

SOME HYPOTHESES ON THE SKIPJACK RESOURCES OF THE PACIFIC OCEAN

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Paper prepared for the Ad Hoc Meeting of Scientists to Discuss Skipjack Fisheries Development and Research Requirements, Particularly in the Western Equatorial Pacific Ocean

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South Pacific Commission
Noumea, New Caledonia
October 1975

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1. Introduction

Although catches of skipjack now account for far more of the world's tuna landings than do those of any other species, comparably little research has been done on this species. It is generally held that the skipjack resources are still substantially underexploited but the published reports supporting this theory have relied upon the lack of evidence to the contrary, to endorse the authors' opinion. In the following paper I have combined several unconfirmed hypotheses about the life history and behaviour of skipjack in an attempt to identify some of the specific problems which need to be overcome if accurate stock assessment is to be achieved. Hopefully discussion of some of these hypotheses will assist in formulating future skipjack research strategies.

2. Skipjack distribution and life history migrations

In recent years it has been accepted that although the skipjack taken throughout the Pacific Ocean are of the one species at least several discreet stocks do exist. It is now accepted that the skipjack taken in the northern and western sectors of the eastern Pacific fishery can be regarded as discreet (sub)-populations (Rothschild 1965, Joseph and Calkins 1969) and recent evidence has added increasing support to Fujino's (1972) ascertainment that the skipjack stocks of the western Pacific are genetically distinguishable from those of more eastern regions of the Pacific, and are indeed also comprised of several sub-populations.

The skipjack in the major fisheries of the western Pacific (i.e. Japan home islands, Japanese southern water, Papua New Guinea, Solomon Islands and New Zealand/Australia), can on the basis of Fujino's classification, be divided into those exploiting purely tropical, western populations (southern water, Papua New Guinea and probably the Solomon Islands), and those exploiting skipjack in more temperate waters or from central or eastern populations (Japan, New Zealand/Australia and fisheries to the east of 165°E).

It must be pointed out that generalizations made for the behaviour of one stock might be in no way applicable to other, even adjacent stocks.

2.1 Distribution of larvae

Numerous reports on the distribution of larval skipjack are available (see Kawasaki 1965, Klawe and Miyake 1967, Joseph and Calkins 1969, Matsumoto and Skillman 1975) but yet considering the magnitude of the adult resource, research into the life history stages of skipjack has been limited. It is accepted that the distribution of larvae in the Pacific Ocean is restricted to generally between the northern and southern limits of the 24° isotherm, with an increase in concentration with progression westwards. Larval distribution is also considered to be limited more to purely equatorial regions in the eastern Pacific, spreading to as far as the 35° parallels in the western regions. Even in the western Pacific larvae are thought to be more densely concentrated in equatorial regions, even though the data from Ueyanagi (1969) would tend to suggest that really warm water i.e. >28°C is not really favourable for larval skipjack.

Data on the vertical distribution of skipjack larvae definitely indicates that they are concentrated above the thermocline but it appears that the larvae are widely, and relatively uniformly, distributed in the surface layers to a depth where the temperature approaches about 21°C or 23°C. In general the lateral and vertical distribution of larvae in the Pacific appears to be very similar to that of adults, although the poleward distribution of larvae is slightly restricted and larvae are not abundant in far eastern regions (Figure 1). This overlap in distribution, coupled with the general acceptance that skipjack are opportunistic feeders strongly suggests that adult skipjack would prey heavily upon skipjack larvae. This suggestion is substantiated by evidence that skipjack are in fact cannibalistic (Nakamura 1965). This argument can be carried further for in the area of known distribution of skipjack larvae in the Pacific (i.e. the surface layers of most tropical waters) there is no doubt that adult skipjack represent the greatest biomass of recognizable predators. The assumption therefore that skipjack are potentially their own greatest predator, at least numerically, has great credence.

2.2. Distribution of juveniles

Probably the most striking feature of the study of juvenile skipjack (from length 12 - 350 mm) is the extremely small number of individual juveniles (approximately 2547) which have been recorded in the literature from the Pacific Ocean (see Matsumoto and Skillman 1975). From discussions with research personnel and fisherman I have come to the conclusion that surface schools of juvenile skipjack are very rarely seen, particularly considering the very great numbers of juveniles which must occur. This suggests that juveniles do not follow the same surface schooling behaviour of adults. It is difficult to substantiate this belief but likewise it is difficult to find evidence to the contrary.

It is interesting to note that although it is agreed that the spawning activity of skipjack is concentrated in the equatorial regions of the central and western Pacific the areas of greatest occurrence of first recruits (post juveniles 350 - 450 mm) into the commercial fisheries occur at the absolute extremes of distribution of the species, i.e. off the Japanese home islands (40-45° N, 145° E), off New Zealand (35-40° S, 175° E), off Baja California (20-30° N, 110° W), off Northern Chile (20° S, 85° W). This is indicative of a general migration from low to high latitude areas, and for some fish, eastwards, during the first one year of life. It is also indicative of a general migration of juvenile skipjack away from the areas of greatest occurrence of large skipjack, which as previously pointed out are potentially the greatest predators.

Although it is based on largely circumstantial evidence, I support the hypothesis that in addition to these substantial lateral migrations the growing skipjack undertake vertical migrations which also tend to remove them from the portions of the water column most densely populated by feeding adult skipjack. These vertical migrations is integrated with the lateral movements and could possibly be as follows:-

- (1) Skipjack spawning is concentrated in the warm equatorial waters and there is also more spawning in the central and western regions.

