MODEL OF THE MIGRATION OF ALBACORE IN THE NORTH PACIFIC OCEAN

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ABSTRACT

On the basis of tag recovery data, age and growth information, and distribution and size frequency data from the various fisheries, a model of the migration of albacore in the North Pacific Ocean has been developed. This model is consistent with the hypothesis that there is a single population of albacore in the North Pacific Ocean.

The model depicts extensive migrations of the albacore from one fishery to another and from one side of the North Pacific to the other side. In general it is shown that albacore recruitment into the commercial fisheries takes place largely in the eastern Pacific, and that there is a greater volume of migration of the commercial sizes of fish in the westerly direction from the American fishery into the Japanese fisheries, than vice versa. There is a tendency for the youngest fish in the American fishery to return to the same fishery the following season rather than to migrate across into the Japanese fisheries. This tendency is reduced in the older fish. Some albacore may be available to the American fishery for as many as four or five successive seasons.

As the albacore attain sexual maturity in temperate waters (6-year-olds and older) they move south into subtropical waters, where they make up the reproductive unit of the North Pacific population. This movement south takes place in the spring at the end of the Japanese winter longline season. It is hypothesized that spawning occurs in subtropical waters during the summer, and that the larval and early juvenile stages are spent in these waters. When about 1 year old, the fish migrate into temperate waters, but do not immediately join the exploited stock. The albacore are generally not available to the commercial fisheries until they are 2 or 3 years old.

On the basis of tag recovery data, age and growth information, and distribution and size frequency data from the various fisheries, a model of the migration of the albacore, *Thunnus germo* (Lacépède), in the North Pacific Ocean is proposed. This model is consistent with the hypothesis that there is a single population of albacore in the North Pacific and that the North Pacific albacore fisheries, both American and Japanese, are exploiting a common resource. The model is presented with the hope that critical examination and testing of it may lead to a better understanding of the albacore resource of the North Pacific Ocean.[1]

NORTH PACIFIC ALBACORE FISHERIES

The three major albacore fisheries in the North Pacific are: (1) The Japanese livebait fishery during April–July off the coast of Japan (Van Campen, 1960); (2) the Japanese longline fishery during October–March from the coast of Japan east to about longitude 170° W. (Nankai Regional Fisheries Research Laboratory, 1954); and (3) the U.S. west coast trolling and livebait fishery during June–November between Baja California and the Pacific Northwest (Clemens, 1955). The

NOTE.—Approved for publication January 18, 1962.

[1] A recent publication by Clemens, Harold B. (1961) ("The Migration, Age, and Growth of Pacific Albacore (*Thunnus germo*), 1951–1958." California Department of Fish and Game, Fish Bulletin 115, 128 pp.) carries a discussion on the same subject of oceanwide migrations of the albacore.

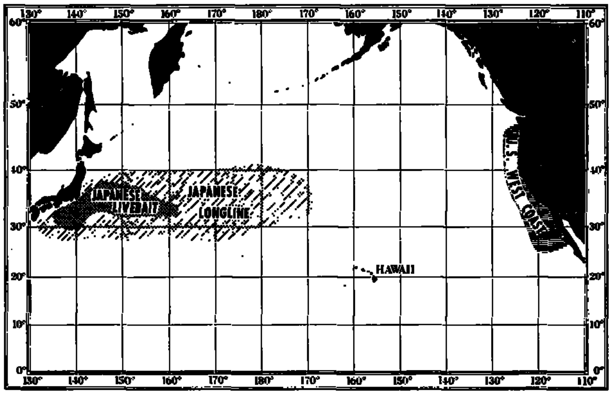


FIGURE 1.—The three major North Pacific fisheries for albacore.

general areas of the three fisheries are shown in figure 1.

SEASONAL DISTRIBUTION AND MOVEMENTS OF THE FISHING GROUNDS

The seasonal shifting of the fishing grounds within the Japanese livebait fishery (fig. 2), Japanese winter longline fishery (fig. 3), and the American west coast fishery (fig. 4) reflects the pattern of the albacore migration within these respective grounds. The Japanese livebait fishery begins off southern Japan in late April or May and gradually moves north and northeast. The fishery reaches its peak in June and rapidly declines in July, as the fish move farther offshore to the eastward.

