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303 RANGE OF THE SKIPJACK TUNA SUBPOPULATION IN THE WESTERN PACIFIC OCEAN

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RÉSUMÉ: Some 6,600 blood specimens were collected from skipjack tuna, Katsuwonus pelamis, from areas off the northeastern and southern coasts of Japan, Okinawa, Bonin-Marianas, Caroline Islands, Solomon Islands, and the areas between the Bonin-Mariana-Caroline archipelagoes and the date line from September 1966 through June 1969. Genetic analyses of these specimen, especially of the serum esterase system, permit a detailed description of range of the subpopulation of the species in the western Pacific in different seasons. Evidence that fish of the western Pacific subpopulation in the waters off the northeastern coast of Japan were replaced within a few weeks in early fall by fish of the central and eastern Pacific subpopulation(s) is presented.

Genetic data, published and unpublished results on movements of tagged fish, spatiotemporal distribution of larvae, and size composition of fish commercially caught, are considered in a discussion of the population structure and migratory route of the subpopulation in the western Pacific Ocean.

INTRODUCTION

On the basis of a series of genetic studies as well as data on larval distribution and the commercial catch, Fujino (1970 and in press a) has drawn a rough sketch of the population structure of the skipjack tuna, Katsuwonus pelamis, subpopulation in the northwestern Pacific Ocean.

More recently, blood specimens were collected from skipjack tuna from the area between Japan-Bonin-Marianas and the date line, waters of the Trust Territory of the Pacific Islands, the Solomon Islands, American Samoa, and waters off the northeast coast of North Island, New Zealand. Biological data which include genetic analyses of these specimens, especially of the serum esterase system, and age composition analysis of the commercial catch permit a detailed description of range, population structure, and migratory routes of the subpopulation of the species in the Northern and Southern Hemispheres of the western Pacific Ocean. Further evidence that fish of one subpopulation in the waters off Japan were replaced within a few weeks by fish of another subpopulation is presented.

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RANGE OF THE WESTERN PACIFIC SUBPOPULATION

A series of extensive genetic studies (Fujino, 1970) has indicated that skipjack tuna of the western Pacific subpopulation are present throughout the year in the waters off the Pacific coast of Japan and the Philippine Sea without being replaced by fish from the central and eastern Pacific subpopulation(s). These studies have also shown that the boundary between migratory ranges of the different subpopulation shifts to the east in summer and to the west in fall and winter in the offshore

