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AN EXAMINATION OF THE HONMA METHOD AND ITS APPLICABILITY IN DEVELOPING INDICES OF ABUNDANCE FOR WESTERN ATLANTIC BLUEFIN TUNA

R. J. Conser
NMFS, Southeast Fisheries Center

SUMMARY

The Honma Method for estimating effective fishing intensity and indices of abundance has been widely used for stock assessment analyses of tunas and billfishes. A detailed mathematical development of the Honma equations and estimators is given, with particular emphasis on the assumptions that are needed to employ the method. The Honma Method is compared with the Robson Generalized Linear Model approach for developing indices of abundance. The Robson Method appears to be preferable on theoretical grounds but the Honma Method has some practical advantages when dealing with large, unbalanced data sets. Honma indices of abundance are developed for western Atlantic bluefin tuna. The Honma large fish index declined dramatically in the early 1960's and fluctuated about a stationary mean since that time. Similarly, the small fish index declined sharply in the mid-1960's and then fluctuated without trend.

RESUME

La méthode Honma d'estimation de l'intensité effective de pêche et des indices d'abondance a été amplement utilisée pour les analyses d'évaluation des stocks de thonidés et poissons porte-épée. Le développement mathématique détaillé des équations et estimateurs de Honma est fourni, en insistant tout particulièrement sur les hypothèses nécessaires pour l'utilisation de cette méthode. La méthode Honma est comparée au modèle linéaire généralisé de Robson pour l'élaboration des indices d'abondance. La méthode de Robson semble préférable du point de vue théorique, mais celle de Honma présente certains avantages pratiques au moment de traiter des jeux de données volumineux et hétérogènes. Les indices Honma d'abondance sont élaborés pour le thon rouge de l'Atlantique ouest. Le taux Honma de grands poissons a décru de façon remarquable au début des années soixante, et fluctue depuis lors aux alentours d'une moyenne stationnaire. De même, l'indice de petits poissons a brusquement baissé au milieu des années soixante, puis fluctué sans montrer de tendance.

RESUMEN

El método Honma para estimar la intensidad efectiva de pesca y los índices de abundancia, ha sido ampliamente aplicado a los análisis de evaluación de poblaciones de túnidos y marlines. Se presenta en detalle un desarrollo matemático de las ecuaciones de Honma y estimadores, poniendo especial énfasis en los supuestos necesarios a la aplicación del método. Se compara el método Honma con el enfoque del "Robson Generalized Linear Model" destinado a desarrollar índices de abundancia. En teoría, el método Robson parece más adecuado, si bien el método Honma presenta ciertas ventajas prácticas en el trato de conjuntos de datos amplios y desequilibrados. Se desarrollan índices Honma de abundancia para el atún rojo del Atlántico Oeste. El índice Honma de peces grandes descendió visiblemente a principios de la década de los 60, fluctuando desde entonces en las proximidades de una media estacionaria. De forma similar, el índice de peces pequeños descendió bruscamente a mediados de los años 60, fluctuando posteriormente sin mostrar tendencia.

INTRODUCTION

The Honma Method for estimating effective fishing intensity and indices of abundance has been widely used for stock assessment analyses of tunas and billfishes, since the publication of Honma's (1974) paper. Similar methods had also been employed prior to this time, mainly by Japanese scientists working on tuna assessments in the Pacific Ocean.

The Honma (1974) paper was published in Japanese with a detailed English summary attached. In the English summary, the development of the equations and estimators, as well as the rationale for their use, is rather brief. In particular, it is difficult to determine the kind and the scope of the assumptions that are required to carry out the method.

The purpose of this paper is threefold:

(1) To provide a detailed development of the Honma equations and estimators, with particular emphasis on the assumptions that are needed to employ the method.

(2) To briefly compare the method, in general terms, with the Robson Analysis of Variance Method (Kimura 1951; SEFC 1984) for developing indices of abundance.

(3) To use the Honma Method for developing indices of abundance for western Atlantic bluefin tuna.

EQUATIONS AND ASSUMPTIONS

If the fish are uniformly distributed over the entire stock area and the stock area is constant throughout the year then following Gulland (1969), the annual catch is given by:

$$C = qg\frac{N}{A} \qquad (1)$$

where C is the annual catch (number per yr)

g is the annual effort (hooks per yr)

N is the average stock size over the year (number)

A is the area inhabited by the stock (number of standard 5 degree subareas)

q is the catchability coefficient [1/(hooks per area)]

Equation (1) requires the following assumptions:

(A1) The fish are uniformly distributed over the entire stock area.

(A2) The stock area is constant over the entire year.

Rearranging terms, the average stock size is given by

$$\bar{N} = \frac{AC}{qg} \qquad (2)$$

Subdividing the entire range of the stock into 5 degree subareas, denoted by the subscript i, we have

$$\bar{N} = \sum_i N_i = \sum_i \frac{A_i C_i}{q_i g_i}$$

Then invoking the following assumptions:

(A3) Catchability has no subarea or monthly component (i.e. catchability is constant over all subareas and since no distinction is made as to the month in which the catch is taken, q is also assumed to be constant over months).

we have,

$$\bar{N} = \frac{1}{q} \sum_i A_i \frac{C_i}{g_i} \qquad (3)$$

The average density ($\bar{d}$) of the fish over the year is then given by

$$\bar{d} = \frac{\bar{N}}{A} = \frac{\frac{1}{q} \sum_i A_i \frac{C_i}{g_i}}{A} \qquad (4)$$

By definition, effective effort (X) is given by

$$X = \frac{C}{\bar{U}} = \frac{C}{q\bar{d}} \qquad (5)$$

where $\bar{U}$ is the effective catch-per-unit-effort and all other terms are defined as before.

Substituting Equation (4) into Equation (5) and simplifying, we have

$$X = \frac{C}{\sum_i \frac{A_i C_i}{g_i} \Big/ A}$$

Then making the following assumption:

(A4) The entire stock area is fished during the course of a year, such that $\sum_i A_i = A$

we have

$$X = \frac{C}{\sum_i \frac{A_i C_i}{g_i} \Big/ \sum_i A_i} \qquad (6)$$

Then since $C = \sum_i (C_i/g_i) * g_i$ we have

$$X = \sum_i \left(\frac{C_i/g_i}{\sum_i \frac{A_i C_i}{g_i} \Big/ \sum_i A_i} \cdot g_i \right) \qquad (7)$$

Equation (7) can be rewritten as

$$X = \sum_i r_i * g_i \qquad (8)$$

where $$r_i = \frac{C_i / g_i}{\sum_i \frac{A_i C_i}{g_i} \Big/ \sum_i A_i} \qquad (9)$$

and r_i is the ratio of density in subarea i to an area-weighted average density (since q is constant). The form of Equation (8) implies that effective effort is estimated by adjusting the nominal effort in subarea i (g_i) by a relative density term for the same subarea (r_i).

Assumptions A1 and A2 are quite restrictive, especially when dealing with highly migratory species. When the fish are not uniformly distributed over the stock area (A1) or when the stock area is not constant throughout the year (A2), due to migration, the only problem arising from deviating from these assumptions is that the sample average density (from Equation 4) will generally be greater than the true density since in general, fishing will be done in the subareas (and months) which produce good catches. The resulting estimate of CPUE (denominator of Equation 6) will still be a valid index of density as long as the ratio of true density to sample density remains constant from year to year. Assumptions A1 and A2 may be replaced, therefore, by a less restrictive assumption:

(A5) The percentage bias in the sample density index (denominator of Equation 6), due to the non-uniform distribution of the fish and the changing stock area throughout the year, is constant from year to year.

Honma discusses the use of Equation (7) for estimating effective effort for tunas in earlier papers by himself and other Japanese scientists. Because of the restrictive assumptions needed to employ Equation (7) on the Japanese longline data (i.e. Assumptions A3-A5), various ad hoc procedures, which used subsets of the entire time series, were developed for stock assessment analyses in the late 1960's. One method [Honma et al. (1971); in Japanese, cited in Honma (1974)] used only data from years when the fishery covered the entire distributional range of the stock. This was done to satisfy Assumption A4 but indirectly satisfies Assumption A5, as well, because the Japanese effort distribution was consistent during the years when the fishery spanned the entire Atlantic Ocean (mid 1960's). However, this method did not allow for the estimation of stock size indices from the early years of the fishery. Another method [Suda and Kume (1967); in Japanese, cited in Honma (1974)] attempted to accomplish this by developing geographical density indices from years when the fishery covered the range of the stock and applying these indices to earlier years, when the fishery was limited geographically. Honma (1974) further developed this method and applied it not only to the earlier years but also to the later years, when the fishery was again more limited geographically. All of these procedures assumed that catchability (separated from density and availability) was constant (Assumption A3). If the type of fishing operation, the type of bait used, etc., affect q, then nominal effort must be adjusted accordingly before using these methods. The development of Honma's (1974) equations and the implied assumptions are given below.

Honma (1974) generalized Equation (8), which has no monthly indices, by adding a term that allowed availability to vary monthly and by introducing the concept of "standard years", over which indices of availability and density were estimated. (Honma actually used quarters of the year rather than months, but most subsequent applications of his method (including his own) have employed months rather than quarters). His generalized expression and the central equation of his method is

$$X_{jk} = a_j \sum_i r_{ij}\, g_{ijk} \qquad (10)$$

where X_{jk} is effective effort fished in the jth month of year k

a_j is an index of availability during month j

r_{ij} is an index of density in subarea i during month j (similar to Equation 9 but generalized)

g_{ijk} is the effort fished in subarea i juring month j of year k

In formulating his method around Equation (10), Honma accounts for the migratory nature of tunas with the monthly availability term (a_j). Any other monthly effects on catchability and any subarea effects (on q) are assumed to be constant, as per Assumption A3. This can be seen more clearly in the following development of Honma's equations and estimators.

He develops an index of density (r_{ij}) analogously to the development of r_i in Equation (9), above

$$r_{ij} = \bar{d}_{ij} \,/\, \bar{d}_j \qquad (11)$$

and

$$r_{ij} = \frac{\bar{N}_{ij}}{A_{ij}} \Bigg/ \sum_i \frac{\bar{N}_{ij}}{A_j} \qquad (12)$$

where $\bar{d}_{ij}$ is the average density in the ith 5 degree subarea during the jth month

$\bar{d}_j$ is the average density in month j throughout the stock area

$\bar{N}_{ij}$ is the average stock size in subarea i during month j

A_{ij} is the area of the ith subarea occupied by the fish during the jth month

A_j is the total area inhabited by the stock during month j

Substituting Equation (2) into Equation (12),

$$r_{ij} = \frac{\dfrac{A_{ij}\ C_{ij}}{q_{ij}\ g_{ij}}}{A_{ij}} \Bigg/ \frac{\sum\limits_i \dfrac{A_{ij}\ C_{ij}}{q_{ij}\ g_{ij}}}{A_j} \tag{13}$$

Since catchability is constant over all subareas within a month (Assumption A3), we have $q_j = q_{ij}$ and

$$r_{ij} = \frac{C_{ij}}{q_j\ g_{ij}} \Bigg/ \frac{\dfrac{1}{q_j} \sum\limits_i \dfrac{A_{ij}\ C_{ij}}{g_{ij}}}{A_j} \tag{14}$$

Then by definition $A_j = \sum\limits_i A_{ij}$

but in practice the A_{ij} will come from the fisheries data and it is, therefore, tacitly assumed that:

(A6) The subareas fished within a month (during "standard years") correspond exactly to the stock area for that month.

(A7) The fish are uniformly distributed throughout each subarea. This avoids having to estimate the portion of each subarea that was occupied by the fish (which cannot be done since the catch and effort data are not available with finer resolution than the 5 degreee subarea).

Then

$$r_{ij} = \frac{C_{ij}}{g_{ij}} \Bigg/ \frac{\sum\limits_i \dfrac{A_{ij}\ C_{ij}}{g_{ij}}}{\sum\limits_i A_{ij}} \tag{15}$$

When data are available for a subarea-month from several years, Honma suggests estimating the subarea-month CPUE term (i.e., C_{ij}/g_{ij}) by

$$U_{ij} = \frac{1}{l_{ij}} \sum_{k=1}^{l_{ij}} C_{ijk} / g_{ijk} \tag{16}$$

where k is the year index

l_{ij} is the number of years area-month ij was fished during the "standard years"

Note that in the Honma notation, d_{ij} is used in place of the U_{ij} used above. This departure from the Honma notation was taken to avoid confusion with the average density term, $\bar{d}_{ij}$, in Equation (11).

