the amount of tilapia used in these trials was quite high, and it appears that most, if not all, of the trials did not provide a nonbiased test for tilapia. The tilapia were probably used as if they were nehu, with little regard for tilapia's own special characteristics and associated problems, which also probably biases the data; but, observing the trial dates, it can be seen that they were conducted during the "fishing season," which could be the reason for a high efficiency figure. Evaluation of these different factors is difficult and will not be attempted here. However, it appears that the efficiency of tilapia, as measured by available data, is quite comparable to the efficiency of nehu in catching skipjack tuna.

As mentioned earlier, there are several problems with tilapia. They are slower swimmers than nehu, and with present fishing methods, the tilapia are "left behind," causing the tuna to fall behind also, and out of range of the pole and line. Tilapia reportedly have a tendency to sound, which also draws the tuna out of range of the pole and line.

The color contrast between nehu and tilapia makes the tilapia a less desirable supplemental baitfish, because the shiny hooks presently used more closely approach the coloration of nehu than that of tilapia. Thus the tuna might be able to differentiate more easily between the hooks and tilapia, making it less effective under the present fishing method.

Another drawback mentioned previously is the sharp dorsal spines that tilapia have, which are apt to injure the chummer's hands. For the size of a baitfish (3.8-6.4 cm), however, the spines should be too poorly developed to present a problem.

Problems and Advantages of Tilapia Culture

One major problem in culturing tilapia is the need for controlled growth. There is a need to cultivate the correct bait-sized fish, and predict when they will reach such a size. In addition, cannibalism occurs in this species, calling for a continuing separating procedure.

On the other hand, there are numerous advantages to using tilapia. They are very hardy and relatively easy to cultivate. They can be raised in fresh, brackish, or salt water, with proper acclimatization. Properly acclimatized, the mortality is negligible, say 5% at most, when held in a baitwell for extended periods. In addition, the fisherman probably will not have to "rest" the bait as he currently does.

Tilapia are edible, and fish that have grown beyond bait size could be sold for human consumption. A public information program would probably have to be carried out, however, before tilapia is readily accepted as food fish.

"Ogo," *Gracilaria coronopifolia*, an algae which is sold locally, could possibly be grown in conjunction with tilapia (E. L. Nakamura, Southeast Region, National Marine Fisheries Service, NOAA, Panama City, Fla., pers. commun.). Since it appears that tilapia do not actively feed upon this algae, it could be harvested, providing additional income and thus helping to defray the operating expenses of a tilapia production plant. There may be other species that could share the tilapia tanks and help defray operating costs while not harming, or being harmed by, the tilapia.

Enclosing the tanks and regulating the temperature could aid in maintaining a constant production throughout the year, and would provide protection from predators and poachers.

Fish Diseases, Cures, and Prevention

Knowledge of fish diseases or parasitic infestations is very important because they can kill a large quantity of fish in a matter of hours or a few days. Hatchery operators must constantly check the fish tanks and fish to ensure early detection and must institute treatment promptly.

Hida et al. (1962) described their problems. Their tanks remained almost disease free in 1958; a minor outbreak of the protozoan *Trichodina* occurred which was controlled by treatment with 0.5 ppm copper sulfate or 3 ppm potassium permanganate solution. They also encountered acute catarrhal enteritis, and because there was no known cure, they simply increased the flow of freshwater. They gave a prophylactic treatment of 3 ppm potassium permanganate or 0.5 ppm copper sulfate before adding new fry in 1959. They attributed their low infection rate, in part, to having an independent water supply for each tank instead of using recirculated water.

Uchida and King (1962) encountered infestations by the ectoparasite, *Trichodina*, and reported that potassium permanganate (3 ppm) was easiest to use and as effective as other methods. They used the same solution to control the protozoan *Chilodon*. Acute catarrhal enteritis, now called infectious pancreatic necrosis, is a viral infection which has characteristics similar to those caused by the protozoan *Octomitus salmonis*. The symptoms are whirling or corkscrewing accompanied by rapid ventilating, and subsequent sinking to the bottom and cessation of feeding. A "pin head" appearance results from this last symptom. Uchida and King found that by treating the feed with PMA (pyridylmercuric acetate) both of these latter diseases were eventually controlled. They also periodically added potassium permanganate as a prophylactic treatment. Their conclusion was that the single most important factor favoring diseases was overcrowding.