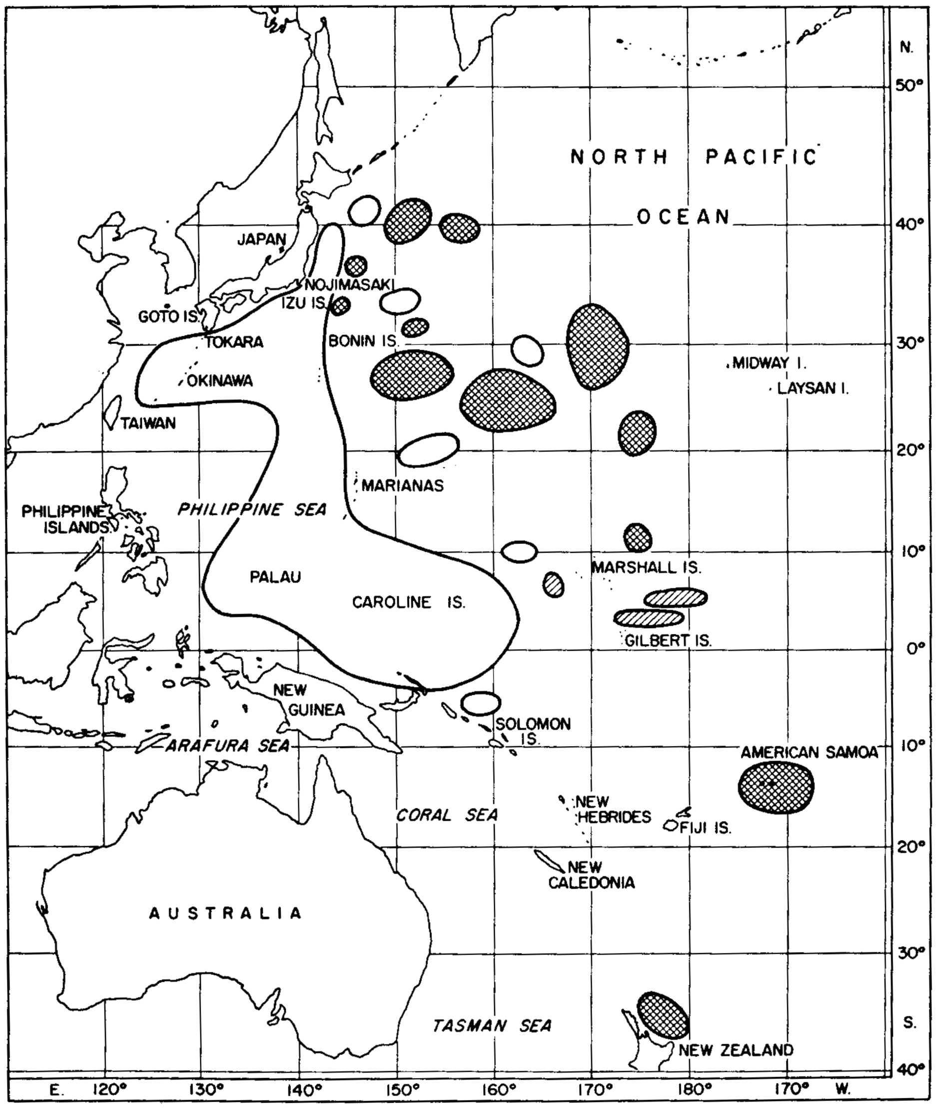

Figure 1. Areas where blood specimens from skipjack tuna were sampled in the western Pacific Ocean. Open areas show locations where fish of the western Pacific subpopulation were taken. Cross-hatched areas show where fish of the central and eastern Pacific subpopulation(s) were taken. Hatched areas indicate where the three lots 70, 71, and 81 (table 1) were sampled.

waters of the east coast of Japan and in the waters between the Bonin-Mariana chain and the international date line. On the basis of the above results, Fujino (in press b) stated that skipjack tuna is sympatric in the ecological sense rather than allopatric.

Figure 1 summarizes areas where blood specimens were sampled. Recently some 800 blood specimens (in 18 lots) were collected from skipjack tuna from the area between Japan-Bonin-Marianas and the date line, the Trust Territory, and the Solomon Islands area. Subpopulations of the samples were identified by the application of rejection limits of frequencies of

Table 1. Subpopulation identification of samples of skipjack tuna taken from offshore waters of the east coast of Japan and areas between Bonin-Mariana-Palau-New Guinea archipelagoes and the international date line[1]

Lot No.	Number of fish examined	Month sampled	Locality		Fork length in cm.
			Latitude	Longitude	
Central and eastern Pacific subpopulation (E^1_{SJ}<0.566)					
76	19	Jan. 1969	28°-29° N.	169°-173° E.	64-86
78	19	Jan. 1969	10°-11° N.	174°-175° E.	55-69
86	31	June 1969	33° N.	144° E.	38-45
89	28	June 1969	32° N.	151° E.	39-53
Unidentified (0.566<E^1_{SJ}<0.590)					
70	87	Nov. 1968	4° N.	175° E.-178° W.	53-79
71	60	Nov. 1968	3°-5° N.	170°-178° E.	50-71
81	42	Feb. 1969	6°-7° N.	164°-165° E.	60-77
Western Pacific subpopulation (E^1_{SJ}>0.590)					
68	60	Nov. 1968	0°-1° S.	140°-142° E.	49-58
73	26	Oct.-Nov. 1968	1°-2° S.	143°-150° E.	35-63
74	23	Nov.-Dec. 1968	5° N.-6° S.	143°-152° E.	57-67
75	37	Dec. 1968	5°-6° S.	157°-160° E.	55-66
77	40	Jan.-Feb. 1969	6° N.	149°-153° E.	52-68
79	18	Feb. 1969	10° N.	149° E.	60-69
80	14	Feb. 1969	8° N.	151° E.	45-65
82	100	Mar. 1969	10°-11° N.	156°-157° E.	61-73
83	99	Mar. 1969	9°-12° N.	160°-164° E.	61-72
87	26	May 1969	33° N.	142° E.	37-44
88	20	June 1969	32° N.	146°-147° E.	40-47

[1] Taken after the samples shown in Fujino (1970: table 11). Lots 68, 73, 74, 77, 82, 83, 86, 87, 88, and 89 were taken by pole and line or trolling and all other lots by longline. Lots 70, 71, and 81 were taken over several days of November 10 through 20, November 3 through 26, and late February, respectively.

