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EFFORT AND CPUE AS MEASURE OF ABUNDANCE

L'EFFORT ET LE CPUE COMME MESURES DE L'ABONDANCE

ESFUERZO Y CAPTURA-POR-UNIDAD-DE-ESFUERZO COMO MEDIDA DE ABUNDANCIA

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Effort and cpue as measure of abundance

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There are two problems in estimating effective effort and cpue. One is how to standardize amount of effort produced by one type of gear of a given size operated for fish distributed unevenly in diverse areas and seasons. The other is how to standardize amount of effort produced by gears of different types or different sizes of the same type. There are many papers related to the former problem. The latter seems to be less studied, and I merely point some of its features.

Fishing intensity of longline

Nominal amount of effort is easily defined by number or time of operations for passive gears such as longline or gill net, or sweeping gears such as trawlers. On the other hand, purse seine or pole-and-line include complex problems because of difficulty in measuring time of searching that plays important role in defining amount of effort.(e. g. Gulland 1974).

Even in the passive gears, however, recent drastic change of operations makes it necessary to evaluate the intensity in years of "incomplete coverage" of distribution range of the fish. One of typical examples is longline fishery aiming at yellowfin tuna in the Atlantic Ocean, which showed

(1) year-to-year shift of fishing grounds, and,
(2) month-to-month change of fishing ground and abundance of available stock, but,
(3) no year-to-year change in distribution and its seasonal fluctuation.

Honma (1974b) gives a method to estimate fishing intensity of this fishery, and a statistical test for validity of the method. Appendix 1 reproduces his English summary.

Biass of cpue

Diverse fisheries often show mutually contradicting yearly changes of cpue's. For instance, expansion of purse seine ground succeeded to increase yield of yellowfin tuna drastically in the eastern Pacific where hook rate in longline fishery has been on the decrease (Honma 1974a). There is no confirmative explanation for this discrepancy. Gulland (1971, personal communication) supposed that the longline gear catches only "stupid" fish of the population. A few longline fishermen told me that they use to set the gear, taking current and water front into account. Aggregation of boats forbides free setting of the huge gears extending over 70 to 80 km, and then decrease efficiency of a single set. It is difficult to confirm nor to deny these suppositions.

Leaving suppositions, I like to introduce distributions of hook rate of yellowfin tuna in longline fishery and catch of the species in surface fishery both in the Pacific Ocean (Fig. 1). These two types of fisheries provide completely different pictures of distribution of the fish. An examination of depth of thermocline and surface temperature (Robinson and Bauer 1971) indicates that the thin tropical surface water handicaps the longline fishery in the eastern Pacific while the surface fishery is less effective in the western Pacific where the fish are spread over the thick surface layer. Hisada (1973) showed that "handline", a special operation of longline gear, is highly efficient on yellowfin and bigeye tunas in certain area of the Coral Sea in October and November. As to bigeye tuna, Suda _et al_. (1969) gave an explanation on geographical cline of length composition in catch of longline fishery seemingly related to depth of thermocline. It is also well known that a particular type of gear explits certain portion of the population (_e.g_. IATTC 1973, p. 38, ICCAT 1972, p. 102). Furthermore, the fishermen try to catch particular species according to intensity of demand at marcket (_e.g_. Shiohama 1971).

These observations provide a clue to analyse selectivity of fishery affecting the cpue. First of all, fish select the habitat of particular environmental features. Horisontal and vertical expansion of habitat determines efficiency of each type of gear with particular mechanical features. For instance, the above difference in distribution of catch due to gear may be caused by a fact that yellowfin tuna at the exploitable phase appear in the surface water warmer than 24°C. These observations indicate it fundamental to compile information on habitat of fish by their ecological features. The previous investigations show such ecological features being determined by developmental and maturity stages (_e.g_. Nakamura 1969).

Table 1 provides an example of investigations on southern bluefin tuna along this line. Information arranged like this provides a clue to establish models fo for estimating fishing intensity at various stages. For instance, the fish are taken by pole-and-line and trolling at 2- to 5-ages, and by longline at 4-age and older. Distribution of fishing intensity of longline fishery on southern bluefin tuna in regard of age changed in the history over 20 years, increasing for immatures of 4- to 6-ages while being constant for the adults (Shingu and Hisada 1971, Warashina and Hisada 1974). Therefore, it is recently proposed a model that includes three phases of exploitation, 2- to 5-ages by pole-and-line and trolling, and 4- to 6-ages and 7-age and older both by longline.