The HBS also encountered fish diseases. They had problems with a "whirling" disease and corrected this by changing the diet from pelleted dry feed to algae. Their prebait-size fish suffered from "pin head" a condition that was corrected by using filamentous algae collected from the ocean, alfalfa pellets, and cooked taro peels. This ailment was believed to have been caused by insufficient algae production in the tanks. They experienced heavy mortality among bait- and prebait-size fish caused by an unidentified disease. They treated this with a 12-h 0.8 ppm copper sulfate solution once every fourth day and increased the rate of water turnover from once every 2.5 days to once every 5 h.

FEATURES OF TANK CONSTRUCTION

The construction of the brood and fry tanks is very important in facilitating the overall operation of a tilapia plant. The cannibalistic characteristics of tilapia make it necessary to separate fry from the brood stock and different size fry from one another.

The HBS constructed a lip around the rim of the brood tanks that provided an area of refuge for the fry (Fig. 1). Periodically, this trough was emptied into fry tanks that had been "aged" with heavy growths of algae upon which the fry fed. There needs to be sufficient difference between the level of the trough and that of the fry tank to create a good head of water for flushing the fry easily and quickly from one location to another. There should also be a cascade arrangement between fry tanks for further separation after the fry begin to grow. Frames with different mesh sizes might also be used to separate the fry.

The bottom of the tanks should slope so as to drain properly and facilitate cleaning. Hose connections should be handy, and might even be saltwater outlets to reduce freshwater consumption.

Plumbing should be arranged so that water can be filtered and recirculated if desired, and proper lighting should be considered for night work and transferring the bait to the baitwells of the vessels.

A good pier with easy access both from land and sea should be available. Work saving devices might include a trough system to deliver bait to the baitwells, a movable crane, preferably motorized, for moving heavy objects, and an automatic feeder. The resulting ease of maintenance and operation would reduce personnel needs, helping to keep costs down.

CONCLUSIONS

In this paper I have analyzed the current break-even cost to the skipjack tuna fisherman of his bait, using an indirect method. I concluded that this cost, to the fisherman, is $30.12 per bucket of bait.

I analyzed the pilot tilapia production plant that was funded and run by the State Division of Fish and Game. From their raw data I drew a current cost estimate for a similar plant that could be theoretically increased to any size to handle either a portion or all of the bait needs of the current skipjack tuna fleet. Using the highest cost estimates, 10% interest on construction costs, land costing $3.00/sq ft payable over a 12-yr period, and using trout feed, I still obtained a cost per bucket of tilapia of $17.56. This includes a 20% profit for the producer.

Therefore I submit that if fishermen no longer catch bait, but purchase it instead and spend full time fishing, their bait will cost them less.

I also looked at the catch rates for tuna when using *nehu* and *tilapia* as bait, and found them to be comparable. Tilapia still need extensive trials as a bait species, however, and tilapia data need further scrutiny.

Tilapia characteristics, both favorable and unfavorable, were discussed and should offer some insight into the problems and advantages of raising tilapia. I also mentioned the possibility of sharing the tilapia tanks with a compatible, marketable species, and thereby helping to defray expenses.

Fish diseases contracted during three different baitfish rearing studies were reviewed, along with their treatments.

CALCULATIONS

$$C_0 = \frac{D_b}{D_f} V - (D_b \cdot C_d)$$

$$= \frac{1187}{1882} (\$3{,}203{,}246) - (1{,}187 \text{ days}) (\$38.46)$$

$$= \$1{,}974{,}674 \text{ net opportunity cost}$$

$$B_a = \frac{Q_a}{Q_b} = Q_a \frac{B_0}{Q_t}$$

= 3,072 tons (40,230 buckets/yr) / (4,877 tons caught for 1973)

= 25,341 buckets (additional amount of bait required to catch additional skipjack tuna)

$$B_t = (B_0 + B_a)$$

= (40,230 buckets) + (25,341 buckets)

= 65,571 buckets.