Substituting Equation (16) into Equation (15), gives Honma's density index

$$r_{ij} = \frac{U_{ij}}{\sum\limits_i A_{ij}\ U_{ij} \Big/ \sum\limits_i A_{ij}} \tag{17}$$

Next, the index of availability (a_j) is developed

$$a_j = \bar{N}_j \Bigg/ \frac{1}{n} \sum_{j=1}^{n} \bar{N}_j \tag{18}$$

where n is the number of months fished during the standard years

Substituting Equation (3) into Equation (18) and assuming $q_j = q_{ij}$ (Assumption A3):

$$a_j = \frac{1}{q_j} \sum_i A_{ij}\ U_{ij} \Bigg/ \frac{1}{n} \sum_{j=1}^{n} \left(\frac{1}{q_j} \sum_i A_{ij}\ U_{ij} \right) \tag{19}$$

Since catchability is constant over months, i.e., $q = q_j$, we have Honma's availability index:

$$a_j = \sum_i A_{ij} U_{ij} \Bigg/ \frac{1}{n} \sum_{j=1}^{n} \sum_i A_{ij} U_{ij} \qquad (20)$$

Neither r_{ij} or a_j have a year index, which implies that they do not change from year to year. Honma suggests estimating these parameters from the "standard years" and using them to estimate effective effort for all years using Equation (10). He recommends that the "standard years" be chosen such that: (1) the fishery covered the entire distributional range of the fish; and (2) the stock size was relatively stable during the period. The first condition attempts to satisfy Assumptions A4-A6, while the second condition is needed to estimate the year invariant parameters (r_{ij} and a_j).

After estimating effective effort (X_{jk}) using Equation (10), annual fishing intensity (f_k) can be estimated from

$$f_k = \sum_{j=1}^{n} f_{jk} = \sum_{j=1}^{n} X_{jk} / A_j \qquad (21)$$

where as above, A_j is the area inhabited by the stock in the jth month. In practice, this is estimated by summing the area of the 5 degree subareas that were fished in month j and that met the following two conditions: (1) the subarea was within a predefined stock area, usually defined by the species' range; and (2) that the U_{ij} from Equation (16) be greater than zero.

Then from Equation (1), we have

$$C_k/f_k = q * \bar{N}_k$$

and thus

$$C_k/f_k \propto \bar{N}_k$$

Thus C_k/f_k is suggested as a stock size index over time.

COMPARISON WITH THE ROBSON METHOD

The Robson Method for developing indices of abundance is an extension of Robson's (1966) analysis of variance (ANOVA) procedure for estimating fishing power. The theory and application of the method are provided by Kimura (1981), SEFC (1984), and others. The procedure allows any effect or interaction between effects, that is thought to influence catchability, to be incorporated into an ANOVA model. If all relevant effects are incorporated into the model, then the year effect can be used as an index of abundance.

Honma discusses his method in the context of an ANOVA model and indicates that the development of his equations assumes a monthly effect (actually, quarterly) and a month-subarea interaction (presumably, a subarea effect as well). He performs a series of ANOVA analyses, using an additive model rather than Robson's multiplicative model, on yellowfin tuna data to ascertain whether or not his model is appropriate for the yellowfin data. He finds the month, subarea, and month-subarea interaction terms to be highly significant. He argues that the ANOVA results establish the validity of his method, at least with respect to the yellowfin tuna data.

The primary difference between the two models concerns the handling of catchability. The Honma method separates catchability from density and availability and assumes that catchability is constant over time and space (or if not constant, then that it has been standardized prior to applying the method). The Robson method makes no such explicit separation but models CPUE as the response variable in a multiplicative model involving any number of main effects and interactions, e.g., month, subarea, month X subarea, bait, vessel size, type of operation, etc. No assumption of constant catchability is made.

Application of the Honma method is generally more subjective than a similar application of the Robson method. This is especially true with respect to the choice of the "standard years" in the Honma method. No analogous decision needs to be made with the Robson method because all years are used in the estimation and a year term is generally included to account for stock size changes over time. Furthermore, because the Robson method is based on a formal statistical procedure (i.e. ANOVA), significance testing and confidence interval estimation are easily done. Neither of these procedures are possible when using the Honma method.

The Honma method is particularly vulnerable to the assumption that the stock distributional pattern, in space and time, is constant from year to year. If this assumption is violated then indices estimated from the "standard years" will not be valid for other years. The Robson method is also dependent on this assumption but the inclusion of interaction terms (e.g., year-month, year-subarea, or year-month-subarea) can greatly alleviate the problem.

If catchability effects (bait, vessel type, etc.) are thought to be important, then the Robson method is preferable. It should account for more of the variability in CPUE and should provide less biased indices of abundance. However, if catchability is constant then the two methods should produce similar indices of abundance.

INDICES OF ABUNDANCE FOR BLUEFIN TUNA

The Honma Method was used to develop indices of abundance for western Atlantic bluefin tuna. Separate indices were generated for large and small fish. The western Atlantic stock area boundaries and the large (age 10 and older) and small (ages 1-5) fish areas (Figure 1), developed by Parrack (pers. comm.), were used in the analysis. Japanese longline catch and effort data were taken from Shiohama et al. (1965) for the years 1957-61, from the annual reports of the Fisheries Agency of Japan (1964-82) for 1962-80, and from the ICCAT Secretariat for 1981-82.

The most subjective aspect of the Honma Method is the choice of the "standard years" period. A period during which the fishery covered a large percentage of the stock area is generally selected. Figure 2 shows the Japanese fleet's percent coverage of the western Atlantic bluefin stock area by month and by year. The period 1965-75 has been frequently used by Japanese scientists when using the Honma Method for tuna and billfish indices in the Atlantic Ocean. This period also provides good coverage of the bluefin stock area (Figure 2) but its use caused the large fish index of abundance to become unstable, particularly in 1980 when the Japanese fleet made large catches in subareas of the Gulf of Mexico for which no density index (r_{ij}) could be estimated using the 1965-75 standard year period. It was, therefore, necessary to expand the standard year period to 1965-80 in order to provide estimates of r_{ij} for all of the subareas fished after 1975. The resulting fleet coverage of the stock area by month during the 1965-80 standard year period is displayed in Figure 3. The resulting Honma index of abundance, C_k/f_k, is displayed in Figure 4 for large fish and in Figure 5 for small fish. The large fish index declined rapidly from 1962 to 1966 and then fluctuated about a stationary mean. The small fish index declined through 1968 and then fluctuated but with greater variability than the large fish index. The increasing trend from 1975 to 1977 may be tracking the strong 1973 year class since bluefin begin recruiting to the Japanese fishery at age 2 and are fully recruited at age 4 (Suzuki 1983).

The ratio of effective effort (X_k) to nominal effort (g_k) by year is shown in Figure 6 for large fish and in Figure 7 for small fish. This ratio is useful for identifying years when the fishery targeted bluefin tuna. The general pattern depicted in the figures corresponds well to the general descriptions of Japanese fleet operations (e.g., Shingu et al. 1980). Normalized indices of availability (a_j) and stock area (A_j) by month are given for large fish (Figure 8) and small fish (Figure 9). For large fish, a_j and A_j are highly correlated ($r = 0.90$). From Equation 20, this would indicate that the U_{ij} are nearly constant within a month and that little month-subarea interaction is apparent for large fish. However, for small fish a_j and A_j are not well correlated ($r = 0.419$) and month-subarea interaction appears to be important.

The Honma indices of abundance are compared to stock size trends from virtual population analysis (Powers et al. 1983) for large fish (Figure 10) and for small fish (Figure 11). For large fish, ages 10-30 were taken from Powers et al. and both indices were normalized to their 1965 values. The VPA trend is rather flat with a slight increase in the early 1970's and a slight, but steady, decline thereafter. The Honma index declines from 1966 through 1970 but then increases to about the same level as the VPA index by the late 1970's. Large differences occur prior to 1964, with the Honma index showing much larger stock sizes. It should be noted, however, that the Powers et al. VPA used a different western Atlantic stock area and that this stock area excluded some large catches off Brazil prior to 1964 that were incorporated into the Honma index.

For small fish, age 1-4 stock sizes were taken from Powers et al. and both indices were normalized to their 1964 values (Figure 11). The Honma index declines more rapidly than the VPA index but they converge to approximately the same level in 1977 and remain well correlated through 1982.

LITERATURE CITED

Fisheries Agency of Japan. 1964-82. Annual report of effort and catch statistics by area on Japanese tuna longline fishery. Research and Development Department, Fisheries Agency of Japan, Japan.

Gulland, J. A. 1969. Manual of methods for fish stock assessment. FAO. Rome. 154 p.

Honma, M. 1974. Estimation of overall effective fishing intensity of tuna longline fishery. Bull. Far Seas Fish. Res. Lab. 10:63-85.

Kimura, D. K. 1981. Standardized measures of relative abundance based on modelling log (CPUE) and their application to Pacific ocean perch. J. Cons. int. Explor. Mer. 39:211-218.

Powers, J. E., R. J. Conser and M. L. Parrack. 1983. An assessment of Atlantic bluefin tuna resources. ICCAT CVSP 18(2):563-611.

Robson, D. S. 1966. Estimation of relative fishing power of individual ships. Res. Bull. Int. Comm. N.W. Atl. Fish. 3:5-14.

SEFC. 1984. A review of some Atlantic bluefin tuna fisheries data. ICCAT CVSP 20(2):354-373.

Shingu C., K. Hisada, and Z. Suzuki. 1980. Description of the Japanese longline fishery for bluefin tuna in the Atlantic. ICCAT CVSP 11:145-160.

Shiohama, T., M. Myojin and H. Sakamoto. 1965. The catch statistic data for the Japanese tuna longline fishery in the Atlantic Ocean and some simple considerations on it. Rep. Nankai Reg. Fish. Res. Lab., No. 21, 131 p.

Suzuki, Z. 1983. CPUE trends of Atlantic bluefin tuna based on age specific effective fishing effort estimated from Japanes longline fishery, 1971-80. ICCAT CVSP 18(2):474-483.

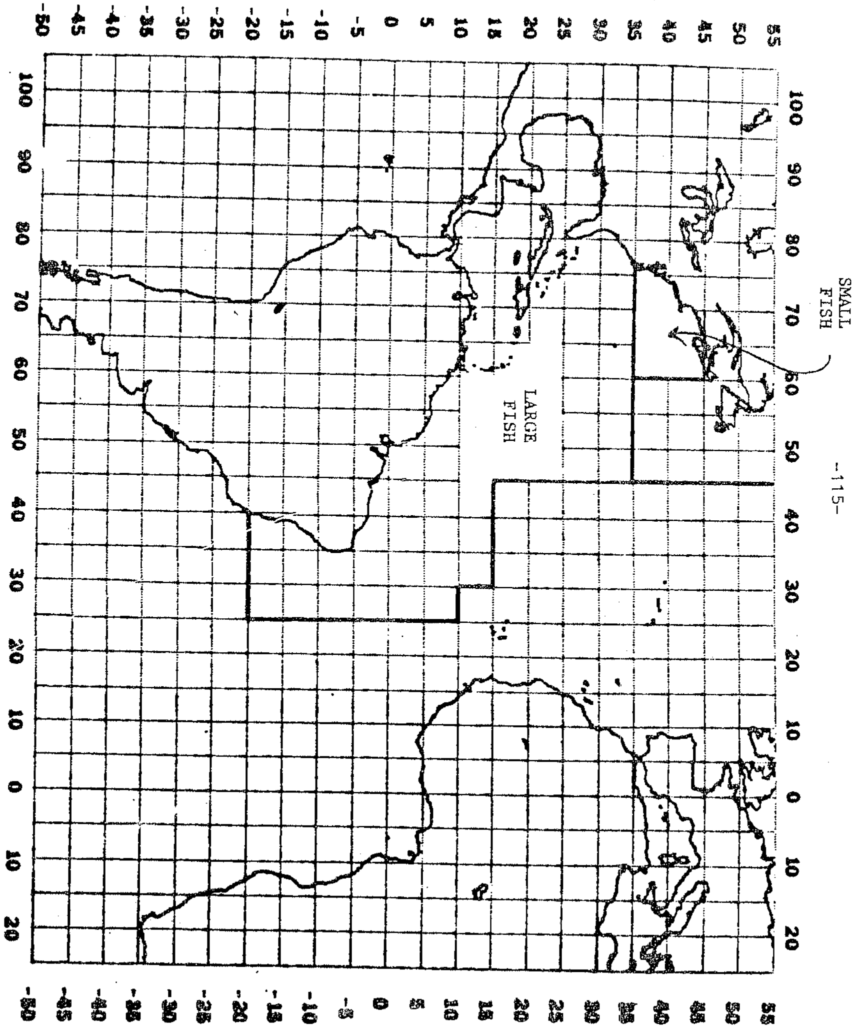

Figure 1. Western Atlantic bluefin tuna stock boundaries and large and small fish areas.