NOTE: Figures, Tables and Appendix follow the Spanish Translation.

Note: Les Figures et Tableaux et l'appendice se trouvent après la version Espagnole.

Nota: Las figuras, las tablas, y el apéndice vienen después de la traducción española.

L'EFFORT ET LE CPUE COMME MESURES DE L'ABONDANCE

Deux problèmes se posent lorsque l'on veut évaluer l'effort et le CPUE réels. L'un se réfère à la façon de normaliser l'effort fourni par un type d'engin donné d'une taille déterminée servant à la capture de poisson présentant une distribution irrégulière dans diverses zones et saisons. L'autre concerne la normalisation de l'effort fourni par des engins de types divers ou par différentes tailles d'un même type. Le premier problème a fait l'objet de nombreux travaux. Le deuxième n'a pas été étudié de façon aussi approfondie, et je voudrais simplement en faire remarquer certains aspects.

Intensité de pêche de la palangre

L'effort nominal de pêche se définit aisément en nombre ou durée des opérations en ce qui concerne les engins passifs tels que la palangre ou les filet maillants, ou les engins traînés tels que le chalut. D'autre part, les senneurs et canneurs posent des problèmes complexes du fait de la difficulté de calculer le temps de recherche qui est un facteur important du calcul du volume de l'effort (voir Gulland, 1974).

Même dans le cas des engins passifs, cependant, les brusques changements récents du mode d'opération ont rendu nécessaire l'évaluation de l'intensité en années de "couverture incomplète" de l'aire de distribution du poisson. Un exemple type est la pêcherie palangrière à l'albacore dans l'Atlantique, qui a présenté:

(1) un déplacement des lieux de pêche d'une année sur l'autre,
(2) des variations d'un mois à l'autre des lieux de pêche et de l'abondance des stocks disponibles, mais
(3) pas de variations d'une année sur l'autre de la distribution ni de ses fluctuations saisonnières.

Honma (1974-b) a fourni une méthode pour évaluer l'intensité de pêche de cette pêcherie, ainsi qu'un test statistique de la validité de la dite méthode. Le résumé en anglais de son travail figure à l'Appendice 1.

Déviation du CPUE

On observe fréquemment dans diverses pêcheries des variations annuelles contradictoires du CPUE. Par exemple, l'expansion de la zone de pêche à la senne coulissante a réussi à accroître de façon remarquable la production d'albacore dans le Pacifique Oriental qui présente une baisse du taux par hameçon de la palangre (Honma, 1974-a). Aucune explication à ce phénomène n'a été confirmée. Le Dr. Gulland (1971, communication personnelle) a pensé que les engins palangriers ne capturaient que les poissons "stupides" de la population. Quelques pêcheurs à la palangre m'ont dit qu'ils mouillaient en général l'engin en tenant compte du courant et du front. La concentration des bateaux interdit le mouillage en toute liberté d'engins énormes s'étendant sur 70 à 80 kms, et réduit donc l'efficacité d'une opération donnée. Ces suppositions sont aussi malaisées à confirmer qu'à réfuter.

Laissant de côté ces suppositions, j'aimerais traiter de la répartition du taux par hameçon de l'albacore dans la pêcherie à la palangre, et de celle des prises de cette espèce dans la pêcherie de surface, dans l'Océan Pacifique dans les deux cas (Figure 1). La répartition du poisson se présente de façon totalement différente dans ces deux types de pêcherie. Une étude de la profondeur du thermocline et de la température de surface (Robinson & Bauer, 1971) montre que le peu d'épaisseur des eaux de surface tropicales gêne la pêcherie à la palangre dans le Pacifique Oriental, alors que la pêcherie de surface est moins rentable dans le Pacifique Occidental où les poissons sont dispersés dans l'épaisse couche de surface. Hisada (1973) a indiqué que la "ligne à main", une variante des engins palangriers, est très efficace pour l'albacore et le thon obèse dans certaines zones de la Mer de Corail en octobre et novembre. Pour ce qui est du thon obèse, Suda et al. (1969) a présenté une explication du clivage géographique de la composition par taille dans les prises à la palangre, comme quoi il serait lié à la profondeur du thermocline. C'est également un fait bien connu qu'un type d'engin donné exploite un secteur déterminé de la population (voir IATTC, 1973, p. 38 - ICCAT, 1972, p. 102). De plus, les pêcheurs tentent de s'emparer d'espèces déterminées selon la demande du marché des consommateurs (voir Shiohama, 1971).

