Evaluation of Bait Substitution Schemes in Hawaiian Fishery for Skipjack Tuna, *Katsuwonus pelamis*

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ABSTRACT

A systematic procedure is presented for judging the feasibility of bait substitution schemes in the Hawaiian fishery for skipjack tuna, *Katsuwonus pelamis*. Over the period 1968-73, the opportunity cost of nehu, *Stolephorus purpureus*, the bait now in use, peaked twice a year: during the first half of July when skipjack tuna catch rates were high and during the second half of December when the ex-vessel price of skipjack tuna was high. The opportunity cost averaged $4.78/lb, and increased by over 100% during the period, due mostly to a rise in ex-vessel price of skipjack tuna.

Feasibility of a bait substitution scheme during any season requires that unit production costs are less than opportunity costs of acquiring nehu and that the quantity of bait produced does not exceed the amount usable. Judgment of feasibility rests on some critical assumptions concerning such factors as the amount of nehu per bucket in the bait fishery, and the attractiveness of substitute baits relative to nehu. These must be substantiated through field experiments and sample surveys.

INTRODUCTION

For many years the Hawaiian fishery for skipjack tuna, or aku, *Katsuwonus pelamis*, has suffered a persistent case of stagnation. In spite of a rising consumer demand for tuna products and an ample exploitable resource, the average annual aku harvest has not been increased. Further, only one new vessel has entered the aku fleet in the last two decades, while many deteriorating boats have been retired and not replaced. The roots of this malaise were recognized long ago—a short supply of an essential ingredient, live bait, and failure of the fishing industry and supporting government agencies to develop substitute or alternative bait supplies in a rather high-risk investment environment.

The baitfish problem is a classic economic problem of technological substitution and its key elements may be conveniently summarized as in Figure 1. This shows the joint behavior of the two key variables, unit production costs and usage rate, for two hypothetical alternative baits and for nehu, *Stolephorus purpureus*, the principal bait now in use. In this two-dimensional phase space, the industry is now at "A," and moving upwards on the nehu curve with rising costs and essentially constant usage rate. The conversion path, illustrated by a dotted line, shows how an expanding aku industry would presumably switch from nehu to a first substitute bait, then to a second alternative bait as economic considerations dictated. Discontinuities in the conversion path represent points of substitution. Ideally we would be able to forecast such a path for a variety of alternative baits, or at least to determine the points of intersection which indicate conditions favorable to the introduction of substitutes. The illustration used here assumes that the two hypothetical substitutes are not yet feasible. In fact, the present positions of the cost paths for alternative baits, relative to the nehu curve, are uncertain. Research in progress may show, for example, that the "Alt 1" substitution scheme could now satisfy the present usage rate (about 170,000 lb/yr) at a unit cost less than the present opportunity cost of nehu (the opportunity cost for nehu used in fishing averaged $4.78/lb over 1968-73)

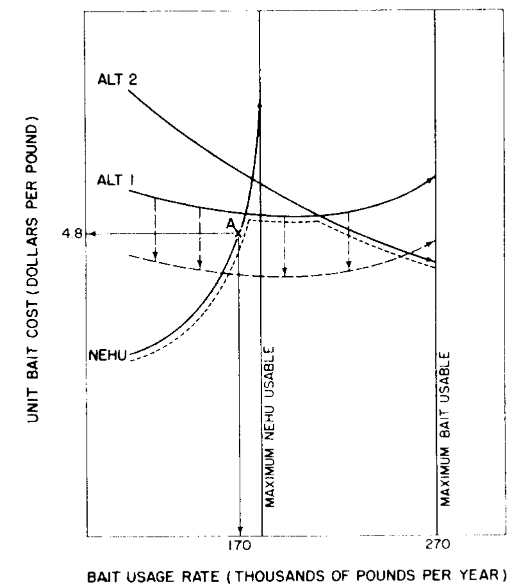

Figure 1.—Hypothetical relationships between unit bait cost and usage rate for nehu and two alternative baits. Dotted line is conversion path. Dashed line indicates uncertainty in position of "Alt. 1." In recent years the industry has been approximately at point "A."