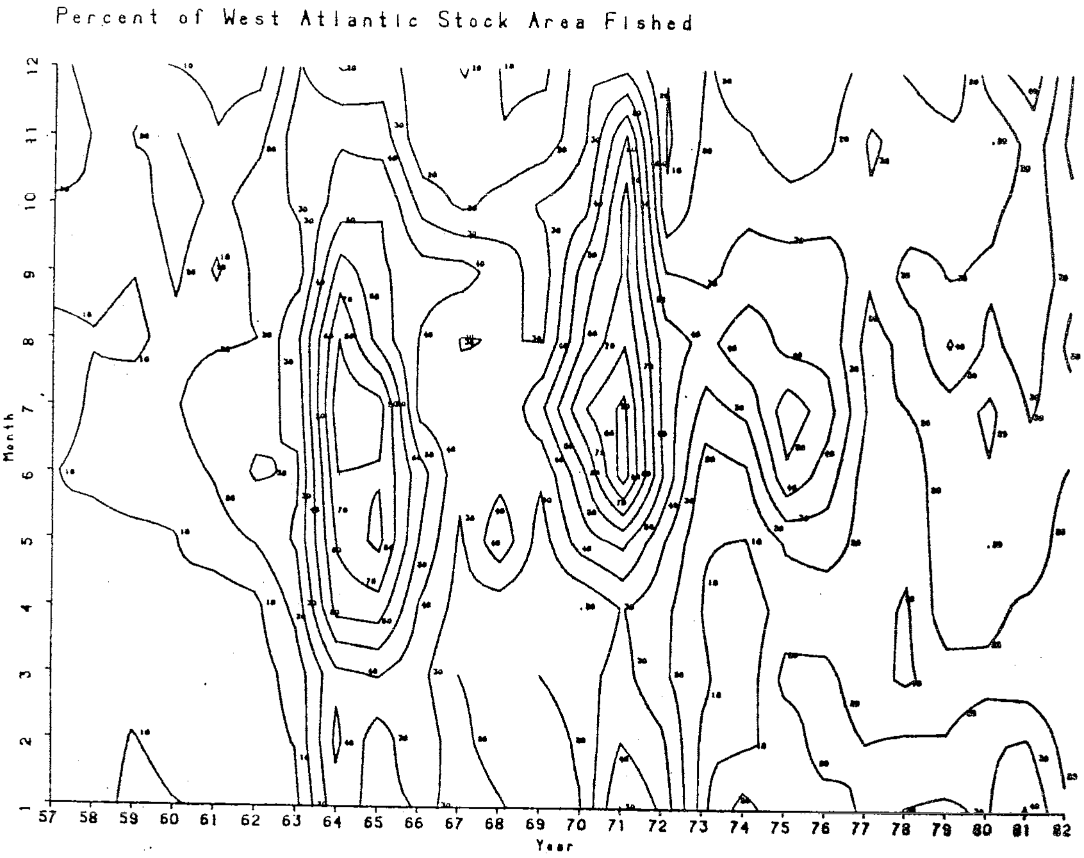

Figure 2. Isopleths showing the percent of the western Atlantic bluefin tuna stock area (See Figure 1) that was fished by the Japanese longline fleet by month and year, 1957-82.

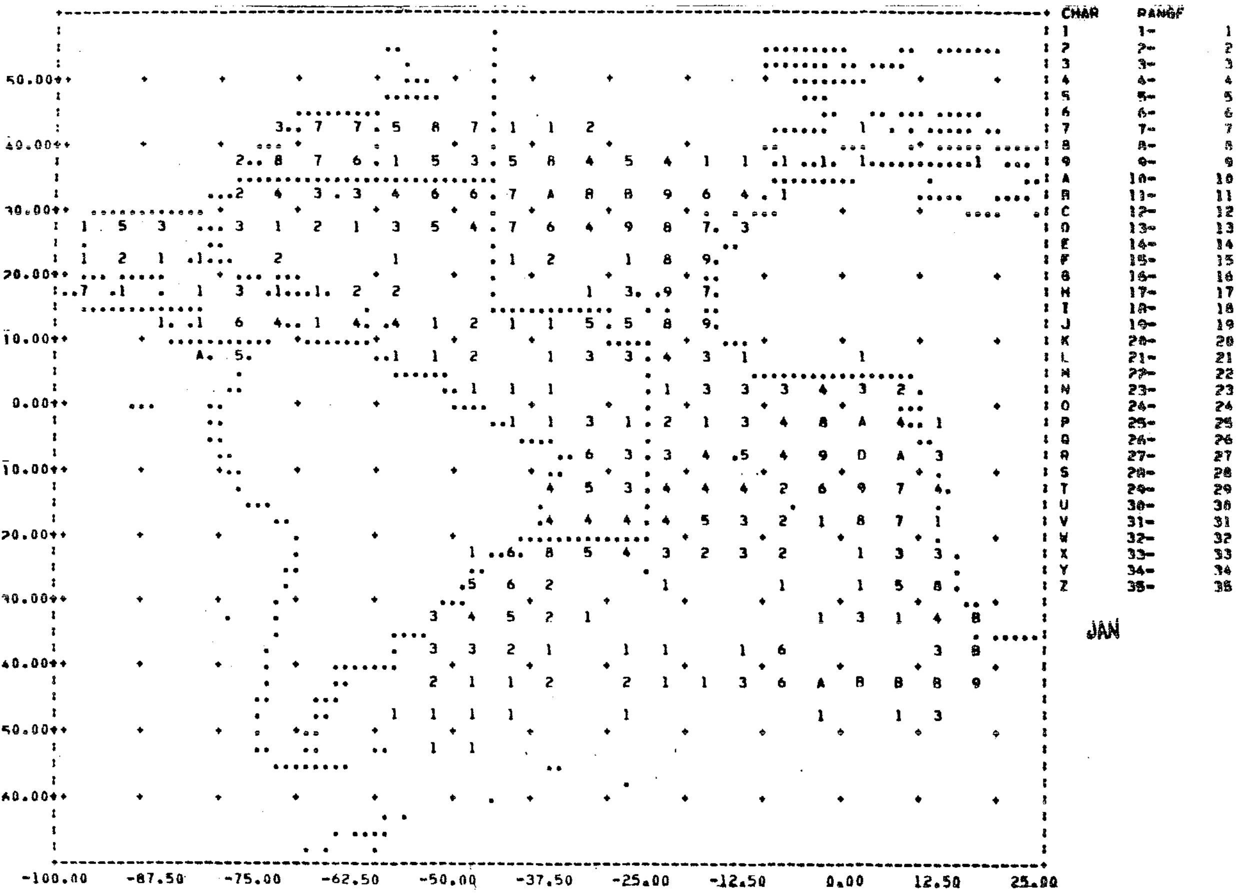

Figure 3. Number of years that a 5^{o} subarea was fished in January during the "standard years" period, 1965-80.

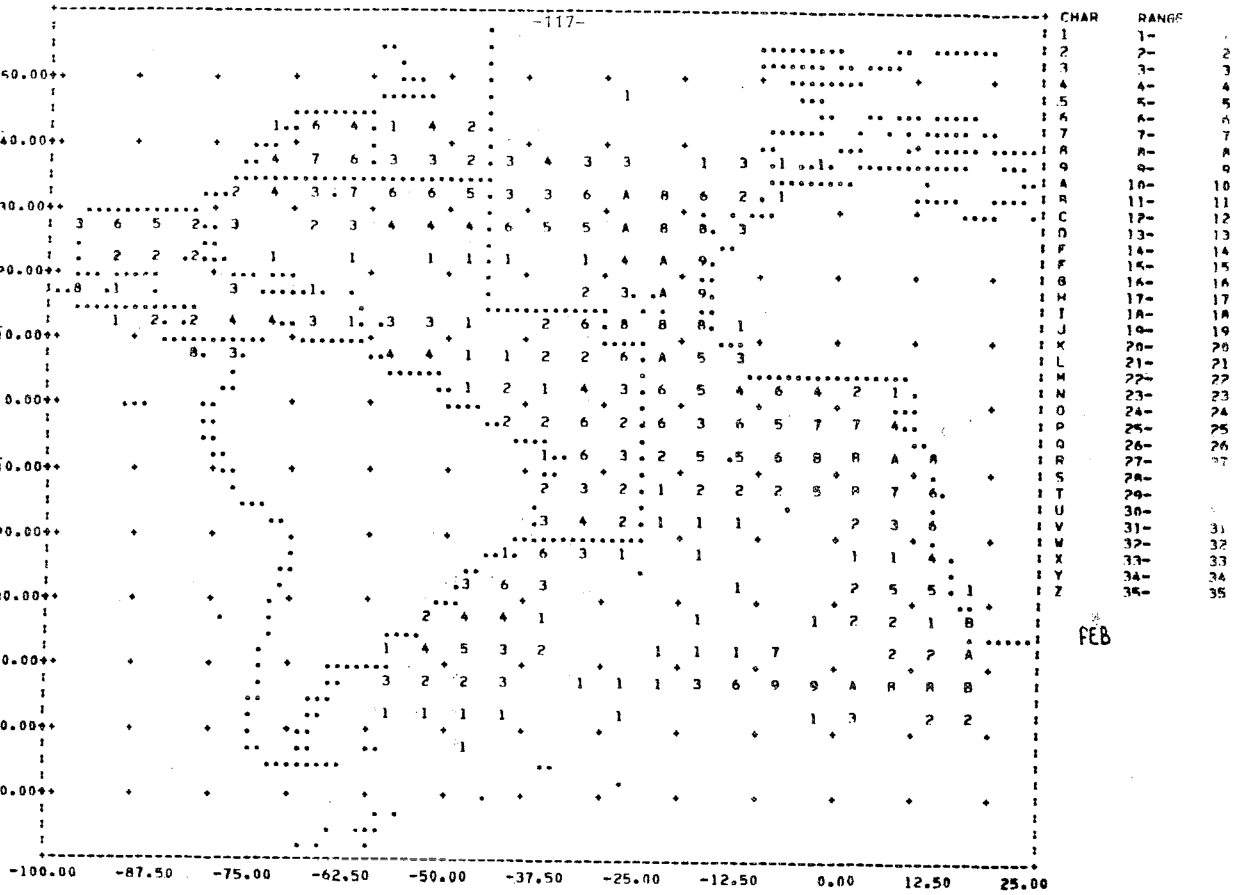

Figure 3 (con't). Number of years fished during February.