Ces observations fournissent un indice pour analyser la sélectivité de la pêcherie intervenant dans le CPUE. Tout d'abord, le poisson choisit un habitat qui présente des conditions de milieu déterminées. L'expansion verticale ou horizontale de cet habitat détermine l'efficacité de chaque type d'engin présentant des aspects techniques particuliers. Par exemple, les différences ci-dessus dues aux engins dans la répartition des prises peuvent provenir du fait que l'albacore à son stade exploitable se trouve dans les eaux de surface de plus de 24º. Ces observations montrent qu'il est indispensable de rassembler des renseignements sur l'habitat du poisson selon ses aspects écologiques. Les recherches antérieures indiquent que ces aspects écologiques sont déterminés par les stades de développement et de maturité (voir Nakamura, 1969).

Un exemple des recherches entreprises dans cette optique sur le thon rouge du sud figure au Tableau 1. L'information rassemblée de cette facon fournit un indice pour l'établissement de modèles servant à estimer l'intensité de la pêche aux différents stades. Par exemple, le poisson est pris à la canne et à la ligne traînante entre 2 et 5 ans, et à la palangre à 4 ans et plus. La répartition de l'intensité de la pêche palangrière au thon rouge du sud en ce qui concerne l'âge a évolué au cours des dernières 20 années, ayant augmenté pour les immatures de 4 à 6 ans, alors qu'elle est demeurée constante pour les adultes (Shingu & Hisada, 1971 - Warashina & Hisada, 1974). On a donc récemment proposé un modèle comprenant trois phases de l'exploitation, poissons de 2-5 ans pris à la canne et à la ligne traînante, et de 4 à 6 ans et de 7 ans et plus à la palangre.

ESFUERZO Y CAPTURA-POR-UNIDAD-DE-ESFUERZO COMO MEDIDA DE ABUNDANCIA

La estimación del esfuerzo real y la captura-por-unidad-de-esfuerzo (CPUE) entrañan dos problemas. Uno es cómo normalizar el esfuerzo producido por un tipo de arte de un determinado tamaño que sirve para la captura de ejemplares distribuídos irregularmente en diversas zonas y temporadas. El otro se refiere a la normalización del esfuerzo producido por artes de diversos tipos o diferentes tamaños del mismo tipo. Existen muchos trabajos escritos en relación al primer problema. En cuanto al segundo, parece que se ha estudiado menos, y simplemente deseo resaltar algunos de sus aspectos.

Intensidad pesquera del palangre

El esfuerzo nominal pesquero se define fácilmente por el número o duración de las operaciones para artes de pesca pasivas tales como el palangre o la red agallera, o artes de arrastre. Por otra parte, el cerco o la caña y liña plantea problemas complejos debido a la dificultad de calcular el tiempo de la búsqueda, que juega un papel importante a la hora de definir el volumen del esfuerzo (ver Gulland, 1974).

Incluso en lo que respecta a los artes de pesca pasivos sin embargo, el cambio drástico reciente en las operaciones hace necesario evaluar la intensidad en años de "cobertura incompleta" del área de distribución de los peces. Uno de los ejemplos típicos es el de la pesquería con palangre que se dedica al rabil en el Oceano Atlántico, que presentó:

(1) cambios de un año a otro de los caladeros de pesca, y,

(2) cambios de un mes a otro de los caladeros de pesca y abundancia de los stocks disponibles, si bien,

(3) no acusó ningún cambio de un año a otro en la distribución y fluctuación estacional.