The Japanese winter longline fishery begins in October, with its center of abundance located in midocean generally between 170° E. and 180° and along latitude 38° N. There is a gradual south-

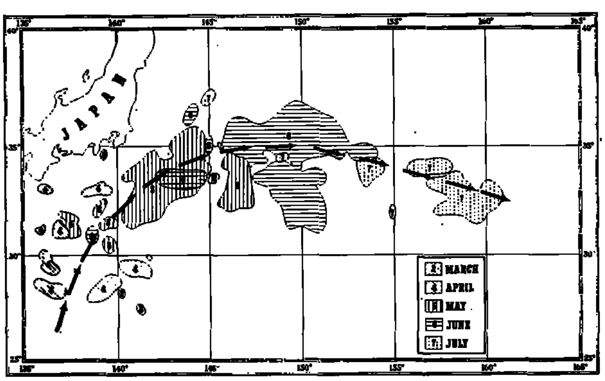


FIGURE 2.—Seasonal pattern of movement of the Japanese livebait fishery. (After Van Campen, 1960, fig. 2.) (The general direction of movement is indicated by the arrow.)

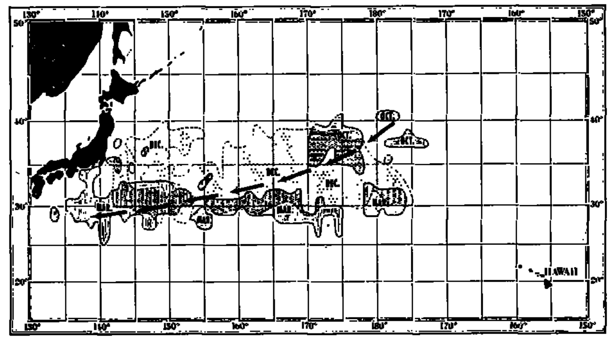


FIGURE 3.—Seasonal pattern of movement of the Japanese winter longline fishery, as constructed from data of the Nankai Regional Fisheries Research Laboratory (1959). (The general direction of movement is indicated by the arrow.)

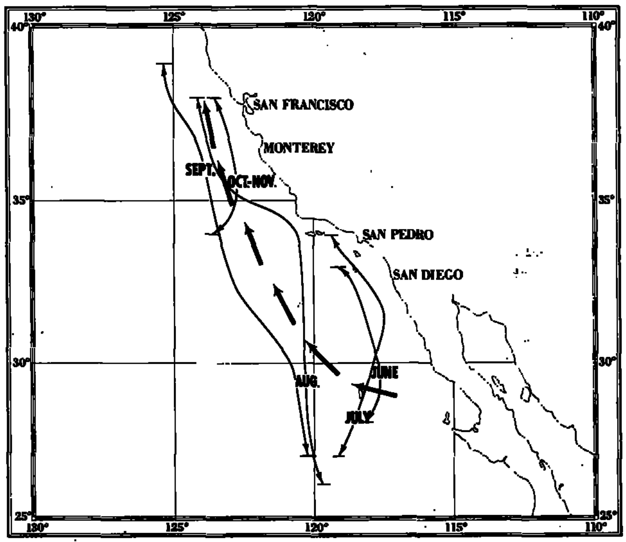


FIGURE 4.—Seasonal movement of the California albacore fishery in 1953. Each line extends over the total area fished during the month and describes diagrammatically the northward expansion of the fishery as the season progresses. (From Clemens, 1955, fig. 24.) (The general direction of movement is indicated by the arrow.)

westward shift of the areas of highest catch rates (Nankai Regional Fisheries Research Laboratory, 1959) which continues through March. Thereafter the fishery declines very rapidly. Towards the end of the fishing season, in March, the center of concentration shifts to around latitude 30° N., longitude 140° E.

The American fishery tends to move northward along the coast as the season progresses (Clemens, 1955). This tendency is indicated in figure 4, which is a partial reproduction of Clemens' figure 24.