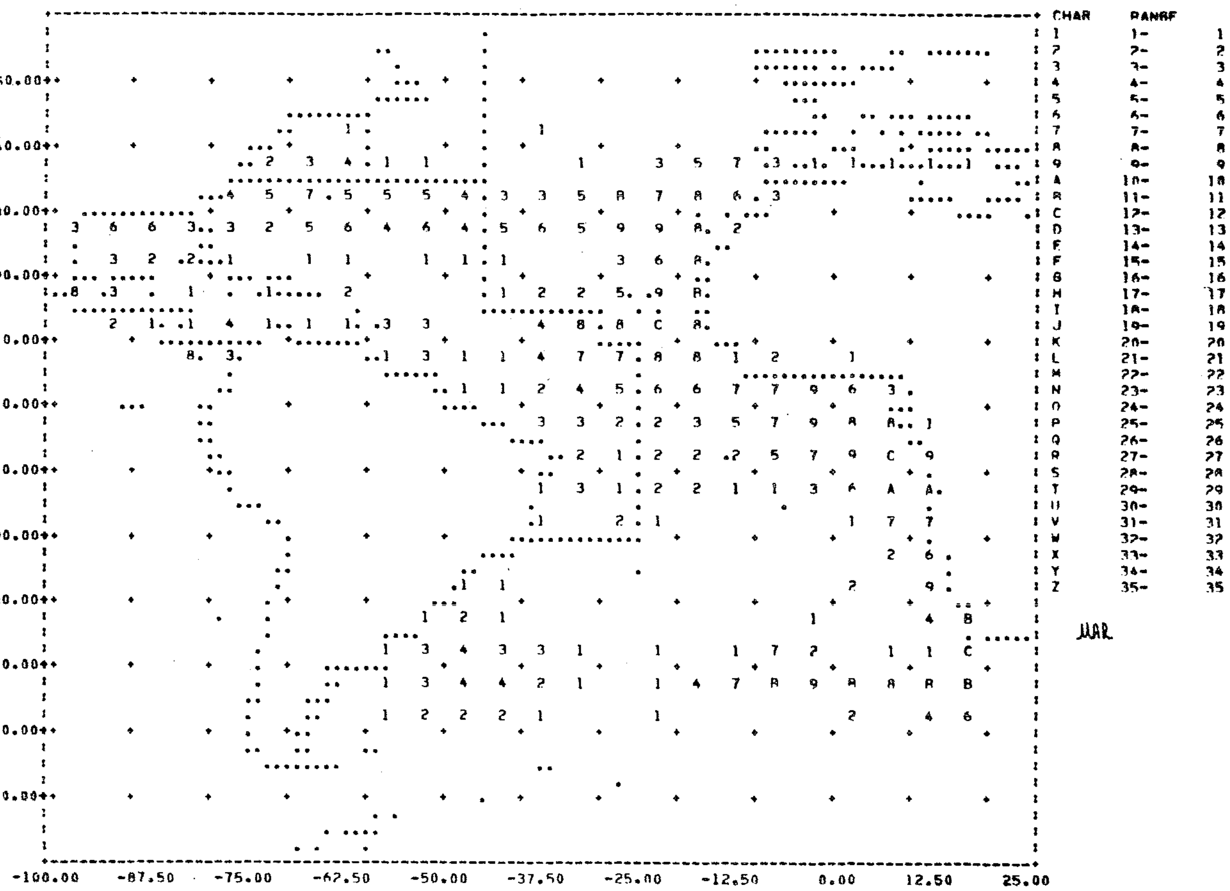

Figure 3 (con't). Number of years fished during March.

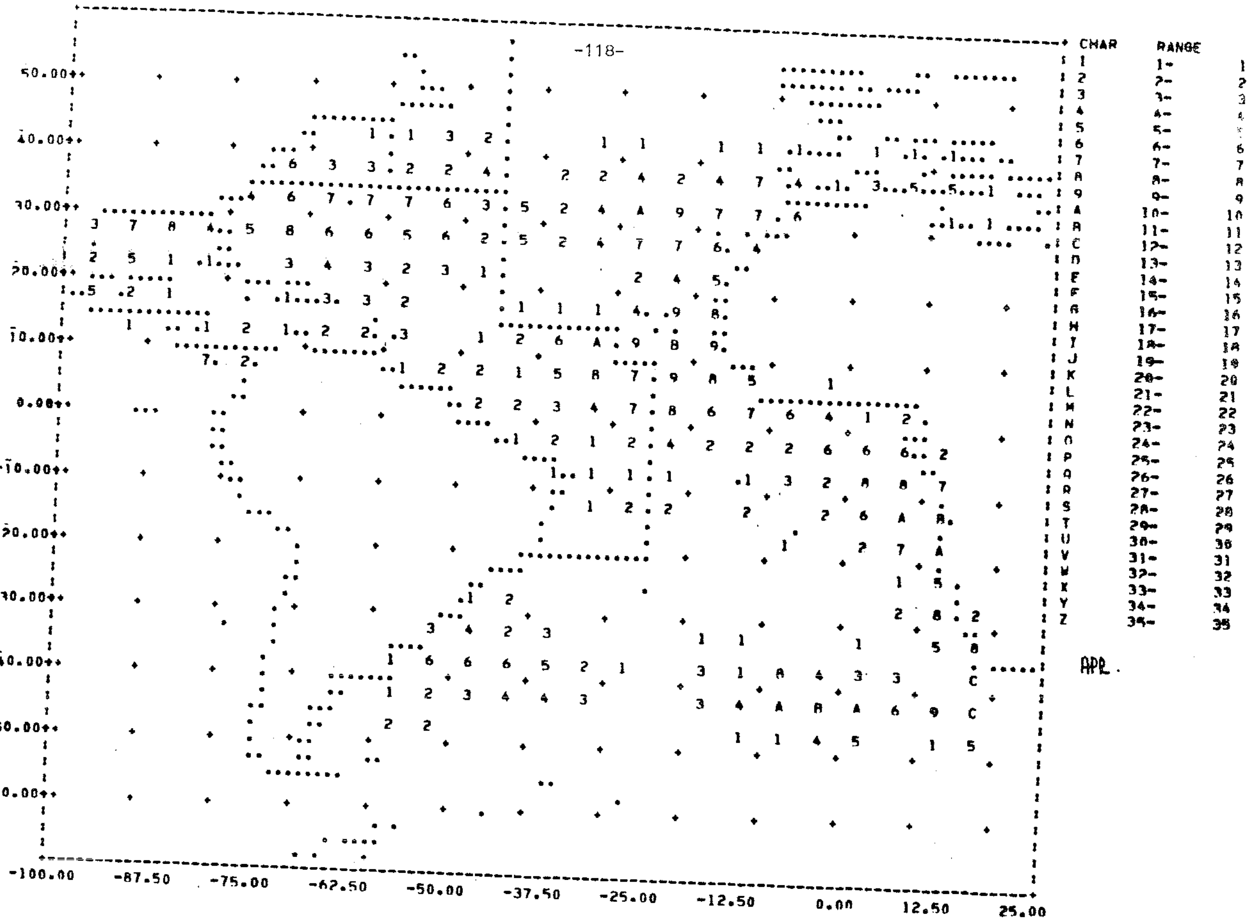

Figure 3 (con't). Number of years fished during April.

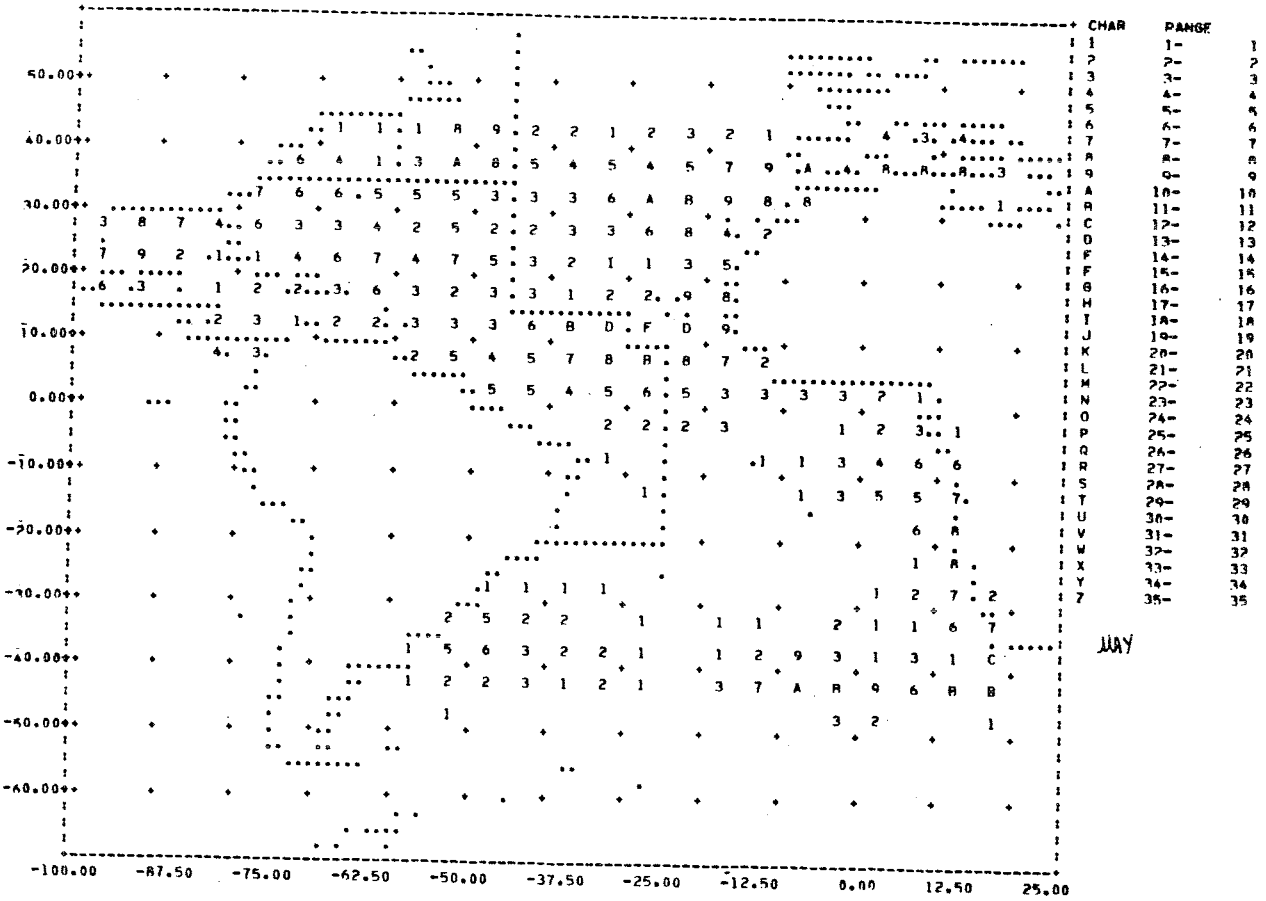

Figure 3 (con't). Number of years fished during May.