Honma (1974-b) da un método para estimar la intensidad pesquera de esta pesquería, y una prueba estadística de la validez de dicho método. En el Apéndice 1 figura su resumen en inglés.

Sesgos de la CPUE

Varias pesquerías a menudo presentan cambios anuales contradictorios de CPUE. Por ejemplo, la expansión del empleo del cerco consiguió aumentar notablemente la producción de rabil en el Pacífico oriental en donde la tasa de capturas por anzuelo en la pesquería con palangre ha ido descendiendo (Honma 1974-a). No hay una explicación confirmada de esta discrepancia. Gulland (1971, comunicación personal) ha supuesto que el arte de palangre solo captura los peces "estúpidos" de la población. Algunos pescadores de palangre me han informado que suelen fijar el arte, teniendo en cuenta la corriente y los frentes de agua. La concentración de barcos impide fijar con facilidad artes grandes de una longitud de unos 70-80 kms, lo que disminuye la eficacia de un lance. Es difícil confirmar o negar estas suposiciones.

Dejando estas suposiciones, desearía decir algo sobre la distribución de la tasa de capturas por anzuelo de rabil en la pesquería con palangre y la captura de esta especie en la pesquería de superficie, ambas en el Oceano Pacífico. (Fig. 1) Estos dos tipos de pesquerías presentan un cuadro totalmente diferente de distribución de la pesca. Un examen de la profundidad de la termoclina y de la temperatura de superficie (Robinson & Bauer, 1971) indica que la capa poco profunda de aguas tropicales de superficie constituye una desventaja en la pesquería con palangre en el Pacífico oriental, mientras que la pesquería de superficie obtiene peores resultados en el Pacífico occidental en donde los peces se extienden en una capa profunda de superficie. Kisada (1973) mostró que la "liña", una de las variantes del arte de palangre, es muy eficaz para el rabil y el patudo en ciertas zonas del mar de Coral en Octubre y Noviembre. En cuanto al patudo, Suda _et al_ (1969) dió una explicación sobre el clino geográfico de la composición de tallas en las capturas con palangre que posiblemente esté relacionado con la profundidad de la termoclina. Es asimismo bien conocido el hecho de que un determinado tipo de arte de pesca explota cierta parte de la población (ver IATTC, 1973, p. 38 - ICCAT, 1972, p. 1o2). Además, los pescadores tratan de capturar especies determinadas según la demanda que se produzca en el mercado. (ver Shiohama, 1971)

Estas observaciones proporcionan una orientación para analizar la selectividad de la pesquería que interviene en el CPUE. En primer lugar, los peces eligen el habitat de acuerdo con unas características especiales ambientales. La expansión horizontal y vertical del habitat determina la eficacia de cada tipo de arte según sus características técnicas particulares. Por ejemplo, las diferencias anteriores en la distribución de la captura debido al arte pueden provenir del hecho de que el rabil en su fase de explotación aparece en aguas de superficie a una temperatura superior a los 24ºC. Estas observaciones indican que es fundamental recoger información sobre el habitat de los peces, según sus aspectos ecológicos. La investigación previa revela que dichos aspectos ecológicos están determinados por los ciclos de desarrollo y madurez. (ver Nakamura, 1969)

La Tabla 1 proporciona un ejemplo de la investigación sobre el atún del sur siguiendo esta línea. Este esquema de información da una pauta para establecer modelos que sirvan para estimar la intensidad pesquera en los diferentes ciclos. Por ejemplo, los peces se capturan con caña y liña y curricán entre los 2 y los 5 años, y con palangre a los 4 años y mayores. La distribución de la intensidad pesquera en la pesquería con palangre del atún del sur, en lo que respecta a la edad, ha ido evolucionando en los últimos 20 años, aumentando para los inmaduros de 4-6 años y permaneciendo constante para los adultos. (Shingu & Hisada, 1971 - Warashina & Hisada, 1974). Por lo tanto, se ha propuesto recientemente un modelo que incluye 3 fases de explotación, peces de 2-5 años capturados con caña y liña y curricán, y de 4-6 años y 7 años y aún mayores, capturados con palangre.