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Solution of the baitfish problem clearly depends on success in two area: 1) technical development of alternative bait supplies at unit costs permitting substitution and 2) practical demonstration of the effectiveness of new baits and the building of confidence in their use among aku fishermen. Several determined efforts have been made along both lines, without much success (e.g., Shomura 1964; Shang and Iversen 1971). At present, two technical alternatives are under consideration, one involving the transportation of northern anchovy, *Engraulis mordax*, from California to Hawaii in special tankers aboard roll-on/roll-off freighters and the other involving local mass-culture of the topminnow, *Poecilia vittata*. The anchovy transport alternative has been field tested rather extensively by the National Marine Fisheries Service, Honolulu Laboratory, for the past year, and topminnow culture, considered a possibility in Hawaii, is being pursued experimentally by the Hawaii Institute of Marine Biology of the University of Hawaii (Herrick 1977).

Before the feasibility of either of these schemes can be properly evaluated, the basic substitution curve for nehu must be elucidated. The purpose of this paper is to set out simple, systematic procedures for determining the present position of the nehu curve and for judging the feasibility of alternative bait substitution schemes.

THE OPPORTUNITY COST OF NEHU

The principal difficulty in constructing a substitution curve for nehu is that there is no free market mechanism to measure the unit cost of nehu, i.e., the value of nehu to fishermen. Instead, the worth of nehu must be appraised in terms of the value of opportunities foregone in the capture of the bait. The opportunity cost of a unit of nehu is simply the value of the aku catch which could be obtained if a unit of baiting time was spent in aku fishing, adjusted for the difference in operating costs. It is the price the fishermen could pay for nehu, in lieu of gathering bait themselves, with no difference in their potential profits.

If we let P_1 denote the fleet's profit under the present system of baiting, and let P_2 represent profit under a new system in which some fraction of bait needs is fulfilled by a substitute, we may state the basic relations as

$$P_1 = \pi \cdot CR \cdot B - k_1 DF - k_2 DB - \overline{K}$$

and

$$P_2 = \pi \cdot CR \cdot B \left(\frac{DF + DB}{DF}\right) - k_1 (DF + \lambda DB) - k_2(1-\lambda) DB - \overline{K} - k_3 \lambda B \left\{\left(\frac{DF + DB}{DF}\right)\right\}$$

where
π = ex-vessel prices of aku (\$/lb),
CR = catch rate; pounds of aku landed per pound of nehu used (lb/lb),
DF = number of days of fishing (old system),
DB = number of days of baiting (old system),
B = amount of nehu used in DF days of fishing (old system) (lb),
λ = proportion of baiting time in old system converted to fishing time in new system,
$\overline{K}$ = fixed costs, or costs independent of the number of days fished, the number of days baited or the amount of bait used (\$),
k_1 = operating costs for a day's fishing (\$/day),
k_2 = operating costs for a day's baiting (\$/day),
k_3 = price of bait purchased under new system (\$/lb used).

The problem now is to find the value of k_3 which satisfies $P_1 = P_2$. This value is the opportunity cost, OC, and is easily found to be

$$OC = \left(\frac{DB}{DF + DB}\right) \left\{\pi \cdot CR - \frac{DF}{B} (k_1 - k_2)\right\}.$$

This is, in substance, equivalent to the result of Shang and Iversen (1971), but is put in a different form and is derived in a more direct and less convoluted manner. Note that the solution for OC is independent of the conversion rate, λ.

For most practical purposes the difference in operating costs may be neglected, and the opportunity cost may be approximated by

$$OC = \left(\frac{DB}{DF + DB}\right) \pi \cdot CR. \qquad (\$/\text{lb})$$

Thus the opportunity cost of nehu may be considered as the product of three factors: 1) The proportion of potential fishing days now spent baiting, 2) the ex-vessel price of aku, and 3) the amount of aku landed per unit of nehu used.