SIZES AND ESTIMATED AGES OF FISH EXPLOITED

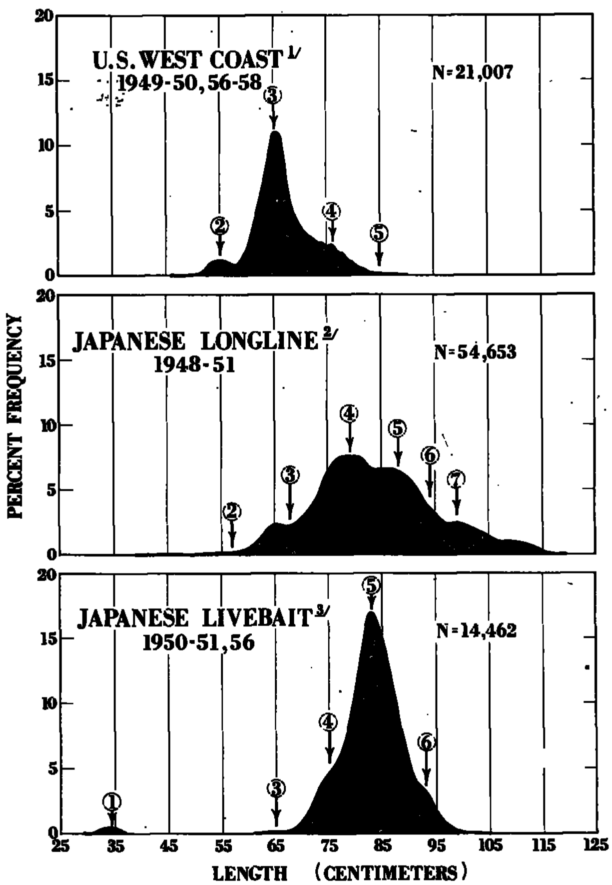
A composite length frequency distribution for each of the fisheries is shown in figure 5. The modal lengths of the age groups are approximations based on the appearance of the modes in the length frequency distributions, as well as on an albacore growth curve derived from tag recovery data (Otsu, 1960).

Studies to date have not yielded a satisfactory method for assigning absolute ages to the albacore. Growth curves have been constructed (Otsu, 1960), but the early growth, below the point of inflection on the curve, remains questionable. By means of a Gompertz equation, Otsu (1960) attempted to describe the entire growth curve of the albacore but concluded that the initial growth as shown by the resulting curve seemed unreasonably slow, since it required about 3 years for the fish to attain a weight of 1 pound (about 30 cm.). He suggested a possible error of 1 or 2 years in the ages assigned by this method.

A group of 30–35 cm. fish occasionally enters the commercial catches. It is possible that these are the first-year fish, and assuming that they are, it is postulated that the albacore are about 2 years old when (at a length of about 50 cm.), they first enter the fisheries in significant numbers. On this assumption, the Japanese livebait fishery generally exploits three age groups, 4-, 5-, and 6-year-olds, whose modal lengths are approximately 75, 83, and 93 cm. Occasionally 1-year-old fish (around 35 cm.) are taken, but not in great numbers, and 2-year-olds are usually absent from the catches. Three-year-old fish appear in small numbers.

The winter longline fishery exploits a wide range of ages, from 2- to 8- or 9-year-old fish. Generally, the catches are composed of the following modal sizes, corresponding to the age groups within this range: 57, 68, 79, 88, 94, 99 cm., and a few fish of larger groups. Most abundant are the 4- and 5-year-old fish (79- and 88-cm. groups).

The American fishery is generally based on three groups, which are approximately 2-, 3-, and 4-year-old fish (55, 65, and 76 cm.), but small numbers of older groups (5- and 6-year-olds) also appear. The 3-year-old fish are usually the most abundant in the catches. Aside from the infrequent occurrence of 1-year-old fish in the Japanese livebait fishery, the youngest members of the albacore population are exploited by the American fishery since here, for the first time, 2- and 3-year-old fish appear in significant quantities.



[1] Compiled from Graham (1959); and from unpublished data of the Fish Commission of Oregon, California Department of Fish and Game, and the Washington State Department of Fisheries.