Break-even (maximum) price for nehu:

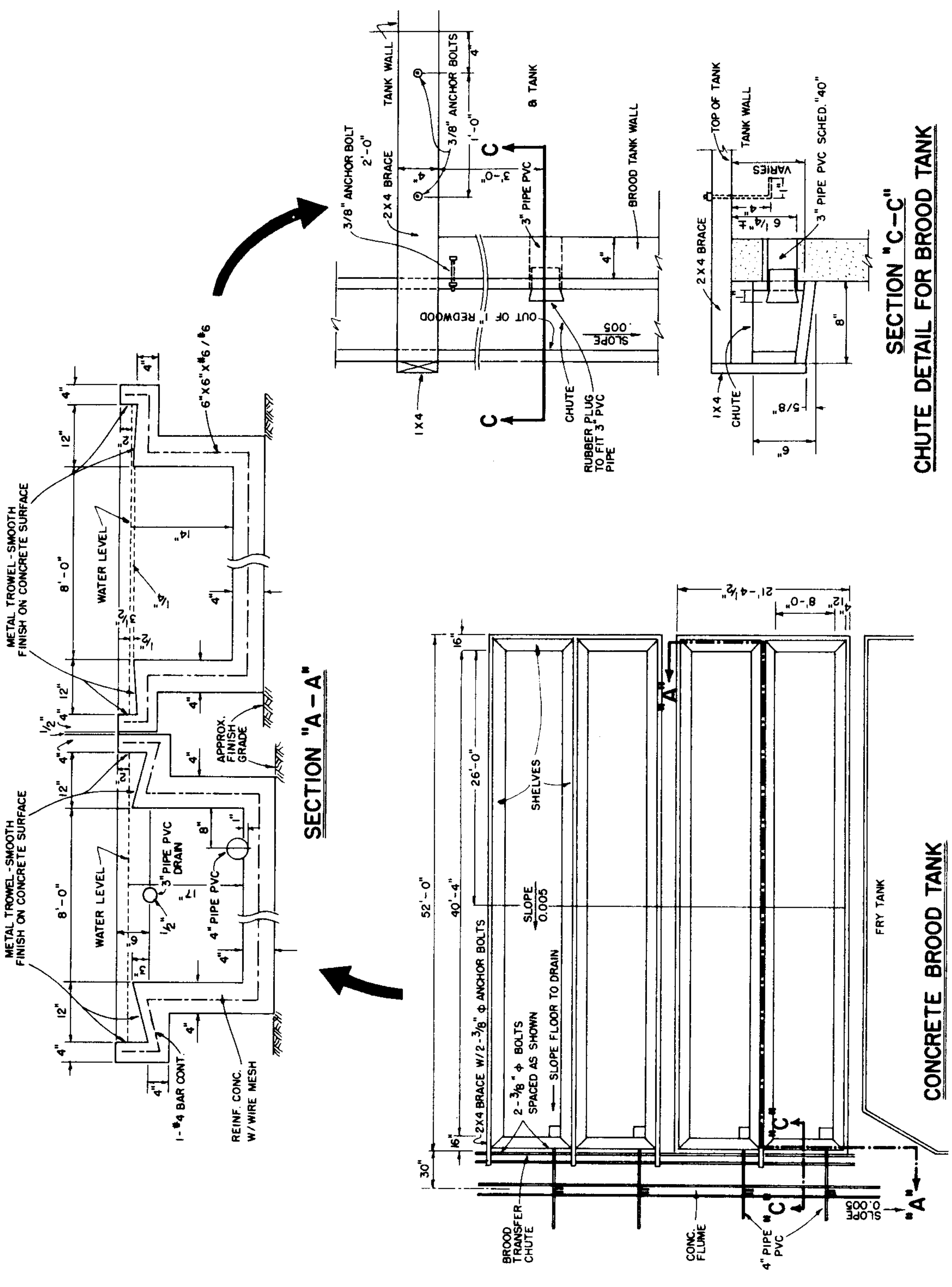
$$C_0/B_t = 1{,}974{,}674/65{,}571 = \$30.12.$$

Determination of the number of pounds of tuna caught per pound of nehu used.