TEMPORAL VARIATION IN THE OPPORTUNITY COST

Feasibility of any alternative to nehu will, of course, require that costs of that bait, per unit used in fishing, be no greater than the opportunity cost of nehu. Of particular significance will be any temporal variation in the value of nehu. A substitution scheme may be quite promising during seasons or years of high aku catch rates, say, but be altogether infeasible otherwise.

To establish the seasonality of the opportunity cost, data from the aku fishery and the baiting operations were analyzed. The data represented a 6-yr period, 1968-73, and were obtained directly from the catch records submitted by aku fishermen to the Hawaii Division of Fish and Game. The computations were based on statistics concerning all baitfishes taken in the daytime for aku fishing. Thus the label "nehu" on the results which follow is meant to indicate only that nehu is the predominant species involved, accounting for over 90% of the total bait catch.

Annual Variation

The range of annual variation in the opportunity cost of nehu and the three component factors is shown in Figure 2. From 1968 through 1973 the opportunity cost more than doubled. Over the same period there was a general increase in the proportion of days baited and in the average catch of aku per pound of nehu used. But the dominant force in increasing the opportunity cost has been a sharp rise in the average aku price. This increased by 80% over the 6-yr period.

The statistics plotted in Figure 2 are also given in Table 1 which presents, in addition, the monthly means of the opportunity cost for each year.

Seasonal Variations

Seasonal patterns of variation in the opportunity cost and its components were determined by computing 6-yr weighted averages of the appropriate biweekly statis-

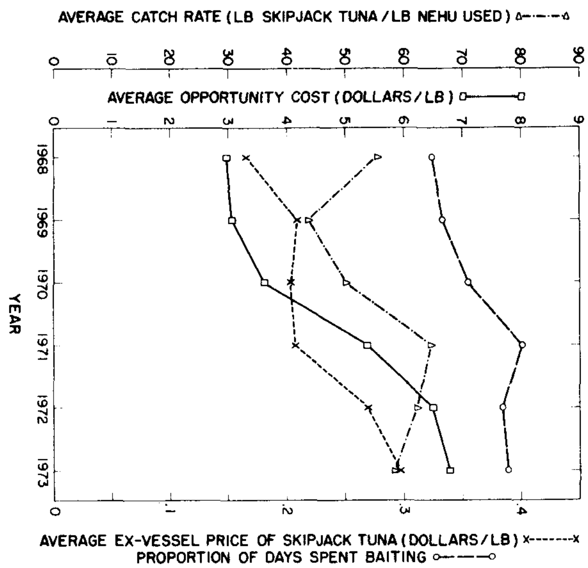

Figure 2.—Trends in the average annual opportunity cost of nehu and in its major components over 1968-73.