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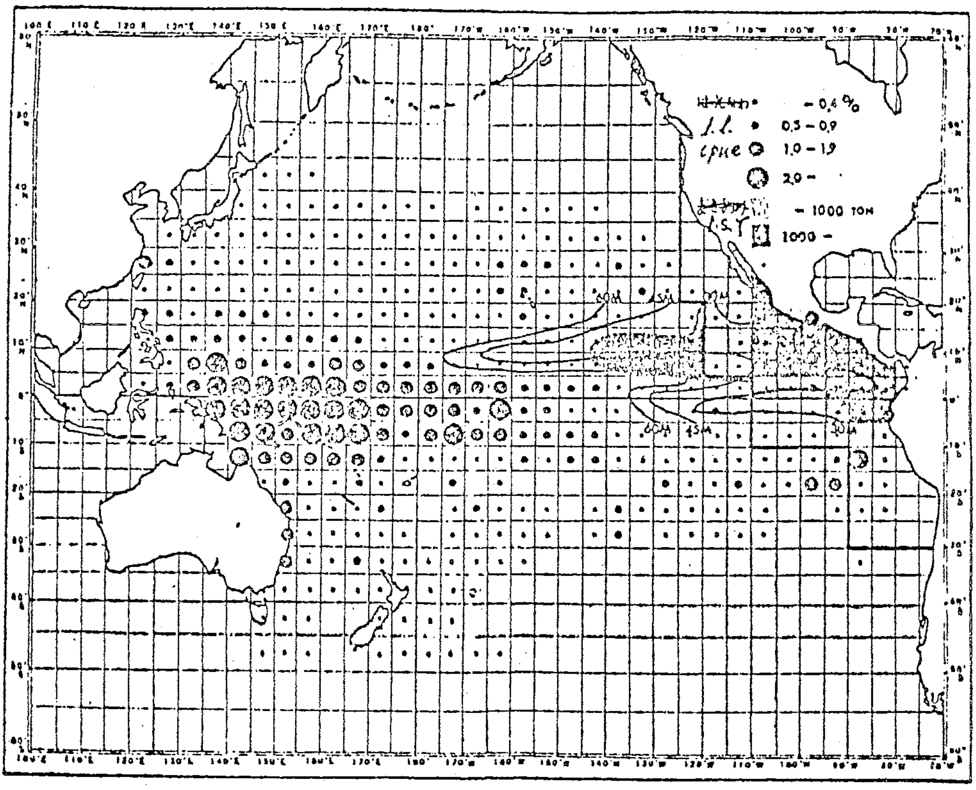

Fig. 1. Distribution of longline hook rate and purse seine catch of yellowfin tuna, together with depth of top of thermocline in the Pacific Ocean.

After Honma (1974).

Appendix 1

Estimation of effective overall fishing intensity of tuna longline fishery—Yellowfin tuna in the Atlantic Ocean as an example of seasonally fluctuating stocks

Misao Honma

Many authors have assumed that range of fishing operation covers, at least in certain period of each year, the whole range of distribution of the stock in question. Under the assumption, the effective fishing effort, X, is easily calculated even if fish and effort are not randomly distributed, by weighting nominal amount of effort, properly standardized for mechanical variation of gears such as size of net, with index of abundance of fish, in each subarea selected so as to realize uniform density of fish therein (Equation 1).

$$X = \sum_i r_i \cdot g_i = \sum_i \left(\frac{C_i / g_i}{\sum_i \frac{A_i C_i}{g_i} \Big/ \sum_i A_i} \times g_i \right) = \frac{C}{N/A} = \frac{C}{\bar{d}} \quad \ldots\ldots \quad (1)$$

where, C_i: catch in i-th subarea,

g_i: nominal effort in i-th subarea, standardized for mechanical variation of gears if required,

N: index of stock size,

$\bar{d}$: average density,

r_i: index of abundance of fish in i-th subarea, or ratio of density in the subarea to the average density,

A_i: areal extent of i-th subarea, and,

A: areal extent of the whole fishing ground.

In the 1950's, the Japanese tuna longline fishery expanded range of their operation successively. This change of fishery required modification to the procedures for estimating amount of effective effort. Hitherto two types of data processing appeared. One is limitation of data for years after the fishing ground covered the distribution range of stocks as in Honma *et al.*'s study (1971) on yellowfin tuna in the Pacific Ocean. The other substitutes geographical distribution of density indices in the fully exploited years to the early period of exploitation when fishing ground did not yet cover the whole distribution range, as proposed by Suda and Kume (1967) to assessment of bigeye tuna stock in the Pacific Ocean.

