Catch Statistics and Abundance of Nehu, *Stolephorus purpureus*, in Kaneohe Bay

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ABSTRACT

Catch and nominal effort statistics from the Kaneohe Bay day-baiting fishery for nehu, *Stolephorus purpureus*, were used to explore hypotheses concerning two sources of variation in baiting success: 1) nehu stock abundance, and 2) abiotic environmental variables. Baiting success was found to be positively correlated with streamflow in a major tributary to Kaneohe Bay, but was unrelated to nominal baiting effort. However, the assumptions underpinning the analyses cannot be accepted with confidence, because the available nominal effort data do not provide a good measure of effective baiting effort. A definitive understanding of nehu stock dynamics will require changes in data collection practices of the Hawaii Division of Fish and Game. In particular, detailed information on catch per set of the bait seine and on size composition of the nehu stock and catch are needed.

INTRODUCTION

The high cost of acquiring bait from the natural stocks of nehu, *Stolephorus purpureus*, has been a major obstacle to the full development of Hawaii's fishery for skipjack tuna, *Katsuwonus pelamis*. Accordingly, it has stimulated government research programs spanning a quarter of a century, seeking to develop cheaper and more reliable substitutes.

Successful creation of alternative bait supplies requires a two-pronged research effort: 1) technical development of new bait sources at unit costs permitting substitution, and 2) practical demonstration of the effectiveness of new baits and building of confidence in their use among skipjack tuna fishermen. Current status reports on research related to several alternative bait substitution schemes are presented elsewhere in this publication. Until effective substitutes are developed, skipjack tuna fishermen will continue to favor the traditional baiting practices and abundance of nehu will be of central concern to the fishing industry.

One concern is apt to be that baiting success or nehu abundance is affected by fishing pressure. The question of overfishing of Oahu nehu stocks was posed early by Hiatt and Tester (1950),[2] but the data available to them did not permit a conclusive study. Even now, details of nehu population dynamics are largely unknown, and the customary approach to nehu stock assessment has been to study an index of abundance, such as catch per unit of fishing effort. This was done by Bachman (1963), who examined the relationship between average catch per day of baiting and the number of days of baiting for several nehu fisheries, using data covering the period from 1948

through 1960. He found no evidence that fishing had diminished the stocks.

In this paper I will summarize the results of some analyses similar to Bachman's which I conducted recently. I will first show that the available unit of nominal fishing effort is probably not a good measure of effective effort, i.e., not proportional to the fishing mortality it generates. In particular, fluctuations in effective fishing effort over a wide range are severely dampened in construction of the catch per nominal effort statistics.

With the shortcomings of the available data clearly in mind, I will explore two analyses using catch statistics from the day fishery of Kaneohe Bay, one of the key baiting grounds of the Hawaii skipjack tuna fleet. The first analysis assumes that the catch of nehu per day of baiting effort is proportional to nehu abundance, and the second assumes that abundance of nehu is relatively constant and that variations in the catch per day reflect changes in catchability or availability of nehu. Results of both analyses should be viewed circumspectly.

CONSTRUCTING AN INDEX OF ABUNDANCE

For the Kaneohe Bay baiting operations, records of nehu catch (in buckets) for each trip to the baiting grounds are available. During a baiting session a boat may make as many as 10 sets of its seine before sufficient nehu are captured to support a trip for skipjack tuna. When nehu are abundant one set may be enough.

If we assume that availability of nehu and effectiveness of the fishing operation (catchability) are constant, a good measure of abundance might be the average catch per set. Unfortunately the number of sets is not recorded. The best one can do is to calculate a provisional index of abundance as the average catch of nehu per "day" of fishing, i.e., per trip to the baiting grounds.

Separate records are available for each boat in the fleet. Four vessels, about one-third of the fleet, had fairly continuous records from 1966 to 1972. Data for the analyses were taken from these four boats. One of the vessels was selected as a standard boat, and the fishing power of each vessel relative to the standard was estimated. The average standardized catch of nehu per day of baiting (CPU) was then computed on a monthly basis, giving an 84-mo sequence.

The Hawaii Division of Fish and Game records for Kaneohe Bay also give the catch of nehu taken in the night-light operations and by users other than skipjack tuna fishermen. Thus, estimates of the total monthly nehu harvest for the Bay are available. These figures were divided by the standard index of nehu abundance to give estimates of total fishing effort, measured in standard boat days (Tables 1, 2; Fig. 1).