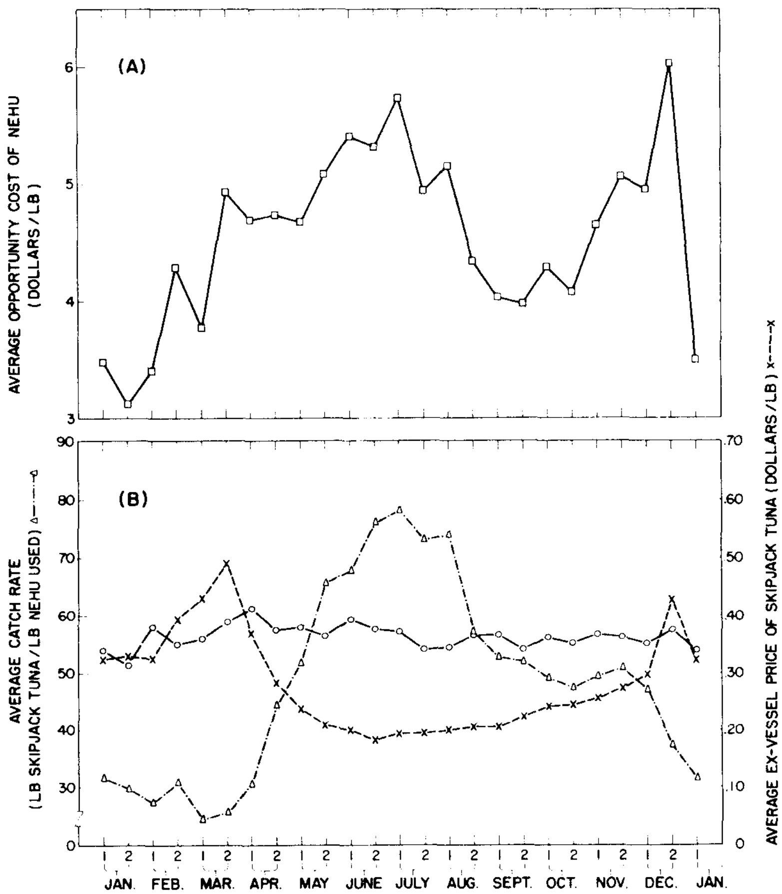

Figure 3.—Seasonal variation in (A) opportunity cost of nehu, and (B) its major components, based on biweekly statistics averaged over 1968-73.

tics. The results are shown in Figure 3 and Table 2. The top panel (A) of Figure 3 shows the seasonal pattern of the average opportunity cost of nehu. The OC rises from a low in the last half of January to a peak in the first half of July, drops sharply to another low in September and turns upward again to reach its highest value of the year in late December. There is a twofold variation in the average biweekly OC during a year.

In the bottom panel (B) of Figure 3, the seasonal behaviors of the three component factors are displayed.

Table 1.—Variation in average opportunity cost of nehu (by month), proportion of days baited, aku caught per nehu used, ex-vessel aku price, aku caught per trip, and annual aku catch for 6-yr period, 1968-73.

	1968	1969	1970	1971	1972	1973
Average opportunity cost ($/lb)						
January	2.25	4.39	1.60	3.27	4.46	3.43
February	2.22	3.48	4.63	2.58	4.83	7.05
March	2.80	3.30	2.22	4.50	7.43	6.18
April	2.83	3.58	2.49	4.59	8.60	7.78
May	2.84	2.84	2.85	6.17	7.85	7.58
June	3.01	3.50	2.74	7.40	6.87	7.93
July	2.66	3.05	4.24	6.08	7.23	8.34
August	3.32	2.50	3.43	4.67	7.85	6.86
September	2.85	2.61	4.80	4.51	4.97	3.35
October	3.34	2.56	4.01	5.02	4.37	4.96
November	3.16	2.58	4.79	7.00	5.41	6.60
December	5.10	2.89	3.78	6.72	7.31	7.37
Annual mean	2.98	3.05	3.61	5.38	6.51	6.80
Proportion of days baited	0.325	0.334	0.355	0.402	0.386	0.390
Aku caught per nehu used (lb/lb)	55.5	43.8	50.0	64.8	62.5	58.6
Ex-vessel aku price ($/lb)	0.165	0.209	0.203	0.207	0.270	0.297
Aku caught per trip (lb/trip)	4,163	3,327	3,836	6,475	5,763	5,588
Annual aku catch (metric tons)	4,218	2,692	3,332	6,004	4,948	4,859

Table 2.—Seasonal variation in proportion of days baited, aku caught per nehu used, average ex-vessel aku price, average opportunity cost of nehu, average aku catch, present bait usage rate and potential bait usage rate. Estimates are weighted means of biweekly statistics covering a 6-yr period, 1968-73.