- (2) Eggs are produced and larvae developed throughout the water column above the thermocline, even though there is a suggestion that their vertical distribution throughout this water mass may not be homogeneous.
- (3) Larval development and growth appear to be associated with a preference for slightly cooler waters ($< 28^{\circ}\text{C}$) with larger juveniles preferring even colder waters.
- (4) The post larvae and small juveniles migrate vertically to approximately the $20\text{--}23^{\circ}$ isotherms where (a) they tend to avoid predation by adults, and (b) feeding for such juveniles may well be more favourable.
- (5) The juveniles tend to remain on or about the 20°C isotherm migrating polewards, and in some cases eastwards, feeding and growing while doing so.
- (6) They emerge at the surface approximately one year later where the 20° isotherm meets the surface (in the western regions off Japan and New Zealand), by which time they have achieved a size of approximately 400 mm.
- (7) They remain in the surface layers from this stage onwards, slowly migrating into more equatorial regions for eventual spawning.
- (8) Mature adults tend to migrate smaller distances in each subsequent year and as they grow into really large fish (i.e. > 10 kg) their physiological limitations in relation to their environment gradually restricts them to a greatly reduced habitat.

These vertical and lateral migrations are simplified in Figure 2.

3. Populations

Since the publication by Fujino (1972) of the hypothesis of a division of the stocks of Pacific skipjack into at least two major populations and probably several other sub-populations, the concept has been generally consolidated. There appears to me to be little doubt that in equatorial regions in the vicinity of 160° E to 170° E there is a definite division of stocks into western population(s) and eastern population(s). It is still however difficult to define further subdivision of either the western or central-eastern populations even though smaller discrete units probably do occur. The accumulated data, including biochemical genetics information, indicates that the central-eastern population(s) may be more easily defined than those of more westerly regions and there appears to be great complexity in the genetic composition (as determined by the study of esterase systems), and migratory behaviour (as determined by tagging studies) of the skipjack stocks in the equatorial waters west of 160° E.

In a previous report (Kearney 1975) I have indicated the size distribution, migration and tagging, growth, longline catch and larval distribution data which strongly support the division of the Pacific skipjack stocks into the two major groups. None of the evidence put forward in this previous report has as yet been refuted and in fact the case has been strengthened by the addition of more recent data. Since this previous report, Sharp (1976 Personal Communication) has indicated even greater complexity for the skipjack resources in the vicinity of Papua New Guinea but has also postulated homogeneity for the fish taken in the 1976 New Zealand fishery. These recent developments have greatly increased the knowledge of population structure of the skipjack resources of the Pacific even though present knowledge of the distribution of the various populations is obviously far from adequate. However even more inadequate is our knowledge of the dynamics of these various populations, particularly in response to increased fishing pressure or to changes in the magnitude or distribution of adjacent or associated populations. If the dynamics of the skipjack stocks of the Pacific are to be understood then we must first determine the identity of the numerous groups and ascertain the degree to which fluctuations in the abundance of any group will be compensated for by a change in the abundance of another group or groups. That is we must determine the degree of density dependence not only within each group, but between groups, and ascertain what degree of compensation will occur if any group or groups should be depleted.

4. Growth

Although the data on the growth of skipjack from the western Pacific are limited the evidence accumulated to date clearly shows a difference in growth rates and L_{∞} between the skipjack of the western and central-eastern population(s). Joseph and Calkins (1969) reviewed previous estimates of the growth of skipjack from the Pacific and in addition derived growth estimates for fish in the eastern region ranging from 11.16 cm per year to 21.84 cm per year, and L_{∞} from 729 to 881 mm for different techniques and methods of data analysis. These growth estimates are of the same order as those previously reported from the Pacific which range from an average of 10.8 cm per year for the eastern area (Diaz 1966) and 27 cm per year from waters around Hawaii (Brock 1954). In more recent years tagging studies in Papua New Guinean waters have determined an average annual growth increment of approximately 7 cm and an L_{∞} of 65 cm for skipjack in that fishery. These estimates are derived from tagged and recaptured fish which had been at liberty for up to 789 days. Ageing studies from otoliths have recently confirmed this slow growth rate for western Pacific fish (Struhsaker 1976, Personal Communication).

Tagging results have also shown that the migrations of skipjack from western regions, while extensive, particularly polewards, are restricted to within the boundaries of the western population postulated by Fujino (Kearney 1975). This information coupled with a comparison of the size composition of catches from either side of Fujino's division leaves little doubt that the growth rate and maximum size of skipjack in the western population are much lower than for the more easterly population(s). There is very little likelihood that these size differences are a result of exploitation of different size classes of the same population.

Although based on very little available evidence it is generally held that the size at first maturity is similar for skipjack in equatorial waters on both sides of the Pacific and occurs at around 45 cm, (see Brock 1954; Orange 1961 and Lewis *et al.* 1974) while skipjack in higher latitudes tend to display less gonad development at similar sizes. Data on the area of occurrence of larval skipjack indicate that larvae are concentrated more in equatorial regions and this pattern of larval distribution clearly demonstrates that spawning activity is much greater in western areas. Furthermore the year round availability of larvae in the western Pacific and the suggestion of a high gonad index throughout the year for skipjack in this area, indicate at least the potential for spawning at all times.

It therefore appears that in addition to the disparity in growth rates between skipjack from the eastern and western Pacific there is a concomitant inverse relationship between spawning activity and growth such that the greater the spawning activity the slower the growth. While it is difficult to prove a cause/effect relationship between growth and reproductive activity the theory is consistent with the limited evidence available.

In addition an examination of plots of length increment, against time at liberty, for tagged and recaptured skipjack from the western Pacific, indicates a point of inflection at about the length at first spawning. In fact for western Pacific skipjack the transition from a comparatively rapid rate of growth to one very slowly approaching L_{∞} occurs over a limited range (45 - 50 cm), which corresponds to the period of rapid gonad development and subsequent spawning. A similar type of inflection can be detected in the growth pattern of other tuna species (e.g. southern bluefin tuna) but as with skipjack from other areas the length at which the inflection occurs will vary (for southern bluefin tuna it occurs at about 112 cm).