A major difficulty in using CPU as a measure of abundance is that skipjack tuna boats generally stay on the baiting grounds until a certain quantity of nehu is captured. This amount is determined largely by the capacity of the vessel's baitwells. A demonstration of this is given in Figure 2, for the four selected vessels, where relative fishing power or catch per day is plotted against average baitwell capacity. This shows clearly that the
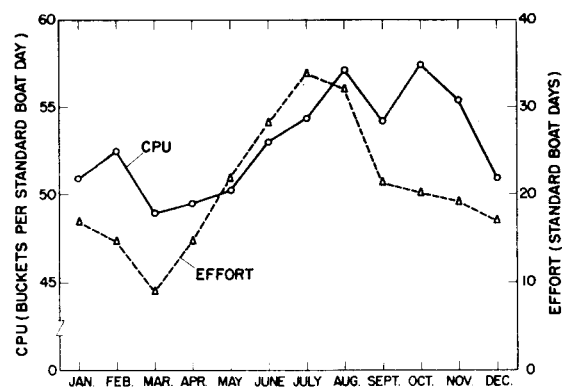

Figure 1.—Monthly average of CPU and effort, computed over 7-yr period (1966-72), for Kaneohe Bay nehu.

average catch per day is not a particularly good index of abundance, even if the number of sets per day does not vary.

During periods when nehu are abundant, the boats will easily fill their baitwells in a trip to the Bay, and the index of abundance will be truncated. Figure 3 shows the relationship between the index of abundance and abun-

Table 1.—Average catch rate of Kaneohe Bay nehu, in buckets per standard boat day, 1966-72.

Month	Year							Mean
	1966	1967	1968	1969	1970	1971	1972	
Jan.	48.57	57.60	56.37	39.96	56.42	50.10	47.39	50.92
Feb.	50.73	65.67	53.94	42.78	47.96	53.27	52.61	52.42
Mar.	55.23	49.97	37.53	51.16	46.66	51.16	50.65	48.91
Apr.	50.82	43.41	54.16	44.91	52.10	53.03	48.01	49.49
May	52.55	45.18	55.65	58.02	47.57	42.88	50.03	50.27
June	48.55	54.90	56.84	51.45	51.64	49.48	58.34	53.03
July	52.88	58.64	56.56	65.11	59.91	34.78	52.57	54.35
Aug.	57.48	57.65	53.81	58.66	61.23	50.95	59.83	57.09
Sept.	56.55	62.14	35.27	62.83	54.79	51.79	55.84	54.17
Oct.	59.03	60.41	49.84	64.42	54.18	55.92	58.04	57.40
Nov.	57.75	59.16	57.20	58.09	47.72	49.38	58.64	55.42
Dec.	62.33	50.75	33.05	57.75	47.42	50.00	55.25	50.94
Mean	54.37	55.46	50.02	54.60	52.30	49.40	53.93	52.87

Table 2.—Average baiting effort in standard boat days, Kaneohe Bay, 1966-72.