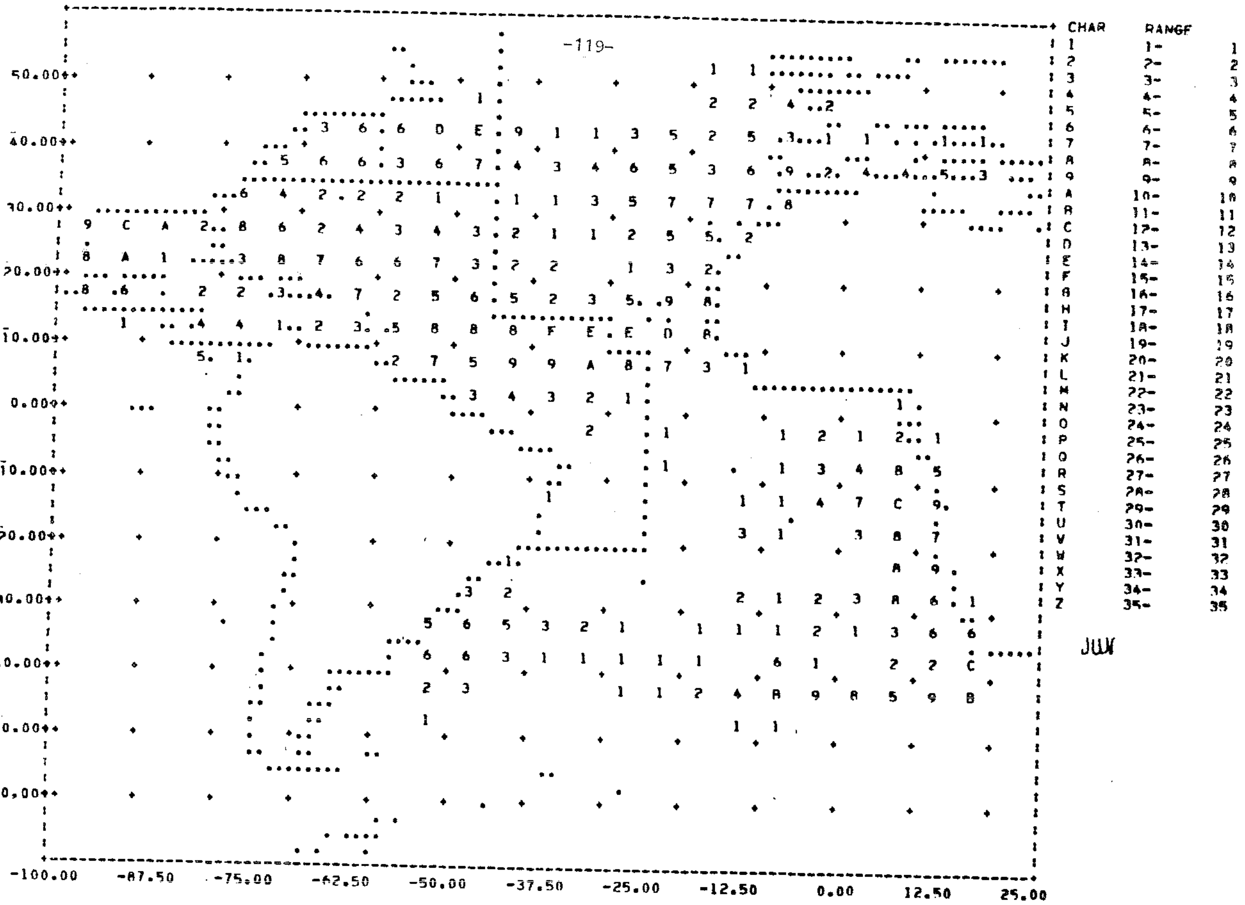

Figure 3 (con't). Number of years fished during June.

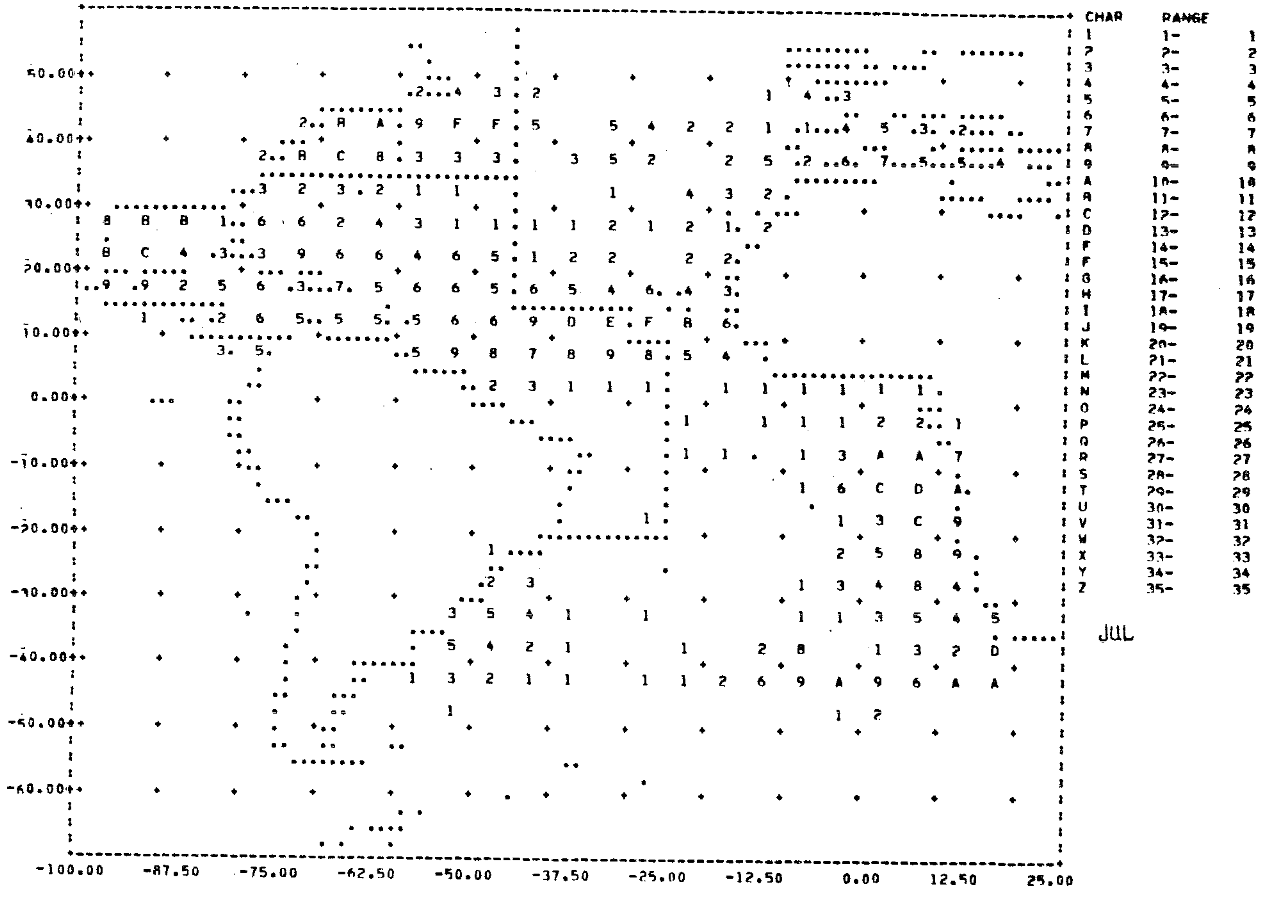

Figure 3 (con't). Number of years fished during July.

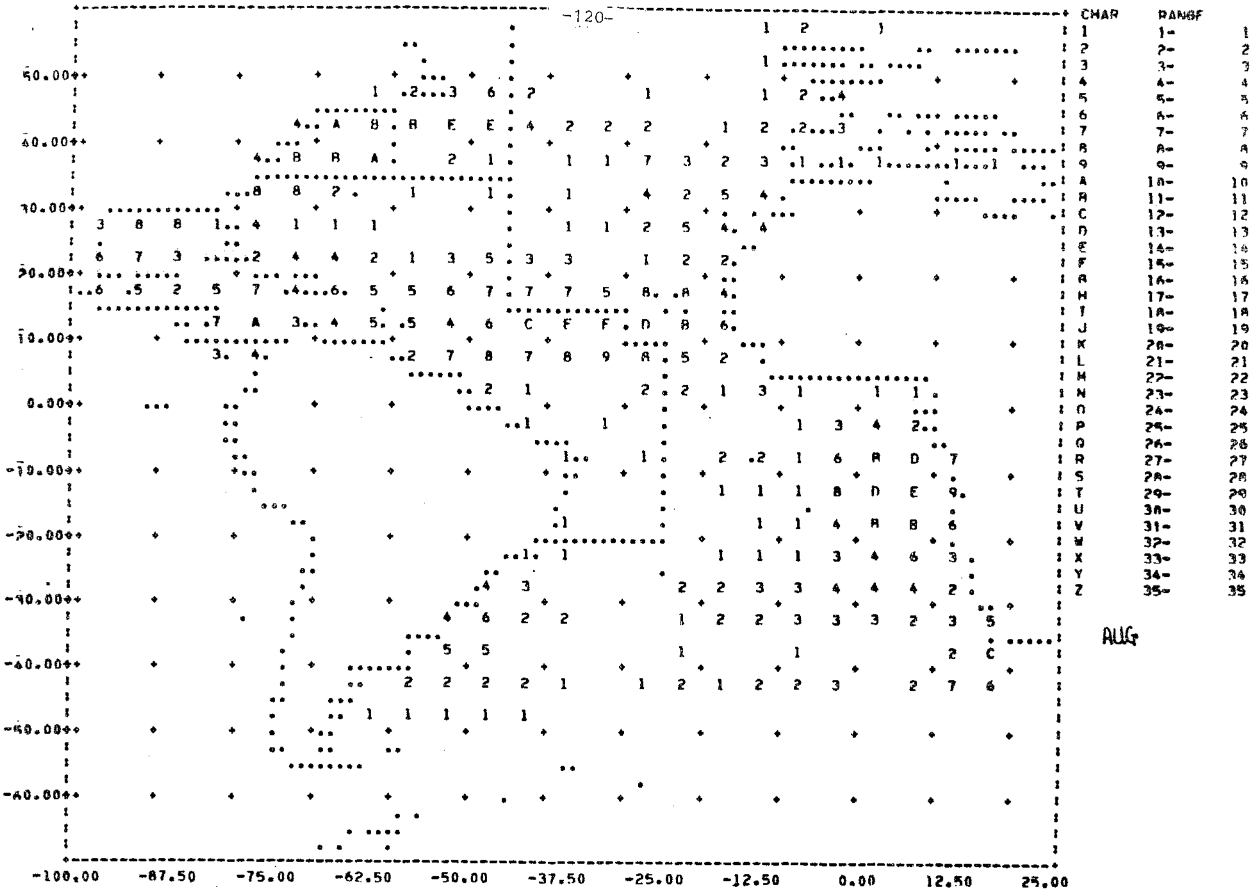

Figure 3 (con't). Number of years fished during August.

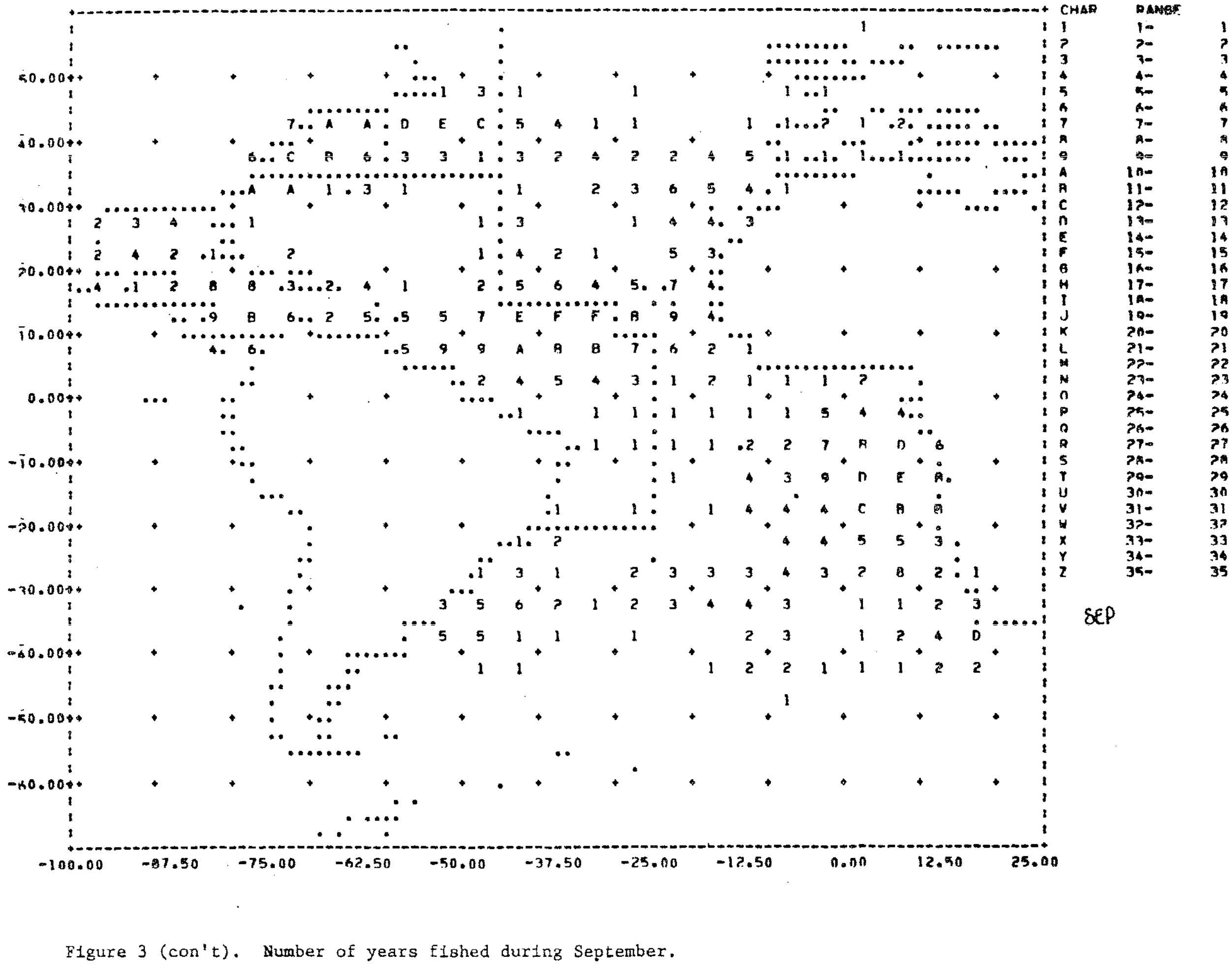

Figure 3 (con't). Number of years fished during September.