I would like to suggest that the rate of growth of skipjack to 45 cm is approximately linear with respect to length, at this point there is a slight decrease in growth rate due to the channelling of energy reserves into the development of gonads (this decrease will be more marked in tropical waters and should not occur in areas where gonad development does not increase at about this length). There is a further more pronounced decrease in growth associated with spawning. Should skipjack develop ripening gonads (possibly stage III depending on the system used) and not spawn (probably due to not finding the required environmental conditions), then growth could accelerate to the pre-development rate. This concept is very roughly depicted in Figure 3.

If such linear growth phases do exist for skipjack and individual fish possess the capability to grow into the size range of a preceding cohort which has undergone more intensive spawning, then the task of identifying cohorts by length frequency distribution becomes virtually impossible in any area where more than one cohort occurs, or where parts of the cohort have been exposed to different environmental conditions which may, or may not, have been suitable for spawning. To say that such a selected relationship between spawning and growth is responsible for the great disparity between the L_{∞} 's of individual fish of the western and eastern populations may be an exaggeration, however, I would assume that genetic mutations as a result of this spawning/growth relationship, coupled with the physiological limitations placed on the western population(s) by their environment (see next section) has resulted in genetically distinct stocks with different blueprints for development.

If the growth pattern of skipjack is comprised of several linear (with respect to length) phases, then the presently accepted practice of using a von Bertalanffy type growth function or curve to fit such data needs to be reviewed. Even if skipjack growth is best described by several linear or almost linear, phases it may well be that the most important component of the overall growth pattern is the rate at which growth changes from the juvenile rate to the much slower rate as maximum size is approached. If this is in fact true then a K value derived from fitting a von Bertalanffy type curve function to describe growth may not result in detectable error, even though the growth cannot be accurately described by a curve. Great care must be taken however, not to assume a consistent value of K for different sub-populations or over different periods in skipjack life history, or for a period greater than that from which data has been obtained to estimate K.

I have one major problem in accepting a multiphasic linear growth pattern for skipjack and that is concerned with biologically justifying a linear relationship between change in length, and time, when weight and length are best related by a cubic function, and weight gain is possibly the best indicator of growth. I therefore suggest that the points of inflection in growth (Figure 3) are apparent because of the great changes in growth which occur at them, and the actual growth phases are probably curvilinear, and appear linear because of the great comparative difference between the growth rates before and after maturity.

5. The environment and the physiological limitations it places on skipjack

In recent years great advances have been made in defining the environmental requirements of skipjack of different sizes. It has been shown that the oxygen and heat dissipation requirements of the species are such that the largest individuals cannot survive for long periods in very warm, low oxygen content water, and it is becoming possible to describe optimum environmental conditions for individuals of many size ranges. Two most significant points are that (1) it is accepted that there are great differences between the environments most suitable for skipjack of different sizes and (2) these environments can exclude skipjack of a particular size from survival in areas suitable for another size. While this latter point has been best defined for the largest skipjack which cannot live for long periods in water warmer than 22°C or in water with an oxygen content of less than 3.5 ml/L, (later discussed) individuals of other size ranges show preferences for certain environmental conditions which have as yet, not been fully described.

Although refinements to the definition of optimum environments for all sized skipjack are still being developed it is interesting to speculate on the total distribution of Pacific skipjack in relation to the available data.

(1) It appears that the traditional fishing grounds of the eastern Pacific can be grouped with the higher latitude (30° N or S) areas of the western Pacific in harbouring skipjack at the size at which they first become accessible to the surface fishing gears currently in use in skipjack fisheries. These areas can also be grouped as being unsuitable for larval or juvenile skipjack and possibly even for gonad development of adults. The common characteristics of these areas which determine these limitations in skipjack habitation appear to be the very narrow depth of the surface water layer of suitable temperature (20-23°C) and the very cold underlying layers which appear unsuitable for skipjack of any size. The vertical range of the suitable environment is thus very limited.

(2) The more westerly regions of the eastern Pacific fishing grounds, which appear to have been more heavily fished in recent years, (since 1973) may be like the areas between 10° and 30° north or south latitude in the western Pacific, and are more suitable for skipjack in the 3 to 5 kg size range. It is difficult to categorize these areas but they do represent a gradation between the habitat of first recruits and the spawning populations of equatorial regions. As skipjack of 3-5 kg are "medium sized" fish it is not surprising that their available habitat is greater, and less rigidly defined than that of more extreme size classes.

(3) The equatorial western Pacific appears completely unsuitable for skipjack greater than 6 kg but ideally suited for gonad development, spawning and larvae, the latter at least in waters cooler than 28°C . This area is characterized by high surface water temperatures (25°C - 31°C) and a deep water column (about 200 metres) above the 20°C isotherm, conditions which are unique to the western equatorial area.

(4) The biggest skipjack (> 10 kg) regularly occur as surface schools only in parts of the central Pacific. Such areas have been defined by Barkley, Neill and Gooding (1975), as having highly oxygenated (3.5 ml/L) surface water and a water temperature within the range of 18°C to 21°C . While very large skipjack can tolerate high surface water temperatures for short periods they must have ready access to cooler highly oxygenated water in which to recuperate after excursions into less favourable areas, perhaps to feed.

While the oxygen content and depth of the 20°C isotherm are probably critical factors in describing why these particular areas are suitable for skipjack of these different sizes, an accurate description of each environment will be extremely difficult, particularly bearing in mind the constant changes which occur in the oceanic environment. Furthermore while the gross differences which occur between the oceanic conditions of equatorial regions and latitudes between 30° and 40° north or south make it comparatively easy to postulate reasons for disparity in the size distribution of skipjack, the occurrence of much smaller areas of size specificity in skipjack abundance within a few hundred kilometers of each other makes an overall explanation more difficult to achieve. Such areas can be found, for example, in the region of the Papua New Guinean skipjack fishery. From Figure 4 it can be seen that the skipjack taken by company C have been of a comparatively uniform size (approximately 5 kg) and consistently much bigger than the average size of skipjack taken in other areas (approximately 3.2 kg) even though the fishing area of company C (Area C. in Figure 5) is separated from the other areas by only 400 km. Tagging experiments have shown that there is migration from the fishing areas of companies A and B to that of company C and there appears little doubt that at least some of the fish from all areas are of a common stock. The occurrence of only larger skipjack in area C, and only in this area, confirms the hypothesis of size specificity by area.