| Month	Year							Mean
	1966	1967	1968	1969	1970	1971	1972	
Jan.	9.88	12.08	29.23	24.88	9.59	22.93	9.83	16.92
Feb.	12.77	6.59	17.02	6.68	22.89	23.28	11.20	14.35
Mar.	15.15	11.23	11.94	2.15	14.36	0.59	7.26	8.95
Apr.	16.23	10.94	13.44	7.99	18.77	14.29	18.64	14.33
May	24.05	14.59	22.14	15.03	16.38	37.78	22.90	21.84
June	21.01	22.35	28.74	26.70	32.69	39.59	25.50	28.08
July	36.63	26.75	37.99	22.27	37.19	52.72	23.93	33.92
Aug.	21.68	27.79	45.88	27.29	36.81	25.04	39.88	32.05
Sept.	12.25	14.63	18.32	19.38	36.45	14.67	32.86	21.22
Oct.	19.91	9.73	19.28	24.28	30.34	9.67	27.62	20.12
Nov.	19.72	21.37	26.94	19.73	29.52	2.37	14.70	19.19
Dec.	15.58	26.56	24.05	15.31	17.29	1.68	18.52	17.00
Mean	18.74	17.05	24.58	17.64	25.19	20.38	21.07	20.66
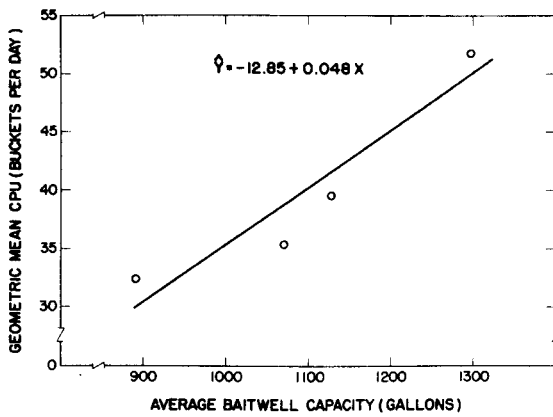
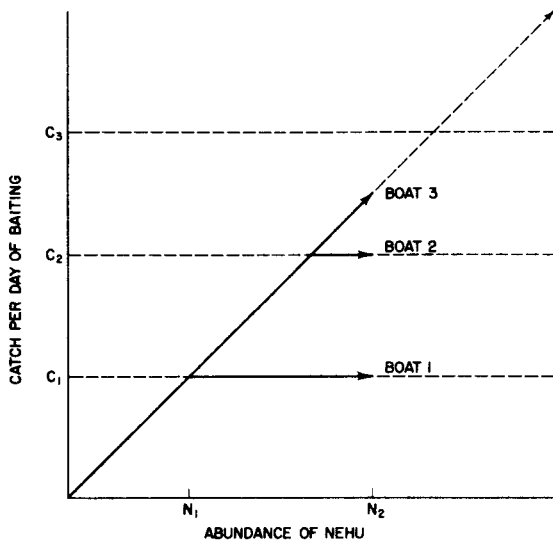Figure 2.—Relationship between average nehu CPU and bait-well capacity for selected skipjack tuna vessels, Kaneohe Bay.

Figure 3.—Catch per day of baiting as a function of nehu abundance for hypothetical vessels with different baitwell capacities (C_1, C_2, C_3).

dance, where there are three vessels with varying bait-well capacities. In this hypothetical situation the catch per day of all three boats is a good measure of abundance as long as abundance does not exceed N_1. If the abundance increases to N_2, only the boat with the largest baitwell capacity, C_3, will still provide a comparable measure of abundance. All this assumes that the number of sets per day is constant. This is patently unrealistic as long as abundance varies.

Thus it is clear that the average catch per day has at least two serious weaknesses when used as an index of abundance: 1) the number of sets per day varies, there tending to be more sets made when nehu are relatively scarce, and 2) baitwell capacity obviously determines an

upper limit to catch per day, and, since the objective is to get a full load of bait if possible, baitwell capacity tends to establish a lower bound to catch per day as well. The net result is that the CPU will "underestimate" abundance when nehu are plentiful and "overestimate" it when the fish are scarce.

SOME ANALYSES

It should be recognized at the outset that any analysis of nehu abundance using the CPU rests on a set of assumptions almost certainly violated. In the following exploratory treatments of the data, I put on the blinders and assume that changes in CPU reflect similar changes in abundance of nehu with reasonable fidelity. Catchability and availability are assumed to be constant.

The empirical relationship between CPU and standardized effort was used to indicate the response of the nehu resource to fishing pressure. Since the average age of nehu in the exploited stock is believed to be only a few months, the data were first averaged by quarters of the year, producing a series of 28 points assumed to represent equilibrium conditions. If the assumptions are correct, the relationship (Fig. 4) clearly indicates no significant effect of fishing effort on average nehu abundance, over the effort levels observed. This result, not surprisingly, is the same as Bachman's.

In the analysis just discussed the only factor explicitly set out as a determinant of stock abundance was fishing effort. Effort was regarded as the input to a "black box" production process with CPU (abundance) as output. An alternative approach is to do a regression analysis in which the other factors of production, such as natural mortality and recruitment are also modeled explicitly. We may begin as before by assuming that
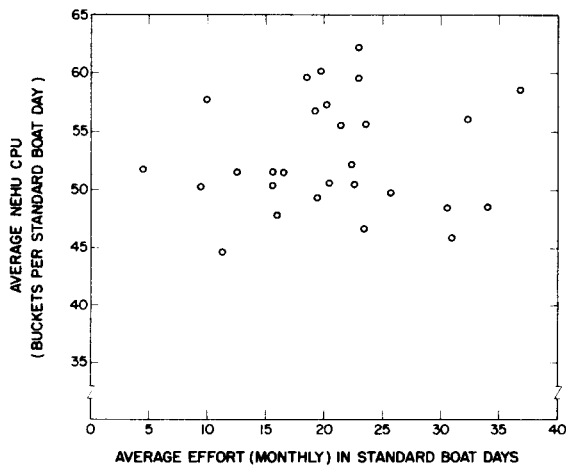
$$U_i = q D_i$$

Figure 4.—Relation between quarterly average nehu CPU and standardized effort for the Kaneohe Bay bait fishery, 1966-72.