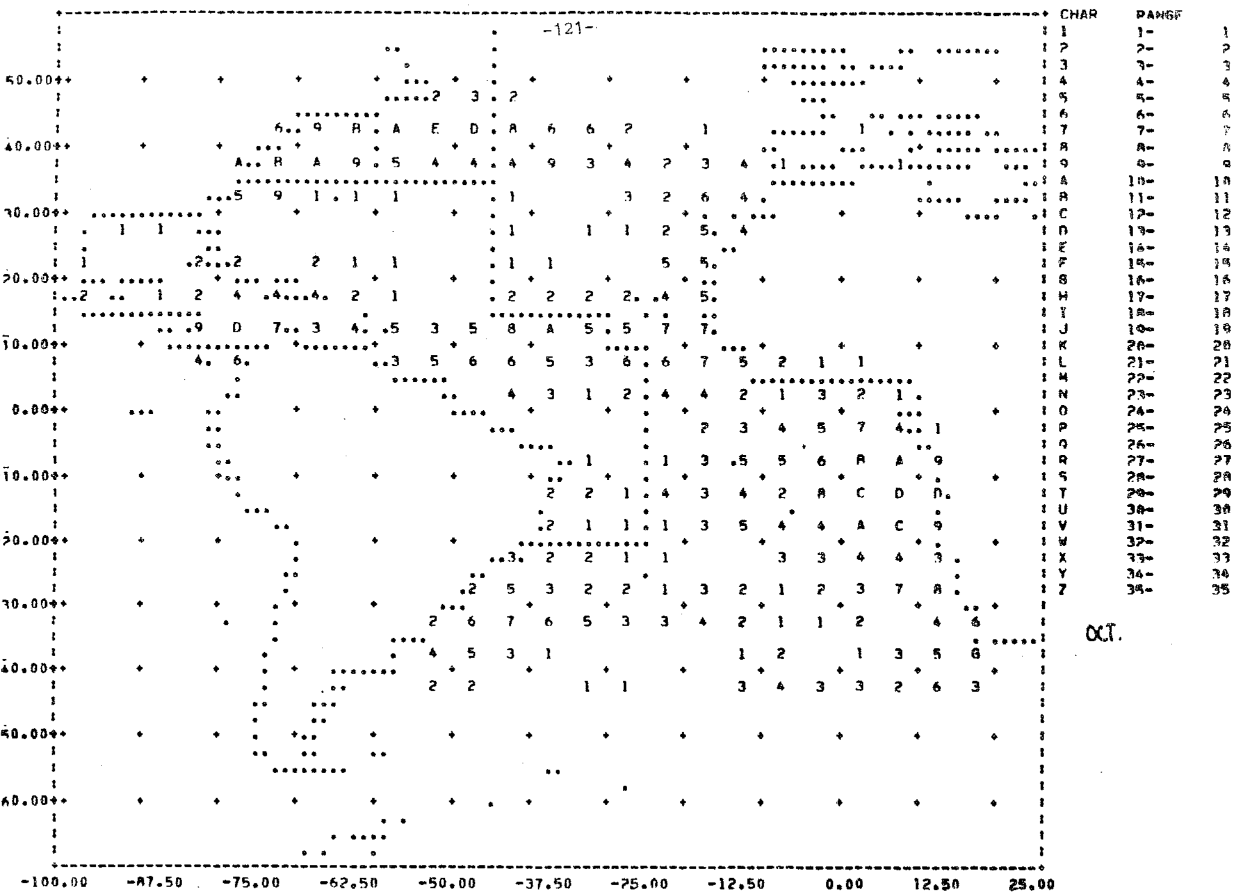

Figure 3 (con't). Number of years fished during October.

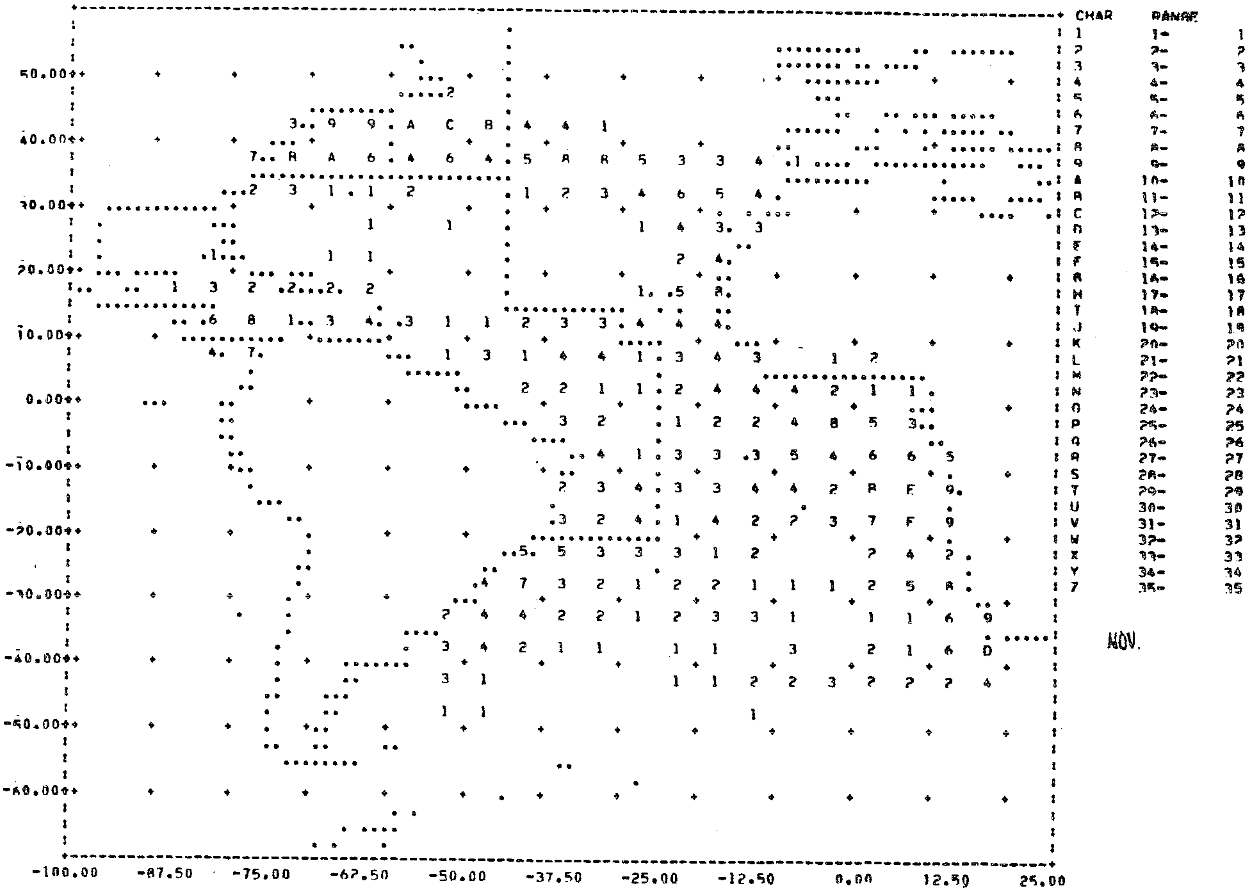

Figure 3 (con't). Number of years fished during November.

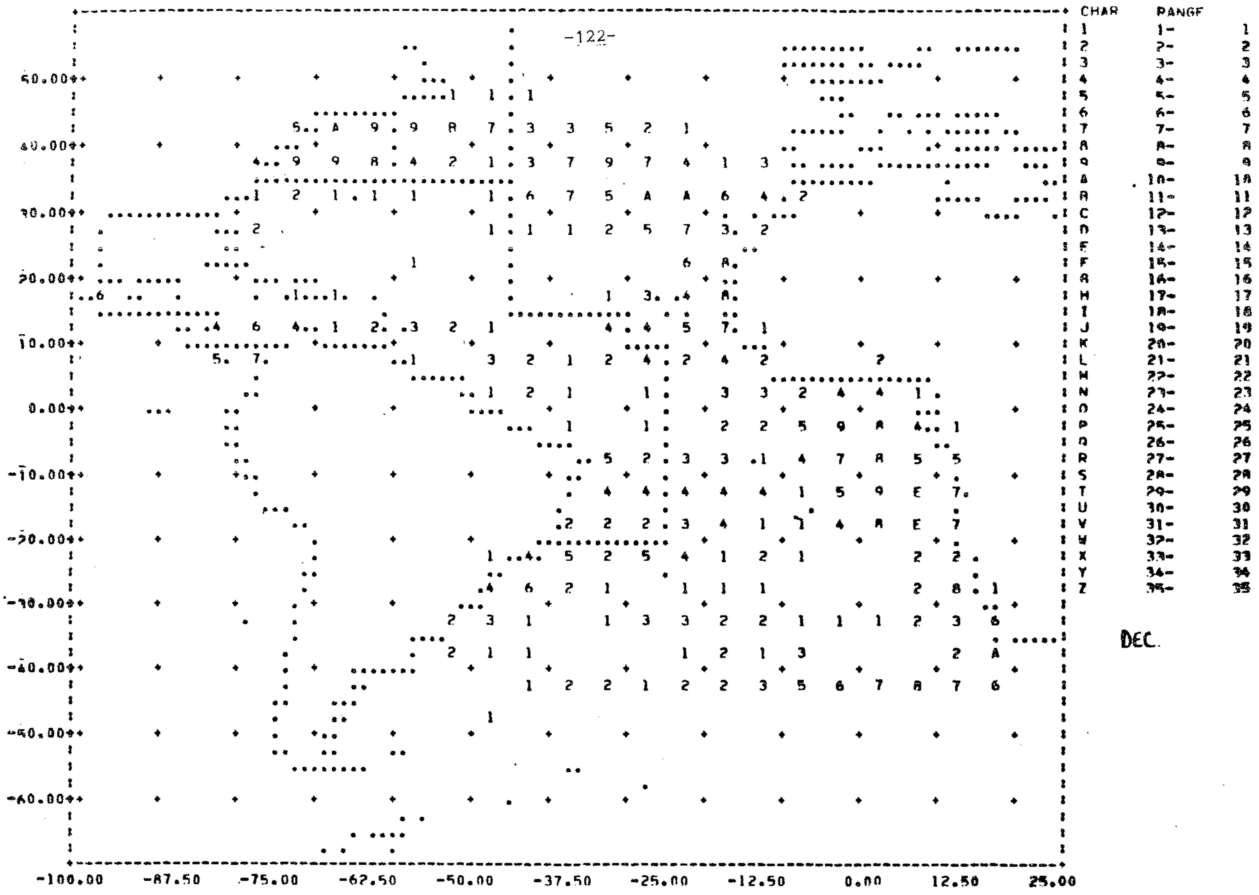

Figure 3 (con't). Number of years fished during December.