Total number of metric tons of skipjack tuna caught from 1954 through 1972 (from Table 7):

(84,139.39 t of tuna) (2,204.6 lb/t)
= 185,493,699 lb of tuna caught.

Total number of buckets of nehu caught, 1954-72: (673,446 buckets of nehu caught) (21.7% mortality)
= 146,137.782 buckets of nehu died



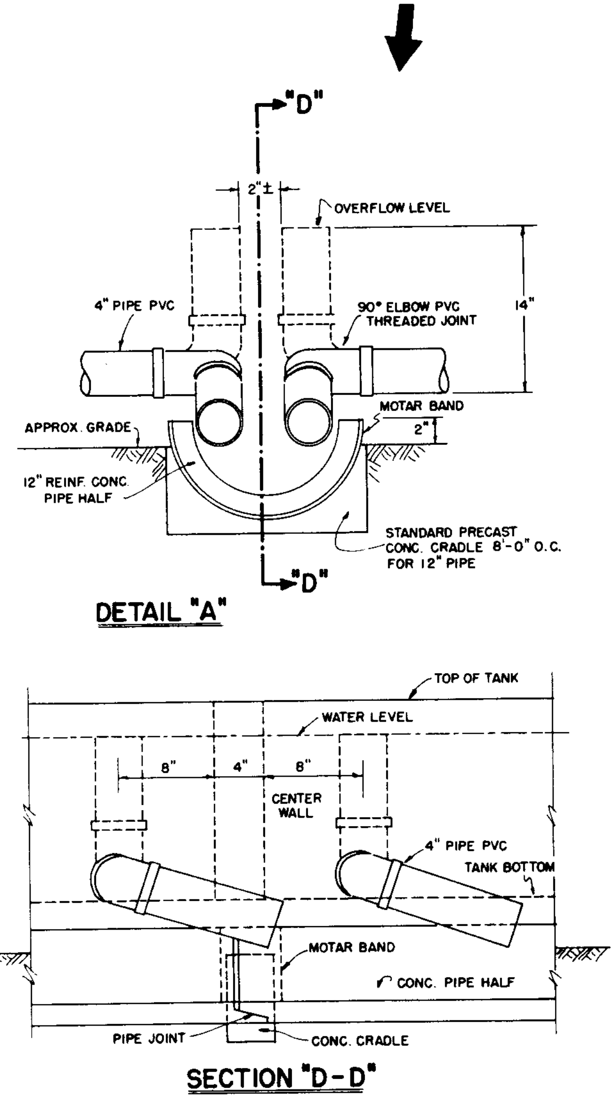
SECTION "A-A"