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where U_i = CPU during period (month) i

D_i = average abundance of exploited stock during period i (number of nehu)

q = constant catchability coefficient.

As a first approximation,

$$U_i = U_{i-1} \exp\left\{-\left(M + \frac{f_{i-1} + f_i}{2} q\right)\right\} + q R_i$$

$$= U_{i-1} S \exp\left\{-q\left(\frac{f_{i-1} + f_i}{2}\right)\right\} + q R_i$$

where M = instantaneous natural mortality rate (monthly)

S = monthly survival rate in absence of fishing mortality

f_i = standard units of fishing effort during period i

R_i = average number of newly recruited fish in exploited stock during period i.

The recruitment process may be modeled by a simple Ricker-type function, e.g.,

$$R_i = a D_{i-\delta} \exp\left\{-b D_{i-\delta}\right\}$$

where for nehu we set δ equal to 2 mo. This may be linearized by expanding the exponential in a Taylor series to obtain

$$R_i = a D_{i-2} - \frac{ab}{2} D_{i-2}^2 + \ldots$$

Alternatively, R_i may be represented by a more general polynomial in D_{i-2} without a constant term,

$$R_i = \gamma_1 D_{i-2} + \gamma_2 D_{i-2}^2 + \gamma_3 D_{i-2}^3 + \ldots$$

Further, since fishing mortality is assumed to be insignificant, we let

$$\exp\left\{-q\left(\frac{f_{i-1} + f_i}{2}\right)\right\} \approx 1 - q\left(\frac{f_{i-1} + f_i}{2}\right).$$

Finally, combining these assumptions we have a linear regression model, in the usual notation,

$$Y_i = \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \ldots$$

where $Y_i = U_i$ $\beta_1 = S$

$X_{1i} = U_{i-1}$ $\beta_2 = -qS$

$X_{2i} = U_{i-1}\left(\frac{f_{i-1} + f_i}{2}\right)$ $\beta_3 = \gamma_1$

$X_{3i} = U_{i-2}$ $\beta_4 = \gamma_2$

$X_{4i} = U_{i-2}^2$

$\vdots$

This regression model is a nonequilibrium form and was fitted to the monthly CPU data with $i = 3, 4, \ldots, 84$. In the recruitment component terms through the fourth degree were allowed. The concoction was fitted using a stepwise regression program. The first term accepted by the stepwise procedure was the natural mortality term. This gave $\hat{S} = 0.34$ or $\hat{M} = 1.07$ on a monthly basis. The second term accepted was the first degree recruitment term, with positive sign. Next was the second degree recruitment term with negative sign. Finally came the third degree term with positive sign. As expected, the fishing mortality term was insignificant. So was the fourth degree recruitment term.

The regression model accounted for only 20% of the variation in CPU. Still, the estimates of the coefficients have the proper signs and the estimate of M is consistent with our best guess of the life-span of nehu, judged tentatively to be about 6 mo. Bayliff (1967) studied the relationship between maximum age (Tmax) and instantaneous total mortality rate (Z) for six species of engraulids. On an annual basis his result was $Z = 6.384/T$max. Using this relation for nehu we set Tmax $= 0.5$ and obtain $\hat{Z} = 12.768$. Assuming that fishing mortality is negligible ($M \approx Z$) we have $M = 1.06$ on a monthly basis, compared with $M = 1.07$ from the regression analysis. The astounding correspondence between these estimates must be judged with due regard for the battery of assumptions made in each case. At best we might infer that the CPU data trace the general trend of nehu abundance, but even this conclusion is tenuous.

The preceding analysis was based on the assumption that CPU is proportional to nehu abundance, with catchability and availability constant. An alternative point of departure is to regard abundance as being relatively constant and to assume that variations in CPU are due to fluctuations in catchability or availability. A simple statement of these conditions is

$$U_i = q DA_i$$

where the new symbols are

A_i = overall availability during the ith time period

$= \prod_j A_{ij}$

A = availability due to factor j during period i

$(0 \leq A_{ij} \leq 1)$.