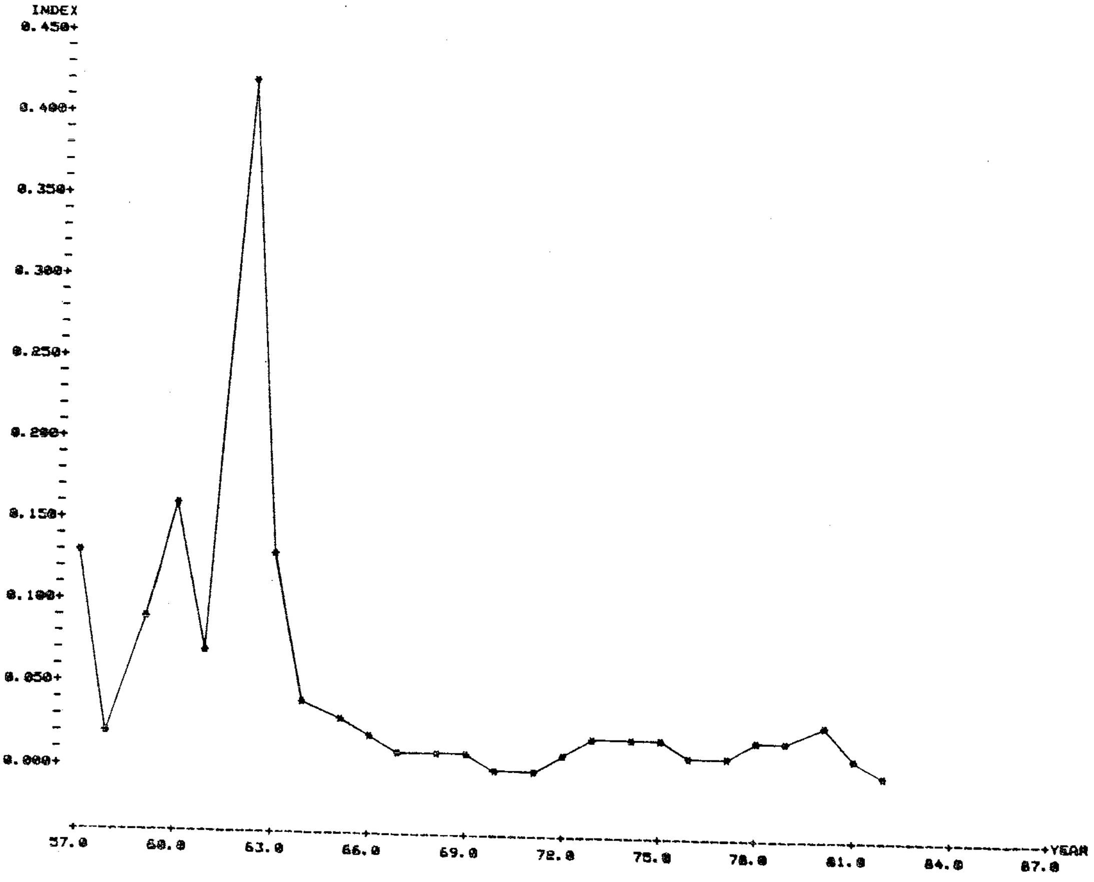

Figure 4. Honma index of abundance for western Atlantic bluefin tuna, large fish, 1957-82. The "standard years" period employed was 1965-80.

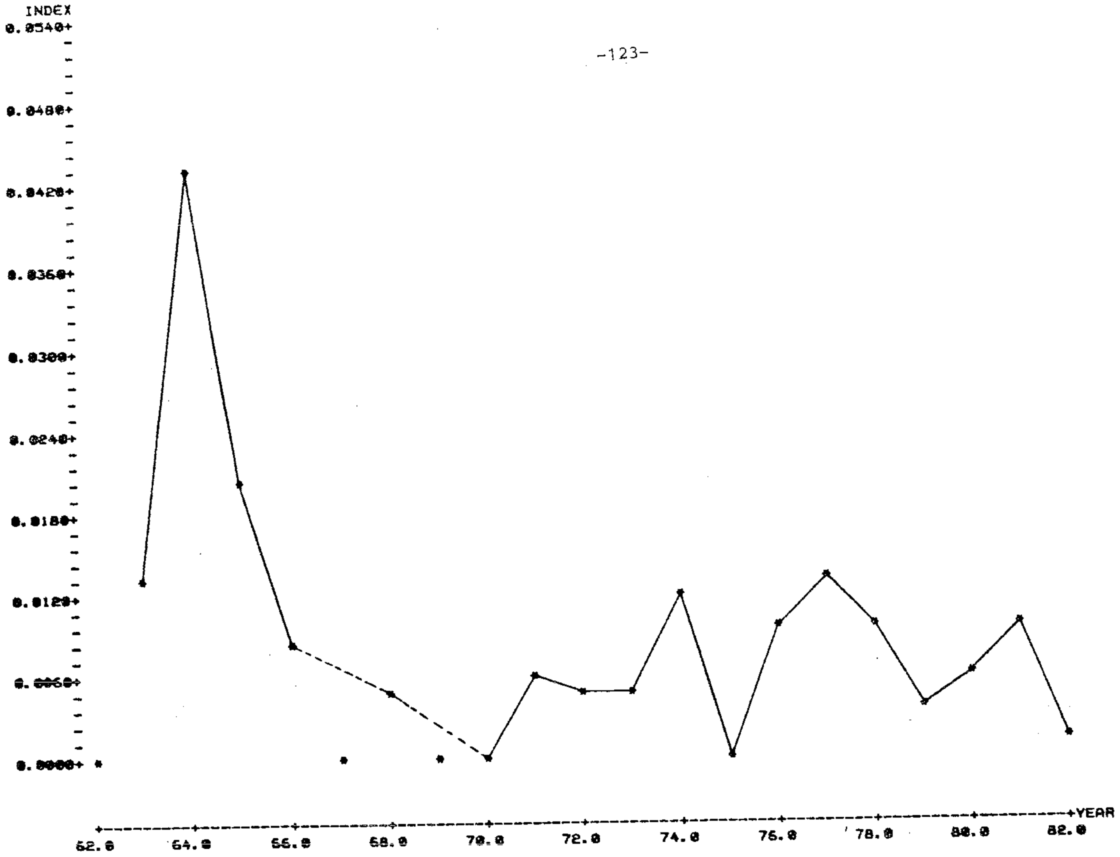

Figure 5. Honma index of abundance for western Atlantic bluefin tuna, small fish, 1963-82. The "standard years" period was 1965-80. No bluefin were caught in the small fish area (Fig. 1) in 1962, 1967, or 1969.

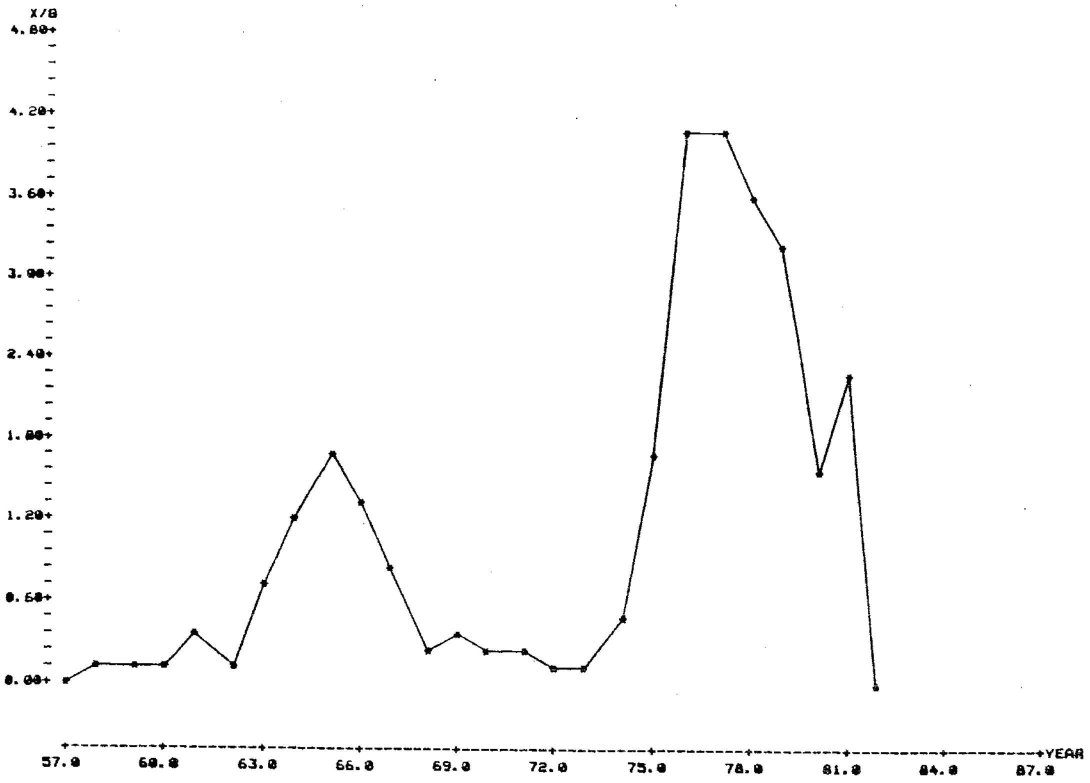

Figure 6. Ratio of effective effort to nominal effort for western Atlantic bluefin tuna, large fish, 1957-82.

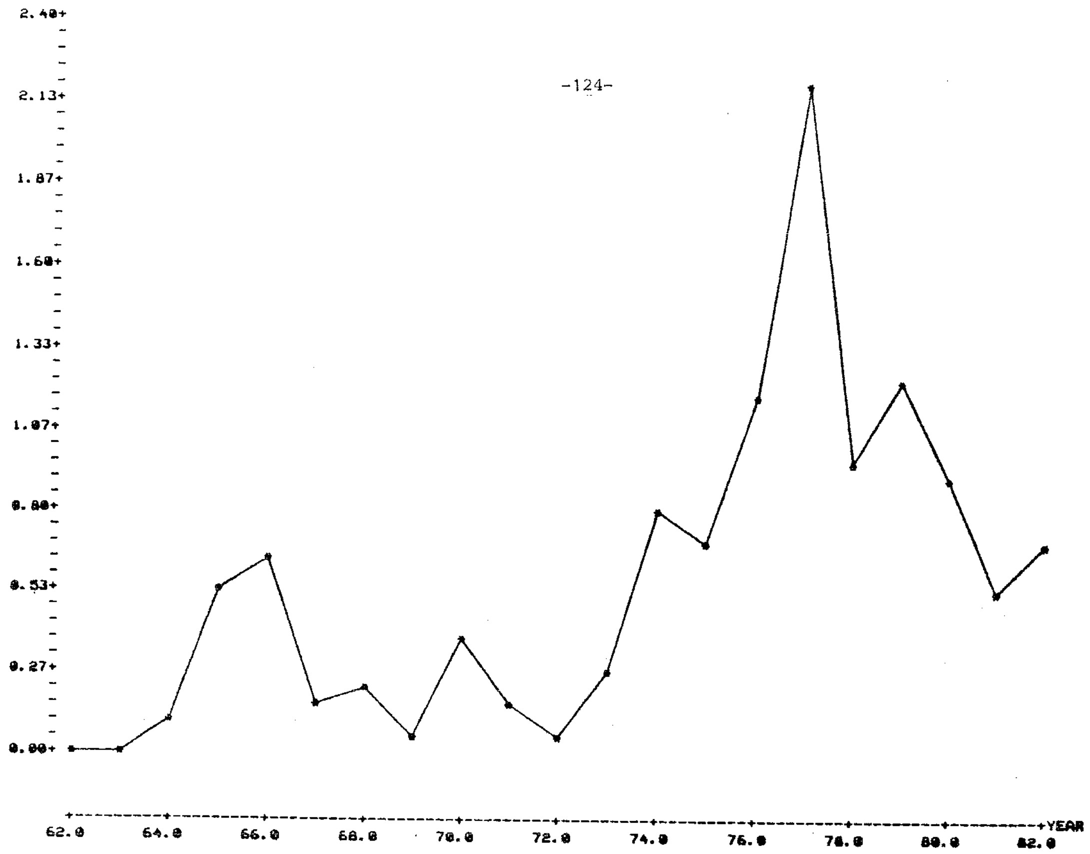

Figure 7. Ratio of effective effort to nominal effort for western Atlantic bluefin tuna, small fish, 1962-82.