[2] Compiled from data in Nankai Regional Fisheries Research Laboratory (1950) and (1951).

[3] Compiled from data in Nankai Regional Fisheries Research Laboratory (1951) and Mie Prefectural Fisheries Experimental Station (1957).

FIGURE 5.—Length frequency distributions of albacore taken in the three major fisheries. (The ages (encircled) are shown at the approximate modal size of each age group.)

MIGRATION OF ALBACORE BETWEEN FISHERIES

Until recently little was known of the distribution of albacore in the approximately 2,000 miles of open ocean between the Japanese winter longline grounds and the west coast of North America. Since 1954, the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, has conducted 10 exploratory fishing and 6 hydro-

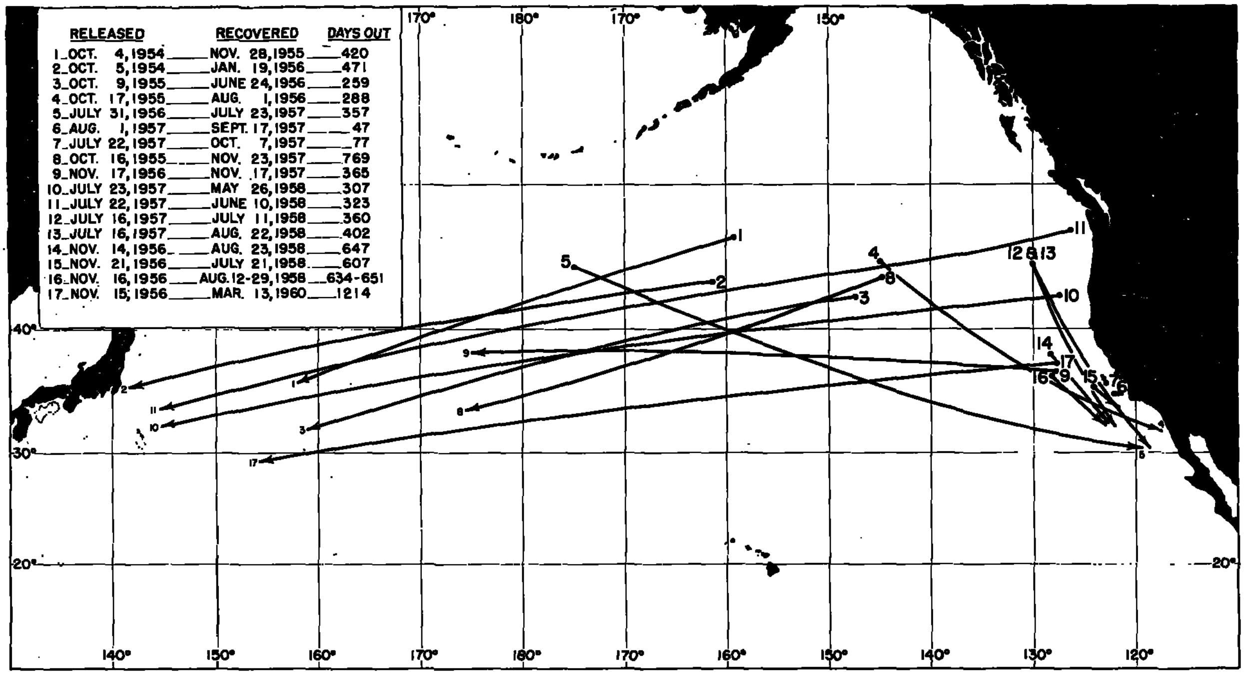


FIGURE 6.—Net movements of albacore tagged by the Bureau of Commercial Fisheries Biological Laboratory, Honolulu. (The lines connect the points of release and recovery of each fish, and the numbers correspond to the "Recovery Number" in table 1).

graphic cruises in that area. The results of these cruises are described by Shomura and Otsu (1956), Graham (1957), and Graham (MS).[2] By longlining, trolling, and gillnetting, it was shown that albacore are generally scarce in this extensive area during the winter and spring. In summer, the surveys disclosed localized areas of abundance between longitudes 160° W. and 175° W., but farther to the east albacore occurrence was sparse. In the fall, the catches indicated a continuous distribution of fish, although not in great abundance, between the declining American fishery and the developing Japanese longline fishery.