Month	Biweekly period	Proportion of days baited	Aku caught per nehu used (lb/lb)	Average ex-vessel price of aku ($/lb)	Average opportunity cost of nehu ($/lb)	Average aku catch (10^2 lb/2 wk)	Present bait usage rate (lb/2 wk)	Potential bait usage rate (lb/2 wk)
January	1	0.340	31.6	0.325	3.49	1,126	3,562	5,397
	2	0.315	29.8	0.330	3.11	1,019	3,420	4,993
February	1	0.381	27.2	0.328	3.41	1,238	4,550	7,350
	2	0.351	30.8	0.397	4.30	756	2,455	3,782
March	1	0.361	24.3	0.432	3.78	642	2,640	4,132
	2	0.391	25.7	0.492	4.95	883	3,436	5,642
April	1	0.415	30.5	0.371	4.70	1,597	5,235	8,949
	2	0.378	44.2	0.284	4.74	2,651	5,997	9,642
May	1	0.380	51.9	0.238	4.69	4,520	8,709	14,046
	2	0.367	66.0	0.210	5.09	6,608	10,012	15,817
June	1	0.395	68.1	0.201	5.41	8,000	11,748	19,418
	2	0.378	76.4	0.184	5.32	9,995	13,083	21,033
July	1	0.375	78.5	0.195	5.74	9,931	12,651	20,241
	2	0.342	73.6	0.197	4.96	9,487	12,890	19,589
August	1	0.347	74.3	0.200	5.16	8,994	12,105	18,537
	2	0.367	57.5	0.207	4.36	6,090	10,592	16,733
September	1	0.367	52.9	0.208	4.04	4,177	7,895	12,472
	2	0.342	52.2	0.223	3.98	3,620	6,935	10,539
October	1	0.363	49.2	0.242	4.31	3,439	6,990	10,973
	2	0.352	47.4	0.245	4.09	3,435	7,247	11,183
November	1	0.369	49.6	0.255	4.66	2,767	5,579	8,842
	2	0.365	51.0	0.272	5.06	2,274	4,459	7,022
December	1	0.352	47.2	0.298	4.94	2,162	4,580	7,068
	2	0.377	37.3	0.430	6.04	1,268	3,399	5,455

The proportion of days baited does not vary over a wide range—from about 32% to 42%. It is not an important determinant of seasonal variation. Perhaps the most significant factor in fluctuations of the *OC* is seasonal change in the catch rate. From a low point in March this component more than trebles in the next 4 mo. The catch rate then begins a steady downturn which continues over an 8-mo period, except for a slight rise in November.

The third component of the *OC*, the ex-vessel price of aku, is very responsive to seasonal changes in the supply of aku on local markets and is thus inversely related to the catch rate (Fig. 3B, 4). The price considered here is the weighted average of the individual prices for fresh fish and for aku delivered to the Hawaiian Tuna Packers cannery. Though in recent years there has been a negotiated minimum price for aku sold on the fresh fish market, it is effective only during the summer season of high aku supply, when most of the aku landed are absorbed by the cannery. In months of short supply, when a relatively large share of the aku catch is sold fresh, the fresh fish price is well above the minimum level.

As shown in Figure 3B, the highest average prices occur in March, and these correspond to the annual minimum in catch rate. As the supply of aku is increased by the steady rise in catch rates during April, May, and June the aku price drops to a June low. During the second half of the "average" year the reverse pattern is observed. There is one brief deviation in the pattern; during the late December holiday season the high demand for aku bids up the price sharply, but by mid-January this effect disappears.

THE FEASIBILITY LINE

In the search for substitute baits, important decisions will have to be made concerning the scale of operations of transport or culture schemes and the extent of bait needs which the substitution schemes are intended to fulfill. A small pilot project might be viable only if its operation was restricted to the relatively brief period of highest opportunity cost for nehu. In most schemes it is likely that as the scale of operations is increased the unit costs of bait production or delivery will be reduced, though at a diminishing rate, and a greater share of total bait needs can be satisfied.

There are two obvious conditions which must be met to establish the feasibility of an alternative bait program: 1) During the period of each year when the substitution scheme is operating, the opportunity cost of nehu must not be less than the unit costs of the alternative bait (appropriately adjusted for mortality between delivery and usage), and 2) the quantity of bait produced by the scheme must not exceed the potential amount usable during the period. Figure 5 shows how a particular substitution scheme, producing bait at $4.50/lb used, generates a feasible period of about 7 mo—5 mo in the spring and summer and 2 mo at the end of the year. During this period, according to Table 2, about 190,000 lb of bait could be used. For each point on the ordinate there is a different maximum usage rate. Together these form the feasibility line or demand curve shown in Figure 6. Substitution schemes producing more bait than can be used or producing bait at a cost exceeding the critical cost will fall in the infeasible region to the right of the line. As the opportunity cost of nehu increases, the curve will of course shift upwards.