Table 2. Gene frequencies of serum esterase system of the samples of skipjack tuna from the southwestern Pacific Ocean

Lot No.	Number of fish examined	Month sampled	Frequency[1] of gene E'_{SJ}	Fork length in cm.
American Samoa[2]				
1	23	Feb. 1970	0.500	57-68
2	23	Feb. 1970	0.544	46-53
3	20	Mar. 1970	0.500	48-60
4	50	Mar. 1970	0.530	44-53
5	29	Mar. 1970	0.448	40-60
6	60	Mar.-Apr. 1970	0.475	48-65
New Zealand[3]				
1	22	Apr. 1970	0.432	47-61
2	20	Apr. 1970	0.500	49-57
3	20	Apr. 1970	0.450	49-57

[1]Compared with rejection limits (Fujino, 1970: fig. 1), all samples were indistinguishable from fish of the central and eastern Pacific subpopulation(s) but distinguishable from fish of the western Pacific subpopulation.

[2]Taken by pole and line during Charles H. Gilbert cruise 117.

[3]Taken by gill netting in the waters off the northeast coast of North Island, New Zealand.

the determinant gene of the fastest clear band of the serum esterase, E'_{sj} (Fujino, 1970: fig.1). The results are summarized in table 1. Samples taken from American Samoa (205 fish in 6 lots) and from New Zealand (62 fish in 3 lots) were all indistinguishable from fish of the central and eastern Pacific subpopulation(s) but distinguishable from fish of the western Pacific subpopulation (Table 2). For lots 70, 71, and 81, frequencies of E'_{sj} fell where the rejection limits (Fujino, 1970: fig.1) for the different subpopulation overlap and were not identified in this regard. The three lots were taken over a period of several days in November 1968 and February 1969 by longline fishing in locations shown as hatched areas in figure 1; no further information was available. The most likely interpretation of the above results would be that each lot was sampled from fish from both the western Pacific and the central and eastern Pacific subpopulations. The results together with earlier results permit me to state that the range of the western Pacific subpopulation extends eastward to approximately long.165°E. without marked seasonal shifts in the equatorial region, placing the boundary in the area between the eastern Caroline Islands and the Marshall-Gilbert Islands. An easterly seasonal shift of the boundary is more pronounced in higher latitudes than in the equtorial region of the northwestern Pacific Ocean.

Fujino (1970) presented evidence which showed that in September off the northeast coast of Japan, fish of the western Pacific subpopulation were replaced within a few days by those of

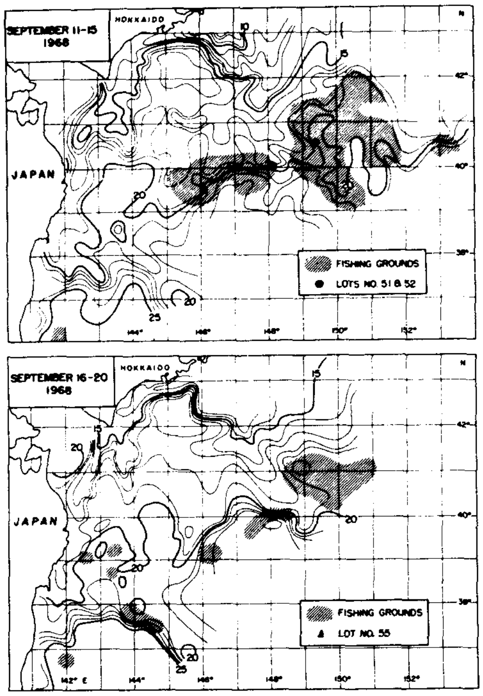

Figure 2. Surface water temperature contours (in °C) in the fishing grounds off the northeast coast of Japan in early and late mid-September 1968, when fish of the western Pacific subpopulation (lots 51 and 52) were replaced by fish of the central and eastern Pacific subpopulation(s) (lot 55). (Source for contours: Japan. Fishing Ground Knowledge Populariz- ing Association, 1968.)

the central and eastern Pacific sub- population(s). Data from three lots of samples, numbers 86 (taken June 3), 87 (taken May 28), and 88 (taken June 3) (see table 1), give evidence that a similar replacement, but in reverse, occurred in the waters off the southern coast of Japan (east side of the Izu Islands) between late May and early June 1969.