The migration of the albacore between the west coast of the United States and the Pacific coast of Japan has been shown in the results of tagging experiments (Otsu, 1960). Data on the size and age composition of fish exploited in the different fisheries provide supplementary evidence on the migrations of albacore among the areas of the North Pacific fisheries.

The Bureau of Commercial Fisheries Biological Laboratory, Honolulu, tagged a total of 934 albacore between January 1954 and September 1958 in the temperate North Pacific between the U.S. west coast and longitude 179° E. (Otsu, 1960). In addition, 270 albacore were tagged in the Japanese livebait fishing grounds in the spring of 1956 (Van Campen and Murphy, 1957). Of the 934 releases in the central and eastern North Pacific, 17 recoveries (1.8 percent) had been reported as of August 1961 (table 1 and fig. 6). To date no recoveries have been made of the 270 fish tagged in the Japanese fishery.

Recoveries of albacore tagged by other research agencies (nine by the Nankai Regional Fisheries Research Laboratory, five by the California Department of Fish and Game, and four by the Fish Commission of Oregon) are listed in table 2 and illustrated in figure 7.

Tag recoveries have shown transpacific movements of fish from the American fishery into the Japanese longline fishery (fig. 6 Nos. 9 and 17; fig. 7, Nos. 19, 20, and 21) and into the Japanese livebait fishery (fig. 6, Nos. 10 and 11; fig. 7, Nos. 18, 22, 23, and 33). There have been movements from the midocean area between the American fishery and the Japanese longline fishery into the American fishery (fig. 6, Nos. 4 and 5), as well as into both Japanese fisheries (fig. 6, Nos. 1, 2, 3,

[2] Graham, Joseph J., Manuscript. The macroecology of the albacore tuna, *Thunnus germo* (Lacépède), in the central North Pacific. Bureau of Commercial Fisheries Biological Laboratory, Honolulu.

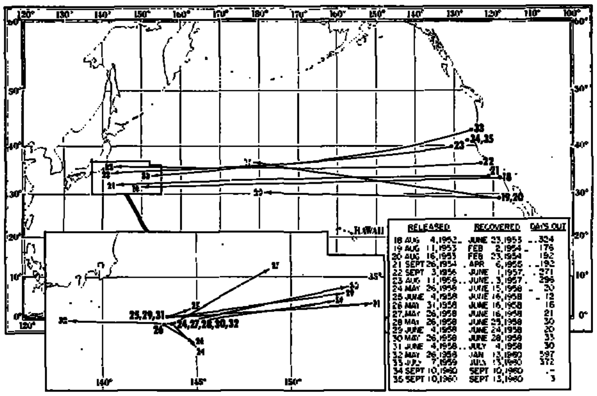


FIGURE 7.—Net movements of albacore tagged by the Nankai Regional Fisheries Research Laboratory, the California Department of Fish and Game, and the Fish Commission of Oregon. (The lines connect the points of release and recovery of each fish, and the numbers correspond to the "Recovery Number" in table 2).

and 8). Tagging in the Japanese livebait fishery has resulted in recaptures which showed a generally easterly movement away from Japan (fig. 7, Nos. 24–31), and one such recovery has been made in the winter longline fishery (fig. 7, No. 32). None of the albacore tagged in the Japanese livebait fishery has been retaken in the American fishery, but, as will be shown later, this probably does not mean that there is a complete lack of migration in that direction.

MODEL OF MIGRATION

Interpretation of the pattern of tag returns indicates that albacore undertake no more than one transpacific crossing during a 1-year period. These movements are considered to be rapid between the established fisheries, and slow within the areas of the fisheries.