EVALUATING ALTERNATIVE BAIT SYSTEMS

The feasible region of Figure 6 defines the set of substitution schemes which may be considered as alternatives to the current practice of using nehu only. Each (hypothetical) scheme in the region will produce an increase in profits to the aku fleet. In addition, there presumably will be benefits to the processing sector of

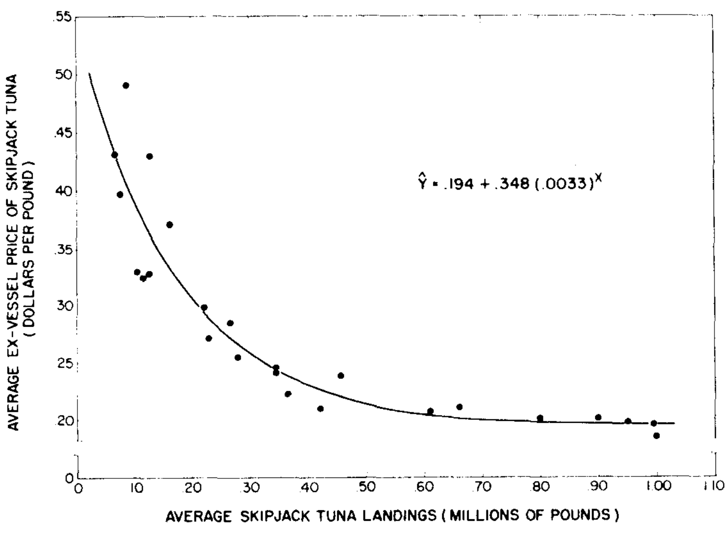

Figure 4.—Relationship between average ex-vessel aku price and average skipjack tuna landings, based on biweekly statistics averaged over 1968-73.

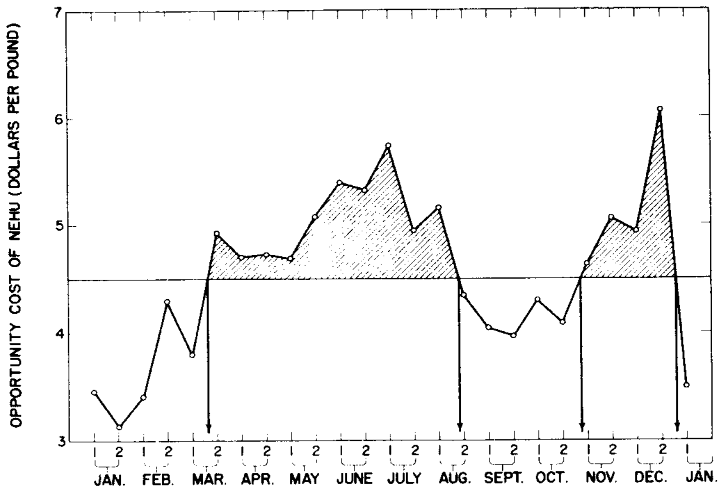

Figure 5.—Seasonal pattern in opportunity cost of nehu, averaged over 1968-73, showing the feasible period for bait substitution generated by a scheme producing bait at a cost of $4.50/lb used.

the industry, unmeasured by the opportunity cost analysis, due to the rise in aku production. We may define the "best" system as the one generating the greatest increase in the fleet's profits.

To compute the catch revenues and net costs under each alternative scheme we first determine the corresponding distribution of work days (potential fishing days). This partitioning is accomplished by solving the system of equations

$$DT = ADF + ADB$$
$$BD = \alpha ADF - \beta ADB$$

where DT = total work days during the feasible period,

BD = amount of bait delivered and used by the substitution scheme during the feasible period,

α = amount of bait used in a day of aku fishing,

β = amount of bait obtained in a day of baiting (after initial mortality),

ADF = adjusted days fishing,

ADB = adjusted days baiting.