Since 1965, fishing grounds of tuna longline fishery showed not only expansion but also shrinking or transition (*e.g.* Hayasi 1973, Hayasi *et al.* 1970, Honma 1973, Suda 1971). Such change of fishing operation implies it be fruitful to develop the Suda and Kume's method. Shiohama (1971) modified this method taking within-year-variation of hook rates into consideration. The present author tries to improve the method so as to fit cases in which distribution pattern of fish differs depending on season of a year, together with to find out conditions required for keeping validity of such method.

Formulation

The longline fishery in the Atlantic Ocean shows remarkable seasonal changes of extent of fishing ground and index of stock size of yellowfin tuna. This makes it necessary to use the catch statistics compiled by season of a year but not the annual total so that we can examine heterogeneity of distribution in a season, and seasonal change of stock size during a year. The present method evaluates relative efficiency, ε_{ij}, of unit effort in *i*-th subarea and *j*-th season as a product of indices of density, r_{ij}, and availability, a_j, based on average density indices, d_{ij} over "standard years" when the fishery covered distribution range of the fish, and when the stock size was relatively stable (Equations 2 to 5). In this particular case, the subarea is Lat. 5° and Long. 5° square, or simply called 5-degree square, and the season is a three-month period or quarter.

$$r_{ij} = \frac{d_{ij}}{\sum_i A_{ij} d_{ij} \Big/ \sum_i A_{ij}} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (2)$$

where, A_{ij}: extent of *i*-th 5-degree square occupied in *j*-th quarter.

$$d_{ij} = \frac{1}{l_{ij}} \sum_{k=1}^{l_{ij}} C_{ijk} \Big/ g_{ijk} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (3)$$

where, C_{ijk}: catch in *i*-th 5-degree square occupied in *j*-th quarter of *k*-th year,

g_{ijk}: nominal effort used in *i*-th 5-degree square occupied in *j*-th quarter of *k*-th year, and,

l_{ij} : number of years when *i*-th 5-degree square was occupied in *j*th quarter.

$$a_j = \frac{\bar{N}_j}{\frac{1}{4}\sum_{j=1}^{4} \bar{N}_j} = \frac{\sum_i A_{ij} d_{ij}}{\frac{1}{4}\sum_{j=1}^{4} \left(\sum_i A_{ij} d_{ij}\right)} \quad \cdots\cdots\cdots\cdots \quad (4)$$

where, $\bar{N}_j$: index of stock size in *j*-th quarter in "standard years".

$$\varepsilon_{ij} = a_j\, r_{ij} = d_{ij} \Bigg/ \frac{\sum_i \sum_j d_{ij} A_{ij}}{4 \sum_i A_{ij}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (5)$$

Amount of effective effort in j-th quarter of k-th year is simply a sum of products of the relative efficiency and nominal effort (Equation 6). Seasonal change of fishing ground requires calculation of yearly sum of overall effective fishing intensity, f_k, as a measure to be proportional to the fishing mortality coefficient in k-th year (Equation 7).

$$X_{jk} = \sum_i \varepsilon_{ij}\, g_{ijk} = a_j \sum_i r_{ij}\, g_{ijk} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (6)$$

$$f_k = \sum_{j=1}^{4} f_{jk} = \sum_{j=1}^{4} X_{jk}/A_j \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (7)$$

where, A_j: extent of the whole fishing ground in j-th quarter in "standard years".