In accordance with the previously discussed hypotheses on growth and size specificity in habitat it may well be that skipjack migrating into area C at a size smaller than the average for the area (for example 4 kg), grow quickly until environmental limitations restrict size at about 5 kg. Larger fish migrating into the area would be subjected to slow growth. This possible diversity in growth rates in this area would help to explain the comparative consistency of skipjack size which is indicative of (a) growth restriction, and/or (b) constant size specific recruitment; both of which support environmental selectivity for the area. It should be reasonably easy to test the former

alternative by examining the growth of fish which have been tagged at a smaller size, by necessity in other areas, and been recaptured in area C. If the growth rate is variable such that an asymptotic size of about 5 kg is rapidly approached then the growth rate of those fish which have been at liberty for shorter periods would be comparatively greater than those which remained in the area for extended periods or even those which took longer to migrate there.

6. Discussion

(1) The foregoing comments on the areas of occurrence of larval, juvenile and adult skipjack are most relevant to a discussion of the dynamics of Pacific skipjack in providing a partial description of the segregation which occurs between skipjack at different stages of their life cycle. It appears that the initial vertical, and subsequent lateral, segregation of very small (larvae and post larvae) individuals from the parent stocks serves to reduce the occurrence of cannibalism which in the offshore oceanic environment of skipjack is anticipated to represent the greatest potential source of predation mortality for very small individuals.

The inadequacy of available data (from stomach analyses) on predation on young skipjack by all tuna species makes it impossible to assess if the skipjack species is its own greatest predator and at what stages in the life cycle such predation is most intense. Stomach analyses from numerous tuna species if carried out according to well researched experimental design, could however, greatly improve our present knowledge of the distribution and migration of skipjack, particularly as juveniles, and could help to more fully explain the predator/prey relationship between such species and skipjack.

If as is suggested by a superficial examination of skipjack distribution the species is its own greatest predator then it is imperative that due consideration be given to the impact of the abundance and distribution of predator sized cohorts of skipjack on the abundance of subsequent cohorts. If such predation more severely restricts the biomass of emerging recruitment cohorts than do other density determining parameters (e.g. availability of food), then the techniques for estimation of sustainable yields from skipjack fisheries must be duly drastically modified. If there is no avoidance of adults by larvae and juveniles then predation would be anticipated to be greatest on very young skipjack (< 70 mm) in latitudes around 10° North and South and it is possible that increased fishing pressure in such areas could result in no decrease, or even an increase in recruitment into skipjack fisheries in higher latitudes. To test such an hypothesis, other than by observing changes in catch rates in selected areas as fishing pressure gradually increases, it would require detailed information on instantaneous rates of mortality for skipjack at all stages of the life cycle. If substantial skipjack cannibalism does occur it is most important to determine if it occurs before or after the period of greatest reduction in the numbers for subsequent recruitment. The lack of detectable correlation between the abundance of adults of spawning size in any one year and the strength of subsequent recruit cohorts suggests there are factors more limiting on recruitment than the number of spawning adults.

(2) The recent advances in the identification of numerous skipjack populations in the Pacific have greatly assisted in defining the limits of the stocks for populations dynamics purposes. What has not yet even been attempted is to define the dynamic interaction which occurs between these various populations. While it is comparatively easy to give verbal definitions of groups of skipjack as being genetically distinguishable populations, subpopulations, groups etc. the implications of the existence of these numerous groups on the assessment of the Pacific skipjack resources are far more elusive. Somehow it needs to be ascertained how depletion of the stocks of one "population" will affect those of another.

Do the various stocks use identical or even similar parts of the total available food or is the depletion of one part of such food by one stock, reflected in a corresponding increase or decrease in the abundance of another? If skipjack/skipjack predation is a major limiting factor, is such predation restricted to within individual stocks? Will the abundance of one stock increase if the abundance of another, perhaps adjacent, stock is decreased by heavy fishing pressure?

While accurate geographical description of all Pacific skipjack stocks is essential for the future assessment and management of the total resource, a great deal more information will still be required on stock dynamics before adequate management can be achieved.

(3) Recent studies of skipjack growth leave no doubt that there is great disparity in the growth and L_{∞} of skipjack from the eastern - central, and western Pacific. I have postulated that this basic difference in growth is effectively associated with the differences in environment and the resultant spawning activity of the fish from different regions. I have suggested that similar types of influences (i.e. variable reproductive activity and availability of environments suitable for growth) can be assumed to cause variable growth within the various populations. Furthermore I have suggested possible linear growth phases for skipjack and indicated that the present acceptance of mathematical representation of a common von Bertalanffy type growth function could, by over generalization, be introducing errors into our estimations of growth which are so great that continued use of such methods is not justified. By these indications I have not meant to suggest that the bases behind the derivation of the von Bertalanffy type function is not applicable. To the contrary I believe it is exactly the nature of the anabolism to catabolism relationship, upon which the von Bertalanffy expression is based, that is responsible for the gross variability in growth which I have postulated. I am merely intending to question whether skipjack growth can be represented by a single curve function and whether the mathematical techniques currently in vogue for the derivation of K from von Bertalanffy type functions are representative of actual individual growth situations. While obviously K values thus derived tend to more accurately represent average rather than individual situations within a population, the problem of whether such a value can be justified and used in subsequent models of skipjack dynamics or whether a more realistic alternative is required and can be derived, must be considered.

(4) The possible influence of variability in the environment on the migrations and growth of skipjack have already been discussed. However further consideration must be given to the possibility that the changing environmental requirements of skipjack during their life cycle and fluctuations in the finite amounts of each suitable environment, not only restricts the growth and reproductive activity of individuals, but may well have great impact on the mortality of skipjack at numerous times throughout its life-cycle.