Skipjack tuna fishing (mostly pole and line with some purse seine) along the Pacific coast of Japan begins in spring in the waters off the south coast of Kyushu, moves northeastwards along the Kuroshio, reaches the waters off the northeast coast of Japan in summer, and ends there in October or November. In 1968, fish that appeared in the waters off the northeast coast of Japan in summer and the early half of September were identified as those of the western Pacific subpopulation, represented by lots 51 (taken from lat. 40°N, long.149°E on September 12) and 52 (taken from lat. 40°N, long. 148°E on September 15) and by many other lots taken earlier (Fujino, 1970). Locations of fishing grounds in these waters from September 11 through 15,1968, are shown with surface temperature contours in figure 2a. Fishing grounds for the following 5 days are indicated in figure 2b, which also shows the locality where fish of the central and eastern Pacific subpopulation(s) first appeared in the latter half of mid-September. They stayed there for several weeks, as evidenced by lots 55 (taken from lat. 37°N, long.144°-145°E on September 18-20), 58 (taken from lat. 38°-39°N, long. 152°-155°E on October 15-18), 59 (taken from lat. 38°-39°N, long. 153°-154°E on October 17-18), and 64 (taken from lat. 40°-41°N, long. 150°E on November 2-5) (Fujino, 1970: table 11). Despite replacement of fish from different subpopulations in such a short period of time, no distinct change was seen in surface temperature patterns during the period. The southward shift of the Oyashio-Kuroshio front, however, began a few weeks later (see Japan. Fishing Ground Knowledge Popularizing Associa- tion, 1968: Rapid reports Nos. 34, 37, and 38). The above evidence to- gether with earlier data suggests that fish of the western Pacific subpopu- lation moved south of southwestwards from the fishing grounds but not east or southeastwards.

INTERNAL STRUCTURE AND MIGRATION OF THE WESTERN PACIFIC SUBPOPULATION

After summarizing the results of a series of extensive investigations of larval and juvenile tunas conduct- ed since 1960, Ueyanagi (1969: appen- dix figs. 7a, 7b, and the text) sta stated that skipjack spawn in the western Pacific between lat. 35°N and 18°S in the northern summer and be- tween lat. 22°N and 24°S in the northern winter.

On the basis of analyses of mon- thly modal progression in size distribution of skipjack tuna taken commercially, Kawasaki (1955a, 1955b, and 1964) stated that there were five groups in the adjacent waters of Japan that display life patterns different from each other: Goto group, chain group in the Okinawa-Tokara area, chain group in the Izu-Bonin area, northeastern inshore group, and northeastern offshore group. Fish of "Goto and the northeastern groups" are migratory and their gonads become active in the northern winter, and gonads of the "chain groups" become active in the northern summer, thus indicating existence of two groups, migratory group and chain group, distinguishable from each other by the state of their gonads.

I examined the existence of two such groups by applying the growth curve for fish taken commercially from the entire western Pacific Ocean as follows. Figure 3 shows the growth curve (solid line) for skipjack tuna, obtained from tagging experiments for fish of the central and eastern Pacific subpopulation(s) through the von Bertalanffy growth function (Rothschild, 1967). The curve is shown for the size range of fish taken commercially. It conforms well to the growth rate estimated from monthly modal progression in size distribution for fish from the western Pacific Ocean (Kawasaki, 1963: Rothschild, 1967), although the estimates are based on fish from different subpopulations. Another set of growth curves (dotted line), shown in figure 3, represents a hypothetical group of fish spawned 6 months later. Although sufficient data are not available for the estimate of growth rates in the larval and juvenile stages, size-age relationships for fish that appear in commercial catches from the western Pacific Ocean can be arbitrarily defined from figure 3.

Fork length in cm.	Age in full year
44 and smaller	0
45 to 63	1
64 to 73	2
74 and larger	3

Application of the growth curve of figure 3 to modal size data of the catch from Japanese coastal waters

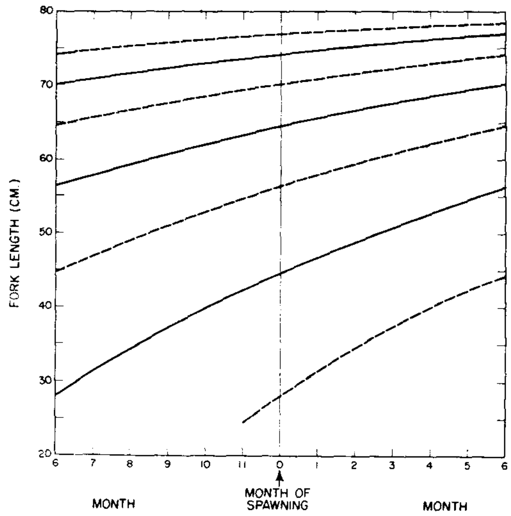

Figure 3. Growth curve (solid line) for skipjack tuna, drawn from tagging experiment data through the von Bertalanffy growth function (Rothschild, 1967) under an assumption that the curve passes the point of 0 cm fork length at 0 months of age (or month of spawning) (Fujino and Kang, 1968). Sizes of fish, represented by the solid curve in the month of spawning, indicate fork lengths at ages in full years. Dotted curve represents growth for fish spawned 6 months later.