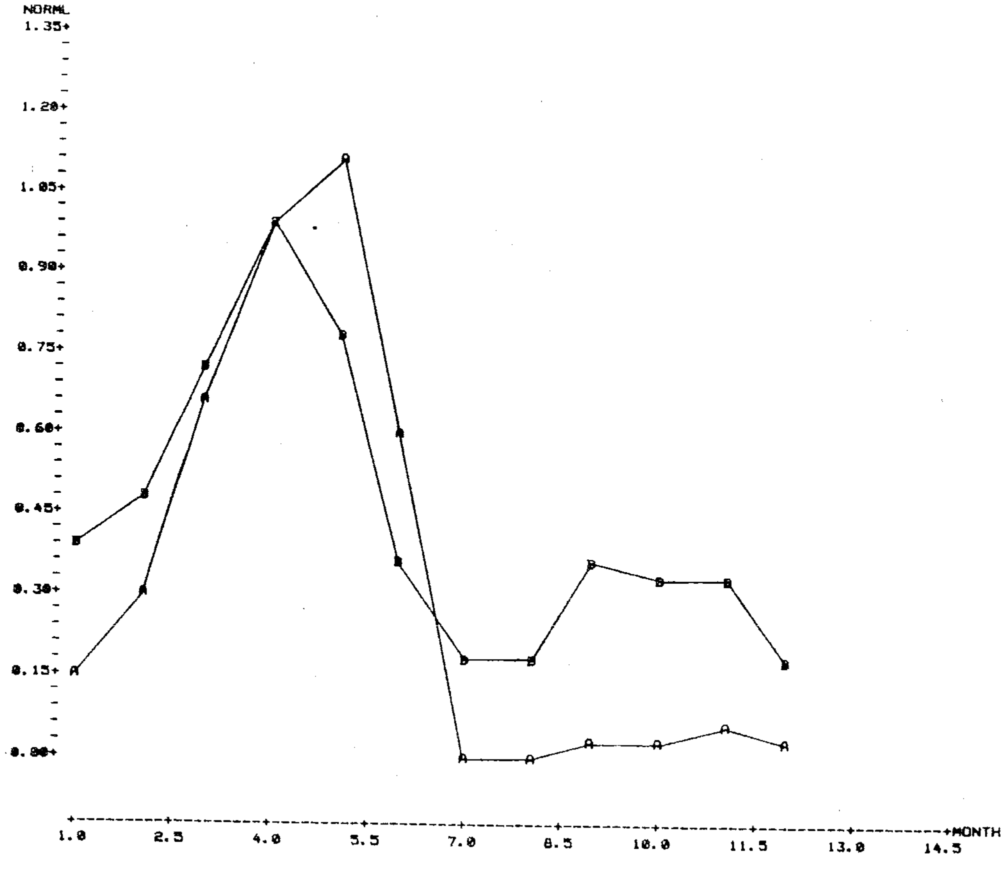

Figure 8. Availability index (A) and bluefin stock area (B) by month. Both indices were normalized to their respective April values. Large fish.

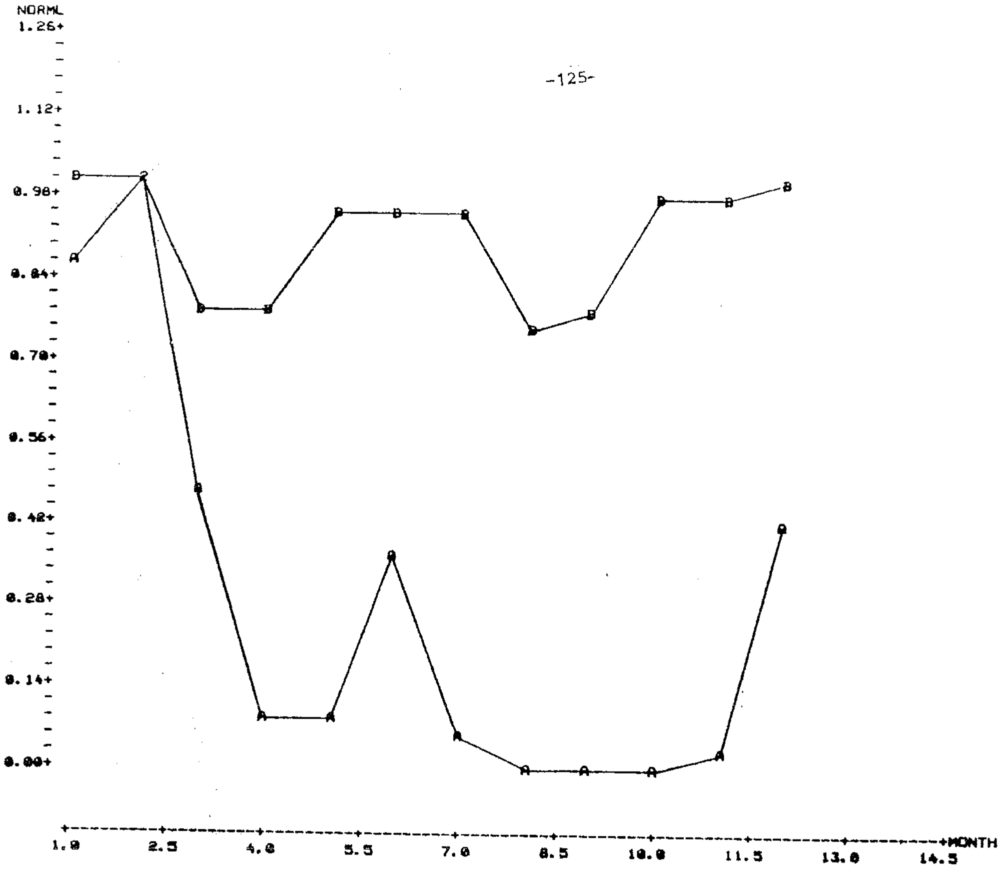

Figure 9. **Availability** index (A) and bluefin stock area (B), **small fish**, by **month**. Both indices were normalized to their **February values**.

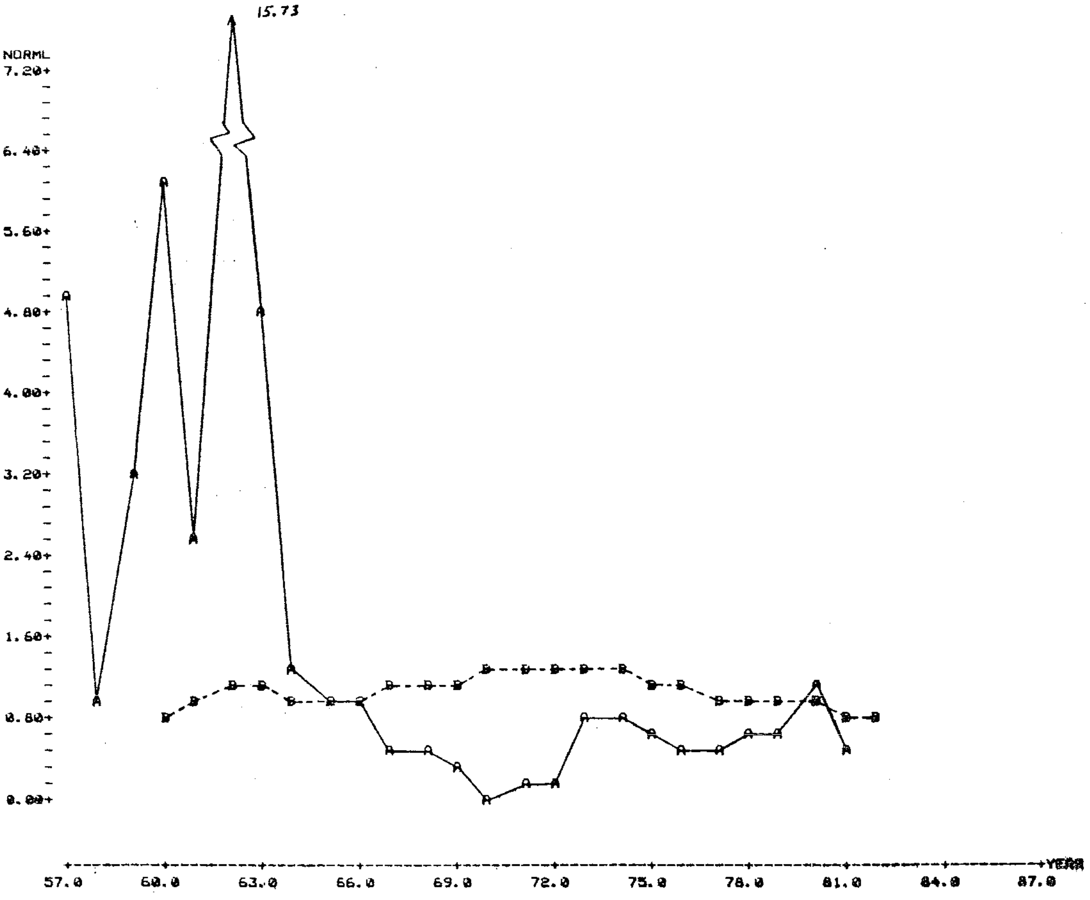

Figure 10. **Comparison** of Honma index of abundance (A) and VPA **stock size** trend (B), large fish. Both standardized to 1965.

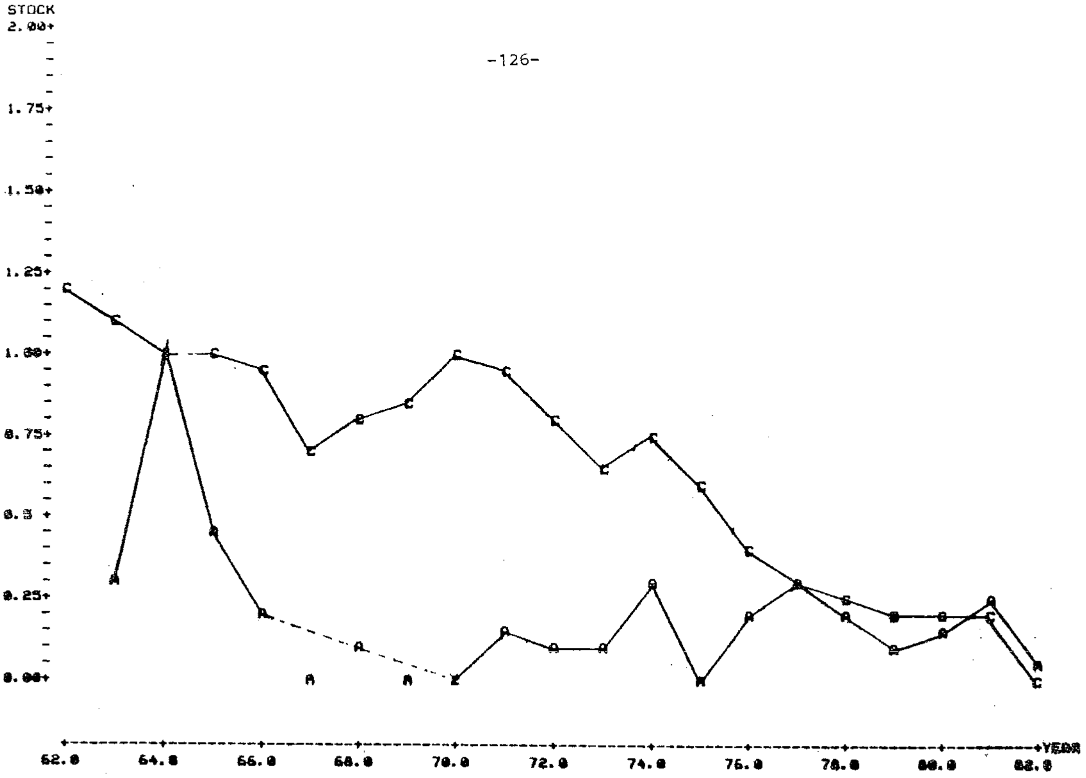

Figure 11. Comparison of Honma index of abundance (A) and VPA stock size trend (C), small fish. Both indices are standardized to their 1964 values.