The skipjack is unique among fishes in that none other has evolved with such a single apparent goal of sustained high swimming speed. The skipjack is the ultimate living fish in hydrodynamic design and physiological "singleminded-ness" towards the attainment of sustained high-level effort. It is therefore not surprising that this level of evolutionary selection has brought it close to the limits of its environment and left the skipjack with little tolerance to changes in this environment. On the other hand the speed, endurance and manoeuvrability of the skipjack make it an extremely effective predator and enable it to make optimum use of the food resources in its environment. This efficiency empowers the skipjack as a species to make optimum use of the total environment to which it is physiologically suited and its great speed and endurance enables it to greatly expand its distribution at times when favourable conditions occur in, or adjacent to, any sector of its normal environment.

It is probable that it is the combination of this locomotive and predatory efficiency, with the rigid restriction of its habitat by environmental parameters, which is responsible for the marked fluctuations in skipjack abundance which occur. Without exception throughout the world "natural" fluctuations in skipjack abundance (at least as indexed by catch per unit of effort) completely overshadow fishery induced changes. In fact I have been unable to detect, let alone evaluate, a consistent relationship between fluctuation in fishing effort and the resultant catch per unit of effort, for any of the skipjack fisheries studied.

It appears certain that at present levels of fishing effort on the skipjack resources of the Pacific the mortalities induced by man are completely overshadowed by those from natural causes. In addition the extreme (by other fisheries standards) fluctuations in skipjack abundance which occur from year to year are indicative of great variation in natural skipjack mortalities. Furthermore the failure of a particularly strong size class in one year to be even detectable as older (larger) fish in the following or subsequent years, indicates that these great natural mortalities can occur at varying stages of the skipjack lifecycle. This suggestion of high mortality for a given size class (which may vary from year to year) is endorsed by the apparent disappearance of selected cohorts of tagged fish and also by the comparatively short time period in which a strong size class is influential in a fishery.

While it is impossible to conclusively substantiate the theory I believe that the great fluctuations in natural mortality responsible for the fluctuations in abundance, are the result of variability in the magnitude of the environment (habitat) available to skipjack of any specific size and I further believe that the magnitude of these mortalities can be so great as to apparently eliminate entire size cohorts in a very short time period (i.e. of the order of weeks).

7. Conclusions relevant to stock assessment

It is agreed that the data presently available are not adequate to enable any accuracy or certainty to be attached to estimates of possible yield from the Pacific skipjack resources. Some of the more conspicuous deficiencies in our knowledge of skipjack are:

- (i) The number of discreet stocks of skipjack and the geographical distribution of each remain unknown.
- (ii) Stock to stock interaction is unknown.
- (iii) Catches still appear to be increasing directly with effort and it is not possible to detect fishery induced changes in C.P.U.E.
- (iv) It is extremely difficult to find fishing units in which the fish and the effort can be considered as sufficiently randomly and uniformly distributed to allow estimates of indices of abundance.
- (v) It is not possible to follow cohort progression in most skipjack fisheries.
- (vi) No mortality estimates are available except for a few small localized fisheries and even in these mortality estimates are not precise.
- (vii) Conventional yield or production models do not appear suitable for skipjack assessment. With possible great variation in both M and K over short time periods the use of M/K as a yield indicator must be questioned.
- (viii) The factors most affecting M and K are not known.
- (ix) There are great "natural" fluctuations in skipjack abundance and there is no known correlation between successive good or bad years. It is not as yet possible to predict approximate abundance.

Although the above-mentioned, and obviously other, deficiencies in our knowledge make accurate resource estimations impossible it is interesting to speculate on what the resources might yield and what will in fact limit the magnitude of that yield. While I cannot give indisputable mathematical or biological justification for my opinion I do feel that the skipjack resources of the Pacific are underexploited and, at least in the equatorial western Pacific, the species is in no danger of being overexploited beyond the point of "maximum sustainable biological yield" as used by Joseph and Calkins 1969. I base this opinion largely on the following:

- (i) The area of distribution of skipjack in the Pacific is immense.
- (ii) The spawning area is less than (i) but still great.
- (iii) Over much of its area of distribution skipjack concentrations are insufficient to support an economical fishery.
- (iv) At least in equatorial western region most of the schools are too small for economical purse-seining and bait boats take only part of every school encountered, ensuring at least some survival even in those areas which may be heavily fished.

- (v) Skipjack do not form spawning aggregations which are more susceptible to fishing.
- (vi) Juvenile stages in the life cycle do not need protection from skipjack or other fisheries.
- (vii) Skipjack occur in many areas where bad weather prevents year-round exploitation.
- (viii) The oceanic range of the species means that capture cost is high and only areas producing high yields are exploited.
- (ix) The natural mortalities of skipjack undergo extreme fluctuations.

Until a more accurate stock description is available it will not be possible to ascertain how the above 9 points apply to the total skipjack resource. It can be argued that when skipjack occur in areas where the 20° isotherm is close to the surface they are more susceptible to purse-seining and hence more vulnerable to the fishery as a whole. In such areas it is more likely that a substantial part of the total stock could be taken and subsequent recruitment could be affected and so, until the relationship between the fish in such areas and those in the equatorial western Pacific is established caution must be exercised in generalizing. Nonetheless I feel that the skipjack, at least in the equatorial western Pacific represent a resource which it will not be possible to fish to the point of "maximum sustainable yield". I feel the economic constraints (particularly with rising fuel and labour costs) coupled with the inconsistent (in terms of density and season) distribution of the species will make a "maximum attainable yield" which is in effect "maximum economic yield", a more likely phenomenon.