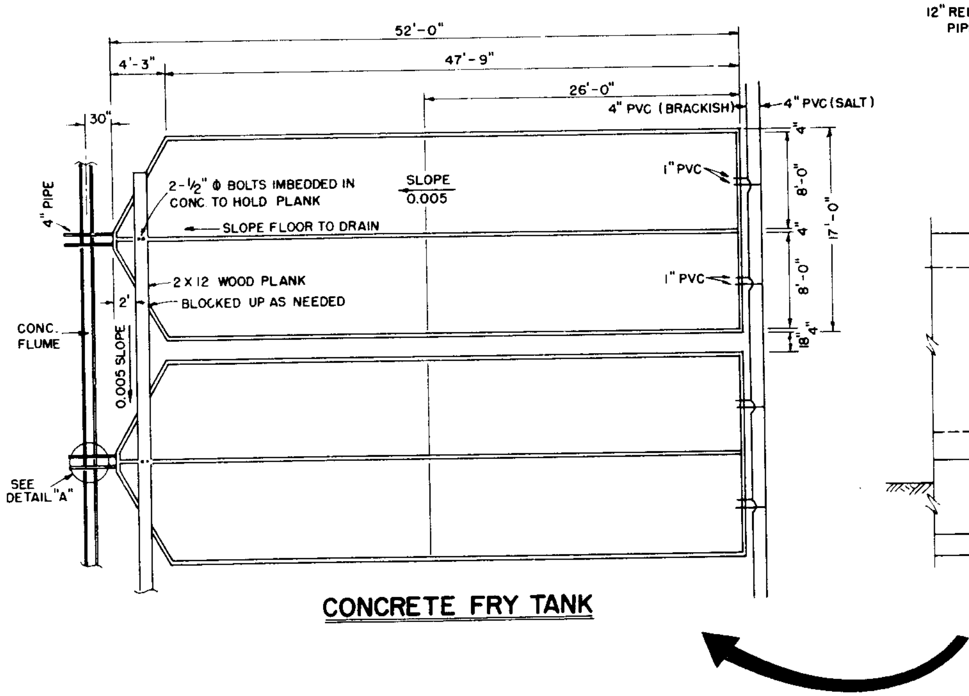
CONCRETE BROOD TANK

SECTION "C-C"
CHUTE DETAIL FOR BROOD TANK

Figure 1.—Copies of blueprints from which the Honolulu Bait Station constructed brood and fry tanks for the rearing of young tilapia.

A. Overall plan for the concrete brood tank.
B. Detailed end view of two concrete brood tanks.
C. Chute detail of brood tank.
D. Detail of concrete drain flume.
E. Concrete tank for rearing tilapia fry.





$(673{,}446) - (146{,}137) = 527{,}308$ buckets of nehu used

$$\frac{185{,}493{,}699 \text{ lb of tuna caught}}{527{,}308 \text{ buckets of nehu used}} = 351.77 \text{ lb of tuna/bucket of nehu}$$

$$\frac{351.77 \text{ lb of tuna/bucket of nehu}}{7 \text{ lb. of nehu/bucket}} = 50.25 \text{ lb of tuna/lb of nehu used}$$

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LITERATURE CITED

BROCK, V. E., and M. TAKATA.
1955. Contribution to the problems of bait fish capture and mortality together with experiments in the use of tilapia as live bait. Territory of Hawaii, Ind. Res. Adv. Counc. Grant 49. Final Rep., 39 p.

HIDA, T. S., J. R. HARADA, and J. E. KING.
1962. Rearing tilapia for tuna bait. U.S. Fish Wildl. Serv., Fish. Bull. 62:1-20.

KING, J. E., and P. T. WILSON.
1957. Studies on tilapia as skipjack bait. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 225, 8 p.

SHANG, Y. C., and R. T. B. IVERSEN.
1971. The production of threadfin shad as live bait for Hawaii's skipjack tuna fishery: An economic feasibility study. Univ. Hawaii, Econ. Res. Cent., 42 p.

SHOMURA, R. S.
1964. Effectiveness of tilapia as live bait for skipjack tuna fishing. Trans. Am. Fish. Soc. 93:291-294.

UCHIDA, R. N., and J. E. KING.
1962. Tank culture of tilapia. U.S. Fish Wildl. Serv., Fish. Bull. 62:21-52.

YOSHIDA, H. O., R. N. UCHIDA, and T. OTSU.
1977. The Pacific tuna pole-and-line and live-bait fisheries. *In* R. S. Shomura (editor), Collection of tuna baitfish papers, p. 36-51. U.S. Dep. Commer., NOAA Tech. Rep. NMFS Circ. 408.

YUEN, H. S. H.
1969. Response of skipjack tuna (*Katsuwonus pelamis*) to experimental changes in pole-and-line fishing operations. *In* A. Ben-Tuvia and W. Dickson (editors), Proceedings of the FAO Conference on Fish Behaviour in Relation to Fishing Techniques and Tactics, Bergen, Norway, 19-27 October 1967. FAO Fish. Rep. 62, 3:607-618.