(Kawasaki, 1964: figs. 1 through 4) permits me to make the following statement: there are two groups of fish spawned in different seasons; fish from both groups appear in all four areas of Tohoku (northeastern Japan), Izu-Bonin, Okinawa-Tokura, and Goto; and fish from one group (A) are dominant in the first three areas and those from the other group (B) are dominant off Goto. Thus the existence of two groups of fish in the Japanese coastal waters is verified, although there is some difference between my view and Kawasaki's, noted in an earlier paragraph of this article. Kawasaki indicated that his "migratory group" (corresponding to Goto and northeastern groups) and "chain group" appear in different areas separately. My analysis showed that fish of the two groups appear together in all areas but that the proportions of the two groups are different by area. Similar analyses of size distribution data from the Marianas and Palau (Fujino, in press a: fig. 5) permit me the following statements. In the Marianas, fish from group B predominate in the northern winter but the situation is not clear in other seasons due to insufficient data. In Palau, group B predominates in all seasons appearing almost exclusively in the northern winter. In other areas in the western Pacific Ocean, including the areas of Daito Island (northeast of Taiwan), Luzon Strait (Kawasaki, 1955a), the Caroline Islands (unpublished data), New Zealand (York, 1969), and New Caledonia (Legand, MS.: table 2), fish from the two groups appear in varying proportions, but insufficient data do not permit any precise statements about their relative abundance.

No genetic difference has been found between the two groups (A and B) taken from the western Pacific subpopulation in the Northern Hemisphere. It can be said from the foregoing evidence that (1) within the western Pacific subpopulation there are two groups that spawn in different seasons, one in summer and another in winter, but are not genetically isolated, and that (2) fish from the two groups migrate to various parts of the western Pacific Ocean in varying proportions. Although there is no direct evidence as to which group spawns in which season, Kawasaki's observations on gonads of fish appearing in the Japanese coastal waters (for example the Goto Islands, where one finds inactive gonads in the northern summer) suggest that fish of group B spawn in the northern winter and those of group A in the northern summer. It is unknown yet, however, whether fish in each group spawn in both seasons or whether each group has a single spawning season separately from the other but with some gene exchange.

Recent tagging experiments conducted in the western Pacific indicated that skipjack migrate (1) from the waters off the east coast of Taiwan to the areas of Goto, Okinawa-Tokara, the southern coast of Kyushu, the Izu Islands, and Tohoku (northeast coast of Japan); (2) from areas off Nojima-saki in two directions: one to the area of the Izu Islands and another to Tohoku; and (3) from Palau to the Marianas (Tohoku Regional Fisheries Research Laboratory, n.d.; Kato, 1969; and Otsu, in press).

1/ Legand, M. Manuscript. Indications sur la bonite a ventre rayé dans le sud Ouest Pacifique. Institut Francais d'Oceanie, Office de la Recherche Scientifique et Technique Outre-Mer, Nouméa, New Caledonia.

DISCUSSION

To formulate a model of population structure and migration for the western Pacific skipjack tuna subpopulation, some discussion of the present studies follows:

(1) Range of the western Pacific subpopulation in the Southern Hemisphere.

Genetic data, especially on the serum esterase system, on skipjack tuna taken from waters of American Samoa and New Zealand (table 2), as well as earlier results (Fujino, 1970), have indicated that the range of the central and eastern Pacific subpopulation(s) extends westwards near the date line and the waters around New Zealand in the southern summer and early fall.

No such data are available to delineate the range of the western Pacific subpopulation in the Southern Hemisphere. As noted earlier, however, skipjack tuna spawn in the southern summer from lat. 22°N to 24°S without marked geographical discontinuity between the Northern and Southern Hemispheres in the western Pacific (Ueyanagi, 1969: appendix fig. 7b). Although the mechanism of gene exchange between the two groups (A and B) within the western Pacific subpopulation in the Northern Hemisphere is as yet unknown, their simultaneous occurrence throughout the areas where data are available plus the continuity of spawning grounds suggest that skipjack tuna in the southwestern Pacific are not genetically isolated from the subpopulation in the northwestern Pacific Ocean. From the above statement it can be said that the range of the western Pacific subpopulation extends across the Equator far into the Southern Hemisphere. The boundary between the western Pacific subpopulation and the central and eastern Pacific subpopulation(s) may be found between New Guinea-Australia and the date line, somewhere near the New Hebrides, the

Loyalty Islands, and the west coast of New Zealand. It is likely that seasonal boundary shifts analogous to those in the Northern Hemisphere take place, although no data are available yet.

(2) Some factors limiting the range of a subpopulation.

Insufficient data do not permit any comprehensive discussion of isolating mechanisms between subpopulations, or factors which limit the range of each. Evidence of replacement of fish of one subpopulation by fish of another, however, provides some fragmentary information indicating that at least two factors play a role.