Statistical test

The equation 6 is necessary when the pattern of geographical distribution of fish varies from season to season. Furthermore, the equation is valid when the seasonal succession of pattern of geographical distribution of fish does not differ among years in question. The former condition is regarded to exist if interaction between subarea and season is a significant source of variation of density index, in a statistical test based on a model given in equation 8. The latter condition is assumed to be real if variances of the other two interactions including "year" are not significantly large compared to "errors" as well as those due to the other factors.

$$d_{ijk} = a + y_k + p_i + q_j + (yp)_{ki} + (yq)_{kj} + (pq)_{ij} + e_{ijk} \quad \cdots \quad (8)$$

where, a: grand mean,

y_k: year deviation, $\sum_k y_k = 0$,

p_i: subarea deviation, $\sum_i p_i = 0$,

q_j: season deviation, $\sum_j q_j = 0$,

$(yp)_{ki}$: interaction between year and subarea,

$(yq)_{kj}$: interaction between year and season,

$(pq)_{ij}$: interaction between subarea and season, and,

e_{ijk} : errors assumed to follow a normald distribution with mean of 0.

Results

(1) Source of variation of density index: Quarter, subarea and their interaction appeared as statistically significant sources of variations in most sets of 34 analyses for data taken during 13 years from 1956 to 1968 in 23 subareas given in Fig. 1. Only 13 sets showed significant variations due to interaction between "year" and either "subarea" or "season" (Table 1). These statistical results show that the pattern of distribution of fish changed from season to season, but the seasonal change itself was fairly stable during the 13 years. These are necessary and satisfactory conditions for using the equation 6. The highly significant variance due to "year" for sufficiently long period from the major distribution ridge represents the succeeding decline of yellowfin tuna stock in longline fishery in the Atlantic Ocean.

(2) Change of density and availability indices: Examinations of d_{ij} and r_{ij} reconfirmed Honma and Hisada's conclusions (1971) that high hook rates occurred in the eastern and western Atlantic separately in the northern winter, and that the two concentrations shifted toward central Atlantic and then joined each other in the northern summer (Fig. 3). Availability index, a_i, was as high as 1.16 in the first quarter and decreased to 0.88 in the fourth quarter (Fig. 4).

(3) Yearly and quarterly estimates of amount of effort, overall fishing intensity and average effectiveness index: In most years the effective effort tended to rise in the early half and to decline in the later half as stock size did. Year-to-year change was common in effective effort and overall effective fishing intensity, having increased up to 1965 and then turned to decline (Figs. 5 and 6). Average effectiveness coefficient, or ratio of effective effort to nominal effort in a quarter, also used to rise in the early half and to lower in the later half, and gradually decreased from about 2.3-2.4 in 1957 and 1958 to 1.1-1.3 in 1966 through 1968 (Fig. 7).

Conclusions

The aforementioned seasonal and yearly fluctuations of average effectiveness coefficient accord with seasonal change of abundance of fish and yearly shift of species preference of fishermen. Furthermore, the statistical analysis has indicated that the present method is necessary and satisfactory for estimating overall effective fishing intensity of longline fishery on yellowfin tuna in the Atlantic Ocean.

On the other hand, there appears no signficant difference in year-to-year changes of the present and previous estimates of intensity of fishing to yellowfin tuna (Table 2). Nevertheless it is preferable to use the present method for its theoretical basis insofar as the computors are available. Further examination of resultant parameters may provide means to evaluate time of recruitment and change of catchability depending on developmental stage of fish and environmental factors, together with other ecological and oceanographical investigations.

Table 1. Distribution pattern in life history of southern bluefin tuna (Shingu, 1970)

Developmental stage and yearly cycle of life	Major morphological features	Known fishing or sampling areas and seasons	
Egg stage			
Pre-larval stage	With yolk sac		
Post-larval stage	Yolk sac absorbed	About 50 post-larvae of 3-8 mm in total length were obtained from the eastern Indian Ocean off northwestern Australia in the southern summer. In addition, a single dubious specimen of 4.5 mm in the length was taken at latitude 21°S, longitude 156°E in the southwestern Pacific (Ueyanagi, 1969)	
Juvenile stage	Adult number of fin rays		
Young stage	Body shape as adult. Australian catch comprises the youngs of 30-110 cm in fork length, one to five years old (Robins, 1962)	Youngs and immatures are occasionally taken by trolling in the waters along New Zealand (McKenzie, 1961)	Probably distributed on whole of the continental shelf of Australia
Immature stage	Japanese catch comprises the immatures of 100-140 cm in the length, four to seven years old (Shingu, 1967)		Exploited widely in the West Wind Drift and related waters between Chile and South Africa. Major fishing grounds so far known are: waters off southeastern Australia, April to October; off New Zealand, the same; southern Australia, September to March; western Indian Ocean, the same; and west of South Africa, year round (Shingu, 1967, MS; Shingu and Hisada, MS, Warashina, MS)