Assuming a single availability process is causing variation in CPU, we factor this out (say the kth one) and take logs to obtain

$$\ln U_i = \theta + \ln A_{ik}$$

where $\theta = \ln\left(q D \prod_{j \neq k} A_{ij}\right) = $ constant.

In the bait fishery of Kaneohe Bay one factor suspected of influencing catchability or availability (it makes no difference in the analysis which process is involved) is turbidity of the water near the mouths of streams where

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nehu congregate. Fishermen often do not attempt to catch nehu during periods of heavy rainfall, when turbidity increases due to the boost in runoff.

An index of runoff into Kaneohe Bay is the average discharge of a major tributary such as Kamooalii Stream, which flows (via Kaneohe Stream) into the southern sector of the Bay near the city of Kaneohe. Appropriate discharge data, in cubic feet per second, are available in reports of the U.S. Geological Survey (1966-72).

Denoting the availability factor by A_i, we may write

$$A_i = \exp\left\{-\beta[d_i - d_0]\right\}$$

where d_i = Kamooalii Stream discharge in period i (cfs)

d_0 = minimum discharge level such that as $d_i \rightarrow d_0, A_i \rightarrow 1$.

Combining this with the previous equation we obtain

$$\ln U_i = \theta' - \beta d_i$$

where $\theta' = \theta + \beta d_0$.

This linear regression model was fitted to log CPU and monthly average discharge data for each year, 1966 through 1972. Logs to base 10 were used. Only two of the regressions were significant, at the 1% level. The other five were not significant. However, six of the seven correlation coefficients were negative, as expected, with values ranging from -0.16 to -0.86. The model was also fitted to all 84 data points, yielding a highly significant regression and a correlation of -0.36.

Finally, the availability model was fitted to the log of the geometric mean of CPU, and the average discharge, with the means computed over the 7 yr (Fig. 5). The regression is highly significant with a correlation coefficient of -0.71. If the assumptions of this analysis are
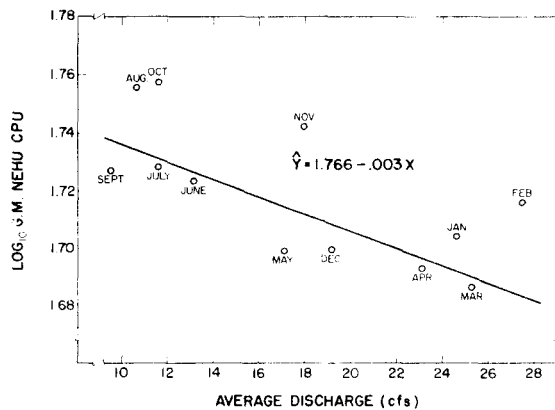
correct, we may take this as evidence that availability, catchability or both are reduced during periods of high rainfall (January through April) and enhanced when streamflows drop (June through October).

THE NEED FOR BETTER DATA

The last analysis above suggests that variations in catch per unit of baiting effort may be due largely to changes in availability or catchability arising from exogenous abiotic variables such as runoff, turbidity, etc. If this is so, we can have little confidence that catch and effort statistics, taken alone, will provide useful measures of nehu abundance, particularly when short-term changes are of interest. This applies equally to measures based on catch per set and those based on catch per day. Still, the results of the exploratory analyses presented here are based on assumptions not easily accepted. While the first analysis indicated no long-term effect of baiting effort on nehu abundance, it is quite possible that there are important short-term effects of baiting effort which are erased from the CPU index in the smoothing processes discussed earlier.

A more definitive analysis of nehu stock dynamics and the relative importance of baiting effort and environmental variables in the regulation of baiting success requires a much stronger data base than is now available. At the minimum, reporting requirements for statistics on nominal baiting effort should be extended to include information on the number of sets made each day by each vessel. In addition, catches of nehu should be sampled systematically and frequently to determine size and age composition, so that more detailed modeling can be done. The responsibility for data collection in the nehu fisheries rests jointly with the Hawaii Division of Fish and Game and with members of the aku fishing industry.

Figure 5.—Regression of log CPU on the average discharge of Kamooalii Stream at Kaneohe. Monthly data averaged over 1966-72.

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