As described already, in 1969, during the wintering of fish of the western Pacific subpopulation in the Philippine Sea, fish of the central and eastern Pacific subpopulation(s) appeared in the waters just to the east of the Izu Islands. They did not migrate further westwards beyond the islands, and between late May and early June were replaced by fish of the western Pacific subpopulation. The observation strongly suggests that the Izu-Bonin-Mariana archipelagoes act as a barrier to the central and eastern Pacific subpopulation(s). Insufficient data do not permit any further discussion on the subject.

As noted, skipjack tuna fishing along the Pacific coast of Japan begins in spring in the waters off the southern coast and the fishing grounds move northeastwards accompanied by a shifting of the Kuroshio front. In 1968, skipjack tuna fishing grounds reached their northeastern extreme (approximately lat. 42°-43°N, long. 156°-157°E) in August. Up to then, the major fishing grounds moved approximately 11 km on an average daily (measured in a straight line). A southwestward movement of the fishing grounds from the extreme location began in early September that year and the daily movement then averaged about 34 km (three times the earlier daily movement--a probable sign of a distinct response to some stimuli) for the early half of September. Then fish of the central and eastern Pacific subpopulation(s) appeared there. The southwestward shift of the skipjack fishing grounds took place a few weeks before an apparent southwestward movement of the Kuroshio-Oyashio front from its northern extreme, and fish of the western Pacific subpopulation disappeared from the waters.

The above observations suggest that skipjack tuna recognize changes in the water through sensory channels (properties such as temperature gradients, a difference in chemical constituents,etc., Harden Jones, 1968), react to the stimuli,and begin a south or southwestward migration. Thus water-mass difference is another possible factor in limiting the range of fish of certain subpopulations.

(3) Significance of the existence of two groups within a subpopulation.

Growth curves for skipjack tuna from tagging experiments were discussed by two independent studies. Rothschild (1967) used data obtained from the experiments conducted in Hawaiian waters. Joseph and Calkins (1969) based their analyses on the results of experiments conducted in the eastern Pacific and stated that parameters of the Rothschild's curve fell within the confidence regions of their estimates. Thus Rothschild's (1967) curve was used for the present analyses of size distribution data.

Despite some possible deviation in the estimate of the growth curve applied, the existence of two groups of skipjack within a single subpopulation is obvious. Lack of difference in genetic composition between the two groups suggests at least one of two possible mechanisms of gene flow between them. (1) Fish of each group spawn in both seasons, summer and winter, thus providing unlimited opportunities for gene exchange. (2) Each group has a single spawning season separate from the other (summer or winter) with a low frequency gene exchange. (A low-frequency continuous or intermitten gene exchange is sufficient for the attainment of genetic homogeneity.) Occasional overlapping of the spawning seasons of the two groups, for example, beginning of spawning of one group before ending of spawning of another, could be the mechanism.

Such a mechanism could also play a part in exchanging genes between skipjack tuna in the Northern and

Southern Hemispheres within the western Pacific Ocean, resulting in homogeneous genetic compositions. Recognition of two groups A and B provides a potential tool for improving our understanding of their ecology and for estimating parameters in stock assessment through analyses of dynamic features of the two groups.

The foregoing discussions strongly suggest the existence of an intermediate state of diversifying into subpopulations from a homogeneous population in skipjack tuna: the existence of two groups that behave differently in the ecological sense without genetic diversity (Mettler and Gregg, 1969: fig. 8.3 and the text, pp. 183-185).

A MODEL OF POPULATION STRUCTURE AND MIGRATION OF SKIPJACK TUNA IN THE WESTERN PACIFIC OCEAN

On the basis of the foregoing analyses, discussions, and other available data, the following model of population structure and migration is proposed.

(1) In the northern winter, fish of the western Pacific subpopulation stay within the Philippine Sea, areas of the Caroline Islands, the Coral Sea, and the Tasman Sea (the eastern limit of the range being near the New Hebrides and off the west coast of New Zealand, with some year-to-year difference). In the northern summer, the range in the Northern Hemisphere extends eastward to about long.165°E; east westerly seasonal shifts of the eastern limit of the range are more marked in higher latitudes than in the equatorial region in the Northern Hemisphere. Similar seasonal shifts must take place in the Southern Hemisphere, although no data are available (see fig. 4). The western limit of the range of the western Pacific subpopulation could reach to the Greater and Lesser Sunda Islands, the east coast of Australia, and the eastern half of the south coast of Australia at least.