TABLE 1.—*Recoveries of albacore tagged by the Bureau of Commercial Fisheries Biological Laboratory, Honolulu*

Recovery No.	Release		Recapture			
	Date	Fishing gear	Date	Fishermen	Vessel	Fishing gear
1	Oct. 4, 1954	Longline	Nov. 28, 1955	Japanese	*No. 1 Seifuku Maru*	Longline.
2	Oct. 5, 1954	Trolling	Jan. 19, 1956	do	unknown	Do.
3	Oct. 9, 1955	do	June 24, 1956	do	*No. 6 Usa Maru*	Livebait.
4	Oct. 17, 1955	do	Aug. 1, 1956	American	unknown	Trolling.
5	July 31, 1956	do	July 23, 1957	do	*Carol Virginia*	Livebait.
6	Aug. 1, 1957	do	Sept. 17, 1957	do	*Crisella*	Trolling.
7	July 22, 1957	do	Oct. 7, 1957	do	*Mercator*	Livebait.
8	Oct. 16, 1955	do	Nov. 23, 1957	Japanese	*No. 3 Hoju Maru*	Longline.
9	Nov. 17, 1956	do	Nov. 17, 1957	do	unknown	Do.
10	July 23, 1957	do	May 26, 1958	do	do	Livebait.
11	July 22, 1957	do	June 10, 1958	do	*No. 2 Zenshin Maru*	Do.
12	July 16, 1957	do	July 11, 1958	American	*Lococo Brothers*	Trolling.
13	July 16, 1957	do	Aug. 22, 1958	do	*Bernard Pedro*	Do.
14	Nov. 14, 1956	do	Aug. 23, 1958	do	*Paul C.*	Do.
15	Nov. 21, 1956	do	July 21, 1958	do	*Mable*	Livebait.
16	Nov. 16, 1956	do	Aug. 12–29 1958	do	*Datho II*	Do.
17	Nov. 15, 1956	do	Mar. 13, 1960	Japanese	*No. 2 Hayatori Maru*	Longline.

Recovery No.	Release			Recapture			
	Position		Size (cm.)	Position		Size (cm.)	Days out
	Latitude	Longitude		Latitude	Longitude		
1	46°30′ N	159°18′ W	78.2	35°45′ N	157°39′ E		420
2	43°31′ N	161°16′ W	68.0	35°23′ N	141°20′ E		471
3	42°16′ N	147°16′ W	63.4	31°54′ N	158°37′ E		259
4	44°55′ N	144°48′ W	59.9	31°21′ N	117°17′ W	72.3	288
5	44°31′ N	174°55′ W	68.4	30°08′ N	119°03′ W	78.0	357
6	34°49′ N	121°57′ W	66.5	34°49 N	121°26′ W		47
7	35°43′ N	122°58′ W	65.5	36°24′ N	123°07′ W	67.0	77
8	43°40′ N	144°40′ W	65.1	33°22′ N	174°07′ E	94.8	769
9	36°44′ N	127°37′ W	85.2	38°08′ N	174°53′ E	97.5	365
10	42°20′ N	127°33′ W	78.0	32°15′ N	144°15′ E	85.2	307
11	47°00′ N	126°18′ W	75.0	33°40′ N	144°00′ E		323
12	44°47′ N	130°04′ W	65.0	30° N	118°45′ W.[1]	77.3	360
13	44°47′ N	130°04′ W	75.0	32° N	122° W.[1]	84.5	402
14	38°00′ N	128°25′ W	79.4	32°15′ N	122°30′ W	92.6	647
15	35°21′ N	123°57′ W	68.6	34°00′ N	122°10′ W	86.4	607
16	36°48′ N	127°33′ W	65.9	32°38′ N	123°00′ W	81.2	634–651
17	37°12′ N	127°41′ W	60.8	29°28′ N	153°45′ E	ca. 90	1,214

[1] Approximate position of recapture.