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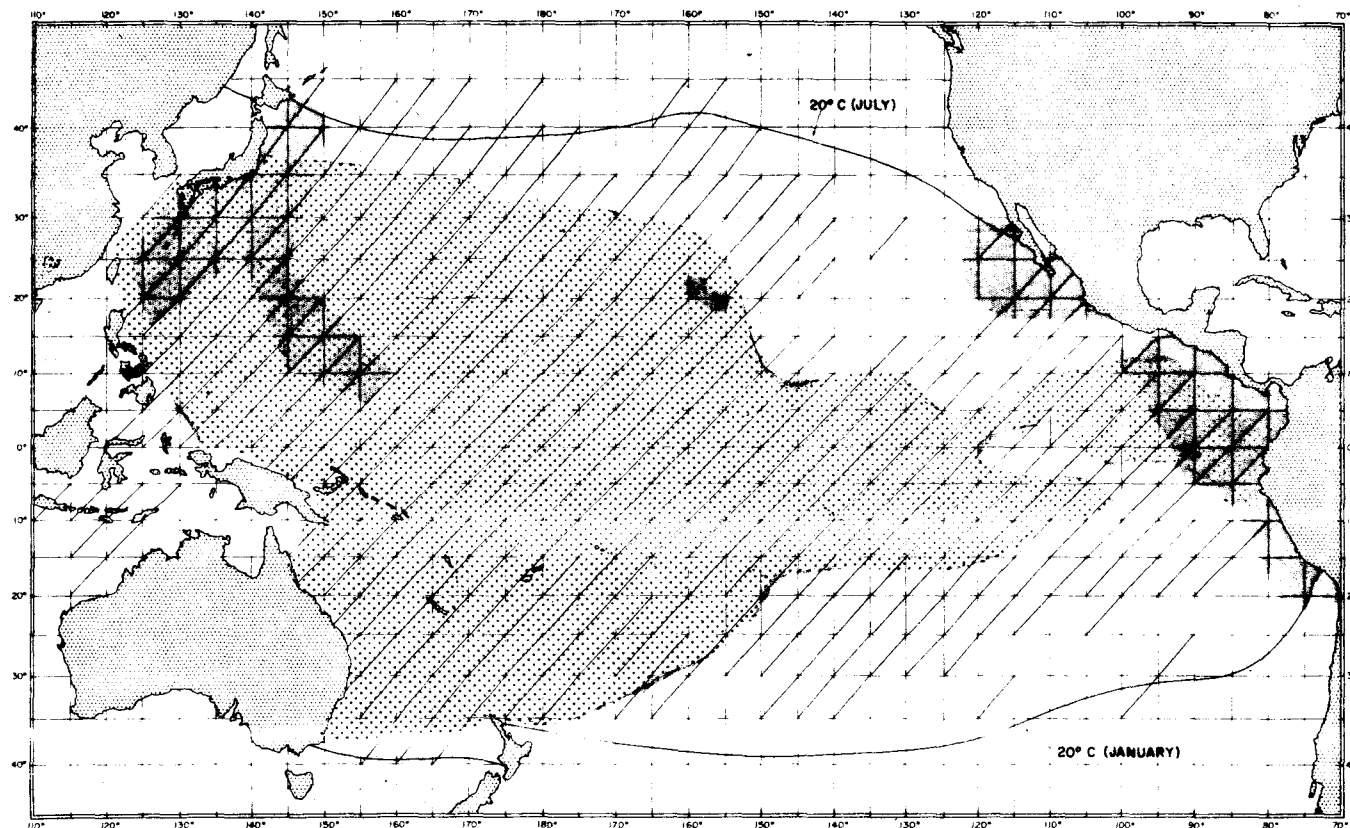


Figure 1. Approximate distribution of adult and larval skipjack in the Pacific Ocean. Larger striped area is that of adults and shaded area that of juveniles. [From Joseph and Calkins 1969 (for adults) and Matsumoto and Skillman 1975 (for juveniles)].

Figure 2 (b). Schematic representation of skipjack migration from the equator to higher latitudes.

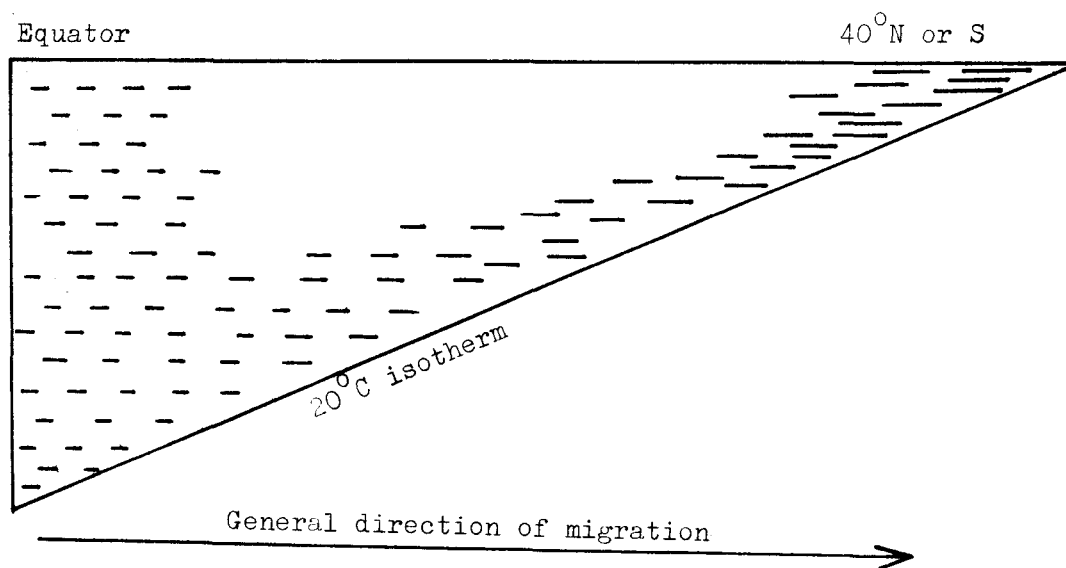


Figure 3. Approximation of postulated linear growth phases of skipjack.