(2) There are two spawning seasons, one in northern summer and another in northern winter. Intensive spawning takes place in the areas approximately between lat. 30°N and 10°S in the northern summer and between lat. 20°N and 22°S in the northern winter within the range of the western Pacific subpopulation noted above (extending west-

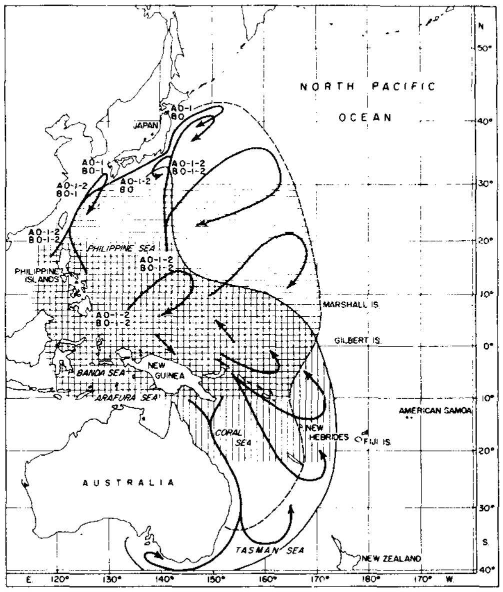

Figure 4. Proposed range and migration routes of skipjack tuna subpopulation in the western Pacific Ocean. Eastern limit of range in the northern winter (southern summer) and northern summer (southern winter) are indicated by a thin solid line and a broken line, respectively. These two lines also represent approximate western limits of ranges of the central and eastern Pacific skipjack tuna subpopulation(s) in the two seasons. Intensive spawning grounds in the northern summer and winter are shown as the areas hatched horizontally and vertically, respectively. Thick solid lines with arrows represent proposed major routes of migration of both group A and B as described in the text. Thick broken lines with arrows show possible infrequent intermingling across the Equator between northern and southern fish. Numerals with a letter A or B mean age classes of fish by group (A or B) in each location, as described in the text. (Sources: Japan. Fishing Ground Knowledge Popularizing Association, 1968; Kawasaki, 1955a, 1955b, 1964; Fujino, in press a.) Such numerals are not shown for the Southern Hemisphere for lack of data.

ward to the areas around the Philippine Islands). As a result, in both the Northern and Southern Hemispheres there are two groups of fish spawned in different seasons and behaving differently from each other in an ecological sense without diversification in genetic composition.

(3) The two groups (A and B) spend their larval and juvenile stages separately from each other in the tropical and subtropical waters. After the juvenile stage, the majority of fish spawned in the northern summer in the Northern Hemisphere (group A) migrates to temperate waters by two major routes: one along the Luzon Strait, the east coast of Taiwan, the Ryukyu Islands, and the south and east coasts of Japan or the Goto Islands in the East China Sea; and the other along the Mariana-Bonin-Izu Islands and the southeast and east coasts of Japan. They migrate in different proportions, by age and by area, beginning in the northern spring and continuing through the fall. These fish winter in the tropical and subtropical waters, in fact, some parts of group A stay the year around in the archipelago areas of the Northern Hemisphere. They spawn in the areas noted in item (2) from May through August, with a peak in June or July.

Some parts of group B, spawned between November and February in the Northern Hemphere, migrate to almost all areas where group A fish appear. They move into the temperate waters about 1 month later than group A fish in the northern summer and fall in verying proportions by age and by area. They spend the northern winter and spring in tropical and subtropical waters; on the whole, greater parts of group B stay in the tropical and subtropical areas. As a result, fish of group A dominate fish of group B from spring through fall in the temperate waters of the Northern Hemisphere, except in the area of the Goto Islands.

(4) Groups A and B, products of southern winter and summer spawning in the Southern Hemisphere, also spend their larval and juvenile stages separately from each other in the subtropical and tropical waters. After that, some parts of the two groups migrate to temperate waters of the Tasman Sea and adjacent regions in varying proportions by age and by area, while the rest remain behind. As a whole, fish of group B predominate from southern spring through fall in the temperate zones of the Southern Hemisphere.

Two major routes are postulated for the migration: one along the Solomon Islands-New Hebrides archipelagoes and another along the coast of New Guinea and the east and southeast coasts of Australia.

Intermingling (with gene exchange) takes place between northern group A and southern group A and between northern group B and southern group B at the time of spawning and during the larval stage. After the larval stage, intermingling of fish from the northern and southern groups probably continues but less frequently. Figure 4 summarizes proposed migration pattersn of the skipjack subpopulation in the western Pacific Ocean.

TESTING OF THE HYPOTHESES

A variety of studies must be conducted to test the hypotheses proposed in the present model. Some aids for planning the work are listed below.

(1) To test the relationship between fish from the Northern and Southern Hemispheres in the western Pacific, genetic data should be collected from various parts of the Tasman Sea and adjacent regions, that is, the east coast of Australia, New Caledonia, the New Hebrides, and the Fiji Islands.