It is easy to show that the only nontrivial solution is

$$ADF = \frac{(DB + \beta DT)}{(\alpha + \beta)}$$

and

$$ADB = DT - ADF$$

The coefficients α and β are different for each feasible period (delivery season) and are computed from current statistics.

With ADB and ADF determined for a particular substitution scheme we can compute the net gain to the aku fleet as

$$\text{GAIN} = P_2 - P_1,$$

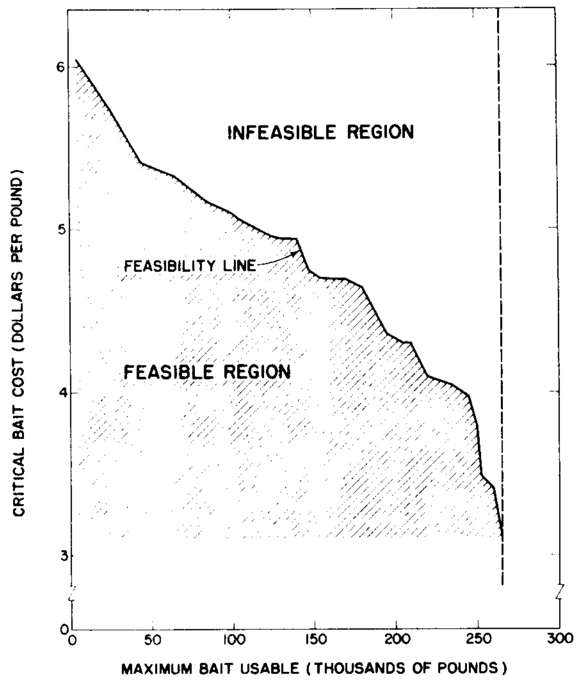

Figure 6.—Feasibility line for judging bait substitution schemes. Schemes falling in the infeasible region produce more bait than can be used in the feasible period generated. The feasibility curve is also the demand curve for bait in the Hawaiian aku fishery.

$$= (ADF - DF)\left\{\pi CR\left(\frac{B}{DF}\right) - k_3\left(\frac{B}{DF}\right)\left(\frac{DT}{DB}\right) - (k_1 - k_2)\right\},$$

= Additional catch revenue − Costs of bait purchase − Additional net operating costs

ASSUMPTIONS AND UNCERTAINTIES

The foregoing sections have outlined three basic steps in establishing the feasibility of bait substitution schemes in the Hawaiian aku fishery. These are: 1) determine the seasonal pattern of the opportunity cost of nehu; 2) compute the boundaries of the feasible region, i.e., determine the feasibility line; and 3) for each alternative substitution scheme in the feasible set compute the corresponding gain to the aku fleet.

At each step a number of critical assumptions are made. Basically there are two classes of assumptions. The first class involves assumptions made in estimating the feasibility line, i.e., the opportunity cost of nehu and the potential bait usage rate. One such assumption e.g., concerns the size of a bucket of nehu. In estimating the opportunity cost of nehu we must convert the bait usage rate from buckets per day, the reported unit, to pounds per day. The standard conversion rate used historically and in this paper is 7 pounds of nehu per bucket. On the other hand we may choose to adopt a figure of 14.2 lb/bucket on the strength of recent sampling (Hida and Wetherall 1977). If this is done, the estimates of potential bait usage will increase by 103%, while estimates of the catch rate and hence the opportunity cost of nehu will be cut by one-half.

The second category of assumptions concerns details of specific substitution schemes considered in step (3)—items such as expected survival rates during bait transport, reproductive capacity of cultured bait, attractiveness of the alternative bait relative to the standard bait, and so on. Survival rates during transport and similar parameters are likely to be fairly well known from experiments and trial runs of the system. However, other important assumptions, such as those concerning the relative attractiveness of the alternative bait, tend to be accepted uncritically. That they become tacit assumptions is a dangerous pitfall in a feasibility analysis—they must be made explicit, and tested if possible.