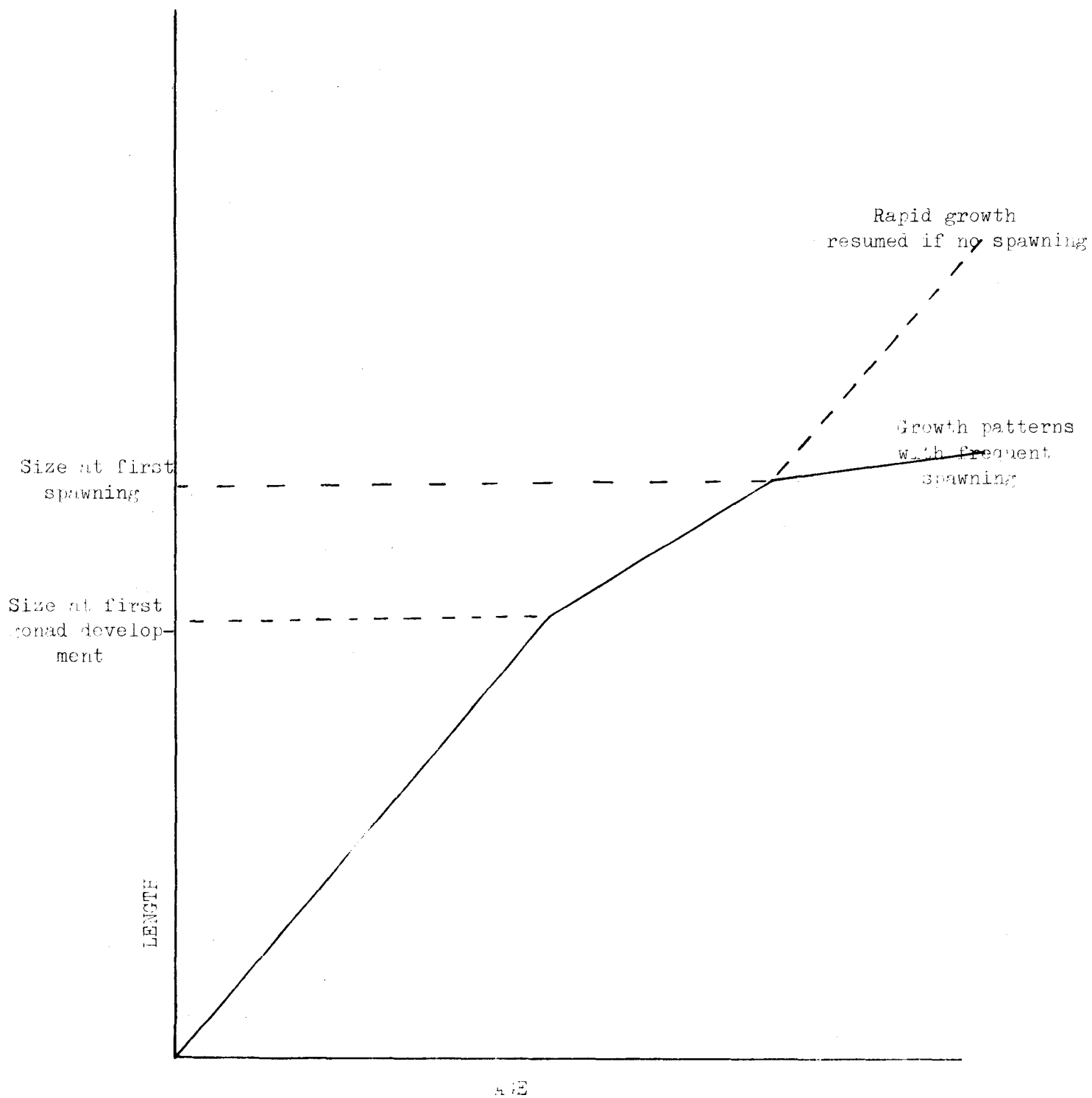
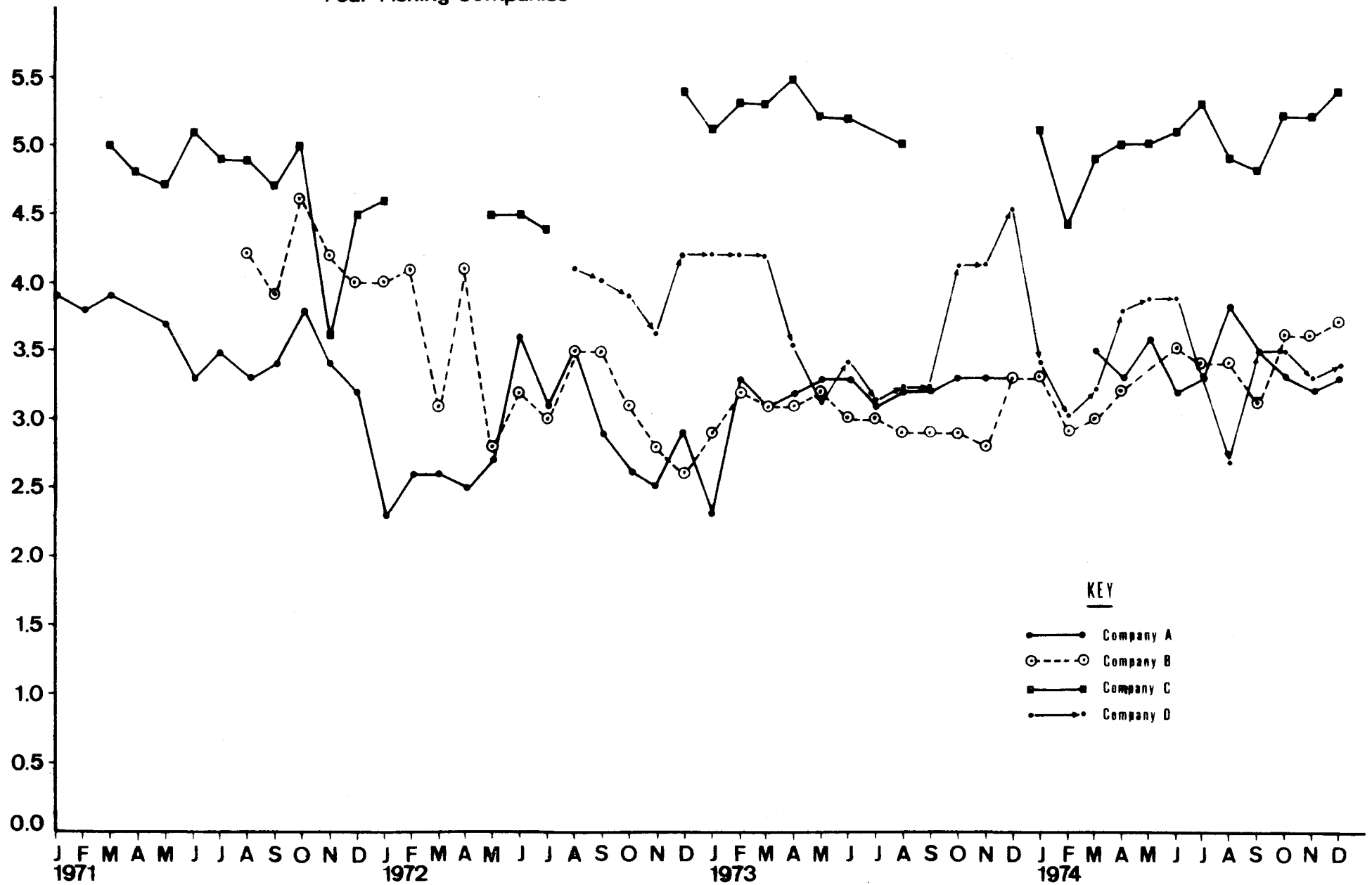