(2) To delineate the western limit of the range of the western Pacific subpopulation, genetic data should be collected from the South China Sea, Java Sea, Banda Sea, Arafura Sea, and the Indian Ocean.

(3) A series of observations of gonads from both groups in different seasons must be conducted to examine the relationship between the groups, first recognized by size composition.

(4) The extent of intermingling between northern group A (or B) and southern group A (or B) can be studied by tagging experiments only.

(5) To test the migratory route along the Mariana-Bonin-Izu chain up to Japanese coastal waters, extensive tagging should be conducted in the archipelago areas.

(6) Finally, for studying isolating mechanisms between the western Pacific and the central and eastern Pacific subpopulation, a series of extensive subpopulation studies of larval and juvenile skipjack tuna must be conducted. This study should be made in the areas where the boundary between the two subpopulations exists and should include simultaneous oceanographic observations.

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LITERATURE CITED

Fujino, K. 1970.
Immunological and biochemical genetics of tunas. Trans. Amer. Fish.Soc. 99:152-178.

In press a. Skipjack tuna subpopulation identified by genetic characteristics in the western Pacific. Proc. CSK Symp., East-West Center, Honolulu,Hawaii,April 29-May 2,1968.

In press b. Genetic markers in skipjack tuna from the Pacific and Atlantic Oceans. Proc. Special Meeting on the Biochemical and Serological Identification of Fish Stocks, the International Council for the Exploration of the Sea, Dublin, Ireland, September 27-28, 1969.

Fujino, K., and T. Kang. 1968.
Transferin groups of tunas. Genetics 59: 79-91.

Harden Jones, F.R. 1968.
Fish migration. St. Martin's Press, New York, 325 pp.

Japan. Fishing Ground Knowledge Popularizing Association. 1968.
Rapid report on fisheries of bluefin tuna, albacore, skipjack tuna, and saury. (Gyojochishiki Fukyukai) Yaizu Branch Office. (In Japanese.)

Joseph, J., and T.P. Calkins. 1969.
Population dynamics of the skipjack tuna (Katsuwonus pelamis) of the eastern Pacific Ocean. Bull. Inter-Amer. Trop. Tuna Comm. 13: 7-273.

Kato, T. (editor). 1969.
Year book of skipjack tuna and other tunas (Katsuo-maguro Nenkan) for 1969. Suisan-shincho Co., Tokyo, 950 pp. (In Japanese.)

Kawasaki, T.
1955a.
On the migration and the growth of the skipjack, Katsuwonus pelamis (Linnaeus), in the southwestern sea area of Japan. Bull. Tohoku Fish. Res. Lab. 4: 83-100. (Translation from Japanese.)

1955b.
On the migration and the growth of the skipjack, Katsuwonus pelamis (Linnaeus), the Izu and Bonin Sea areas and the northeastern sea area long the Pacific coast of Japan. Bull. Tohoku Fish. Res. Lab. 4: 101-119. (Translation from Japanese.)

1963.
The growth of skipjack on the northeastern Sea of Japan. Bull. Tohoku Fish. Res. Lab. 23:44-60. (In Japanese with English summary.)

1964.
Population structure and dynamics of skipjack in the North Pacific and its adjacent waters. Bull. Tohoku Fish. Res. Lab. 24:28-47. (In Japanese with English summary.)

Mettler, L.E., and T.G. Gregg.
1969.
Population genetics and evolution. Prentice-Hall, Inc. Englewood Cliffs, New Jersey, 212 pp.

Otsu, T.
In press. Tagging of skipjack tuna, Katsuowonus pelamis, in Palau. Proc. CSK Symp., East-West Center, Honolulu, Hawaii, April 29-May 2, 1968.

Rothschild, B.J. 1967.
Estimates of the growth of skipjack tuna (Katsuwonus pelamis) in the Hawaiian Islands. Proc. Indo-Pacif. Fish. Coun. 12, Sect. 2: 100-111.

Tohoku Regional Fisheries Research Laboratory.
n.d.
Results of skipjack tagging investigations in 1967 and 1968, 18 pp. (In Japanese.)

Ueyanagi, S. 1969.
Observations on the distribution of tuna larvae in the Indo-Pacific Ocean with emphasis on the delineation of the spawning areas of albacore, Thunnus alalunga. Bull. Far Seas Fish. Lab. 2: 177-256. (In Japanese with English synopsis.)

York, A.G. 1969.
Tuna investigations - east coast area of New Zealand 1965-1967. Fish. Tech. Rep. N.Z. Marc. Dep. 40, 80 pp.