In the case of relative attractiveness of the standard bait and its alternatives, it is common at the outset to assume equivalence, but in the absence of concrete evidence supporting this assumption. a range of values should be explored. For a first-cut assessment, a reasonable range can be established without field trials. On theoretical grounds, e.g., we may expect that attractiveness of a pound of chummed bait is proportional to the surface area of the bait. The surface area of an individual fish is roughly proportional to the square of its length, so fish for fish the larger northern anchovy may be more attractive than nehu. But there are more nehu per pound. The number per pound is the reciprocal of average individual weight, and this is proportional to the cube of length. Combining the "surface area" and "number per pound" considerations, and noting the similarity in morphometrics between the two species, we may conclude that pound for pound the relative attractiveness of nehu versus anchovy is inversely proportional to the ratio of their average lengths. That is, if the anchovy are twice as long, they are only half as attractive as nehu, pound for pound. While this analysis ignores possible differences in behavior and other important characteristics (Yuen 1977), it provides useful guidance for setting limits to the assumption on relative attractiveness.

The effect of average size on relative attractiveness is important not only in choosing between two alternative bait species, but also in finding the best size for any particular species. Where a range of bait sizes is available, an optimum size surely exists. Of course, determining the optimum will involve consideration not only of relative attractiveness but also other factors such as carrying capacity of baitwells for different sized fish, relative production costs, and so on.

Finally, implicit in the earlier discussion on evaluating alternative systems is the assumption that the entire amount of bait delivered is purchased and used by the aku fishermen (or accepted and used, in the case of a vertically integrated system). If this is not the case, and some bait dies or is discarded between the time of delivery and fishing, then two important results follow. First, the unit cost of bait under the scheme is increased. If the fraction of bait ultimately used is μ, the cost will increase by a factor of $\frac{1}{\mu}$ over the unit cost under full utilization. Second, the net gain to the fleet will not be as great. The correct result is found using the equation given above for GAIN, but substituting a more general expression for adjusted days fishing,

$$ADF(\mu) = \frac{(\mu BD + DT)}{(\alpha + \beta)}$$

and, if the bait is purchased at cost, an amended cost figure, $\frac{k_3}{\mu}$.

It is clear, then, that in judging bait substitution schemes no meaningful conclusions can be drawn without a careful consideration of assumptions underpinning the analysis. Quoting appropriately from Chapman (1965), ". . . if far reaching assumptions are made, then strong conclusions are reached. But if these assumptions are not accepted, then the whole structure built upon sand collapses."

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LITERATURE CITED

CHAPMAN, D. G.
1965. The estimation of mortality and recruitment from a single-tagging experiment. Biometrics 21:529-542.

HERRICK, S. F., Jr.
1977. Some economic and technological aspects related to commercial production of the topminnow *Poecilia vittata*. *In* R. S. Shomura (editor), Collection of tuna baitfish papers, p. 156-159. U.S. Dep. Commer., NOAA Tech. Rep., NMFS Circ. 408.

HIDA, T. S., and J. A. WETHERALL.
1977. Estimates of the amount of nehu, *Stolephorus purpureus*,

per bucket of bait in the Hawaiian fishery for skipjack tuna, *Katsuwonus pelamis*. *In* R. S. Shomura (editor), Collection of tuna baitfish papers, p. 55-56. U.S. Dep. Commer., NOAA Tech. Rep. NMFS Circ. 408.

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

SHOMURA, R. S.
1964. Effectiveness of tilapia as live bait for skipjack tuna fishing. Trans. Am. Fish. Soc. 98:291-294.

YUEN, H. S. H.
1977. Desired characteristics of a bait for skipjack tuna, *Katsuwonus pelamis*. *In* R. S. Shomura (editor), Collection of tuna baitfish papers, p. 52-54. U.S. Dep. Commer., NOAA Tech. Rep. NMFS Circ. 408.