Fig. 4 Fluctuations With Time of the Average Size of Skipjack Taken By Each of the Four Fishing Companies



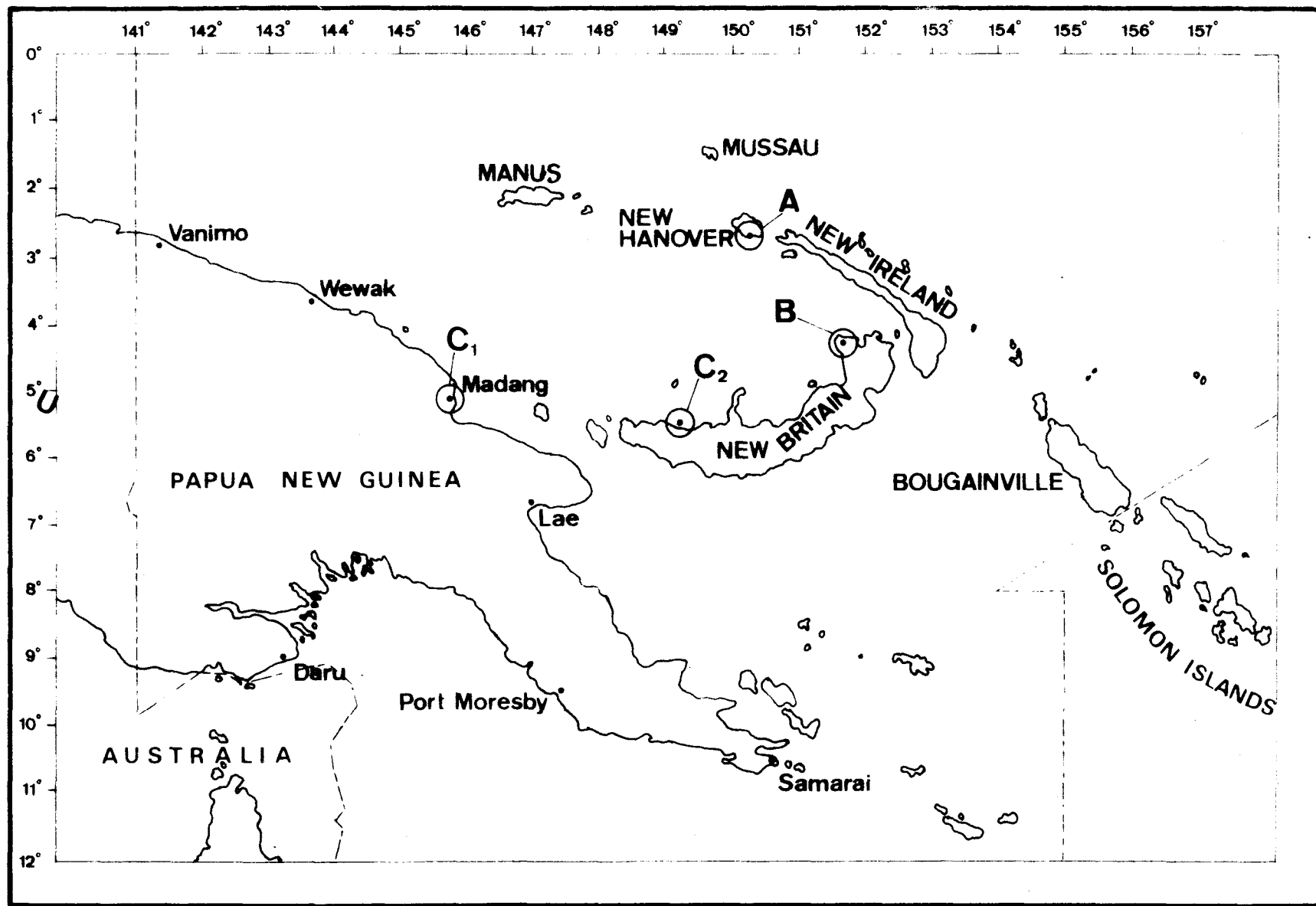


Fig. 5 Positions of the Exclusive Baitfishing Areas of Each Company