Developmental stage and yearly cycle of life		Major morphological features		Known fishing or sampling areas and seasons
Adult stage	Feeding phase	Japanese catch comprises adults of 140-190 cm in fork length seven to fourteen years old (Shingu, 1967)	Fatty body and beautiful meat (Warashina, 1968; Warashina and Hisada, MS)	Feeding adults are taken widely in the West Wind Drift and related waters. Major fishing grounds for the adults are quite the same with those for the immatures. But the feeding adults are more abundant in high latitude waters than the immatures and spawning adults (Shingu, 1967, MS; Shingu and Hisada, MS, Warashina, 1968; Warashina and Hisada, MS)
	Pre-spawning phase		Fatty body, fading meat and advancing gonads (Warashina, 1968; Warashina and Hisada, MS, Shingu, MS)	Waters along western Australia, August to October. The pre-spawning adults seem to migrate east of latitude 110°E (Shingu, MS, Warashina, 1968; Warashina and Hisada, MS)
	Mid-spawning phase		Seldom captured by longline. Probably lean body, dark meat and advanced gonads (Shingu, 1967, MS; Warashina, 1968; Warashina and Hisada, MS)	Eastern Indian Ocean off northwestern Australia, October to March. Hook rate in the spawning ground lowers in November to January, surmised as the mid-spawning season (Mimura and Warashina, 1962; Shingu, 1967, MS)
	Post-spawning phase		Lean body and dark meat (Shingu, MS, Warashina, 1968; Warashina and Hisada. MS)	Waters along western Australia, December to March. The post-spawning adults seem to migrate west of longitude 110°E. The spents are also taken in the West Wind Drift during December to June (Shingu, MS, Warashina, 1968; Warashina and Hisada, MS)

Table 1. Continued.

Developmental stage and yearly cycle of life	Abiotic factors of habitat		
	Water mass	Submarine topography	Temperature and salinity at surface
Egg stage	Probably the transitional zone between the Sub-tropical and Tropical Zones by Rochford (1962)		
Pre-larval stage			
Post-larval stage	Transitional zone between the Sub-tropical and Tropical Zones defined as such by Rochford (1962)		Temperature ranged 28°C to 30°C at successive stations, except one of 24.7°C (Ueyanagi, 1969)
Juvenile stage			
Young stage	Northern edge of West Wind Drift (Shingu, MS)	Continental shelf	In the Australian waters, 16°C to 20°C, and 34.8% to 35.9%
Immature stage	West Wind Drift and its northward branches (Shingu, 1967, MS)	Aggregate in the vicinity of continent, islands and banks, although migrate, in wide ranges of oceans	In the waters around eastern Australia, 14°C to 19°C and 35.0% to 37.0% for northward migration period of May to October, and 5°C to 15°C and 34.0% to 35.5% for southward migration period of November to April

Developmental stage and yearly cycle of life	Abiotic factors of habitat		
	Water mass	Submarine topography	Temperature and salinity at surface
Feeding phase	West Wind Drift and its northward branches (Shingu, 1967, MS; Warashina, 1968; Warashina and Hisada, MS)	Aggregate in the vicinity of continents, islands and submarine banos, although migrate within wide range of oceans	Mainly 8°C to 15°C
Adult stage: Pre-spawning phase	West Australian Current (Shingu, MS; Warashina and Hisada, MS)		Attracted to high temperature over 20°C
Adult stage: Mid-spawning phase	Transitional zone between the Subtropical and Tropical Zones by Rochford (1962)		In northern part, north of latitude 20°S, 24°C to 30°C, and 34.0% to 35.0%, and in southern part, south of latitude 20°S, 17°C to 25°C (Shingu, MS)
Post-spawning phase	Southward branch of equatorial current along western coast of Australia and West Wind Drift (Shingu, 1967, MS; Warashina, 1968; Warashina and Hisada, MS)		Attracted to low temperature below 15°C

After Alverson (1971).