TABLE 2.—*Recoveries of albacore tagged by the California Department of Fish and Game, the Fish Commission of Oregon, and the Nankai Regional Fisheries Research Laboratory*

Recovery No.	Release			Recapture			
	Date	Agency [1]	Fishing gear	Date	Fishermen	Vessel	Fishing gear
18	Aug. 4, 1952	CFG [2]	Trolling	June 23, 1953	Japanese	*No. 5 Chosho Maru*	Livebait.
19	Aug. 11, 1953	CFG	do	Feb. 2, 1954	do	*No. 1 Konpira Maru*	Long line.
20	Aug. 16, 1953	CFG	do	Feb. 23, 1954	do	*Sin-o Maru*	Do.
21	Sept. 26, 1954	CFG	do	Apr. 6, 1955	do	*No. 5 Shoyei Maru*	Do.
22	Sept. 3, 1956	CFG	do	June 1, 1957	do	unknown	Livebait.
23	Aug. 11, 1956	OFC	do	June 3, 1957	do	do	Do.
24	May 26, 1958	NRFRL	Livebait	June 15, 1958	do	*No. 15 Hoko Maru*	Do.
25	June 4, 1958	NRFRL	do	June 16, 1958	do	*No. 3 Wasumi Maru*	Do.
26	May 31, 1958	NRFRL	do	June 16, 1958	do	*No. 7 Kyowa Maru*	Do.
27	May 26, 1958	NRFRL	do	June 16, 1958	do	*No. 8 Fukuichi Maru*	Do.
28	May 26, 1958	NRFRL	do	June 25, 1958	do	*Chiyo Maru*	Do.
29	June 4, 1958	NRFRL	do	June 24, 1958	do	unknown	Do.
30	May 26, 1958	NRFRL	do	June 28, 1958	do	do	Do.
31	June 4, 1958	NRFRL	do	July 4, 1958	do	do	Do.
32	May 26, 1958	NRFRL	do	Jan. 13, 1960	do	do	Longline.
33	July 7, 1959	OFC	Trolling	July 13, 1960	do	*Taiwa Maru*	Livebait.
34	Sept. 10, 1960	OFC	Seine	Sept. 10, 1960	American	unknown	Do.
35	Sept. 10, 1960	OFC	do	Sept. 13, 1960	do	do	Do.

Recovery No.	Release			Recapture			
	Position		Size (cm.)	Position		Size (cm.)	Days out
	Latitude	Longitude		Latitude	Longitude		
18	33°25′ N	118°15′ W	76.0	31°30′ N	149°40′ E		324
19	29°00′ N	118°30′ W	84.0	36°40′ N	178°12′ E	88.0	176
20	29°00′ N	118°30′ W	91.0	30°10′ N	178°54′ W	93.0	192
21	33°42′ N	121°15′ W		31°55′ N	143°15′ E	ca. 75	192
22	36°39′ N	123°16′ W		35°50′ N	142°50′ E		271
23	39°57′ N	130°38′ W		34°30′ N	142°00′ E	75.7	296
24	33°00′ N	143°45′ E	ca. 81	32°01′ N	144°58′ E		20
25	33°18′ N	143°31′ E	ca. 81	33°40′ N	144°40′ E	79.1	12
26	32°59′ N	143°19′ E	ca. 81	32°07′ N	144°52′ E		16
27	33°00′ N	143°45′ E	ca. 87	35°23′ N	148°54′ E	84.8	21
28	33°00′ N	143°45′ E	ca. 82	33°58′ N	152°20′ E	81.5	30
29	33°18′ N	143°31′ E	ca. 85	34°18′ N	152°51′ E		20
30	33°00′ N	143°45′ E		34°37′ N	153°03′ E	76.5	33
31	33°18′ N	143°31′ E	ca. 83	33°52′ N	154°21′ E		30
32	33°00′ N	143°45′ E	ca. 70	33°08′ N	138°15′ E	ca. 92	597
33	43°01′ N	125°34′ W	67.0	33°53′ N	152°23′ E		372
34	46°01′ N	126°30′ W	66.0	46°04′ N	126°27′ W		4 hr.
35	46°04′ N	126°27′ W	68.0	46°10′ N	126°10′ W		3

[1] CFG=California Department of Fish and Game; OFC=Fish Commission of Oregon; and NRFRL=Nankai Regional Fisheries Research Laboratory

[2] Data of the California tag recoveries were reported by Ganssle and Clemens (1953), Blunt (1954), Investigative Society of Tuna Fishery (1955), and in personal correspondence from H. B. Clemens dated July 9, 1957.

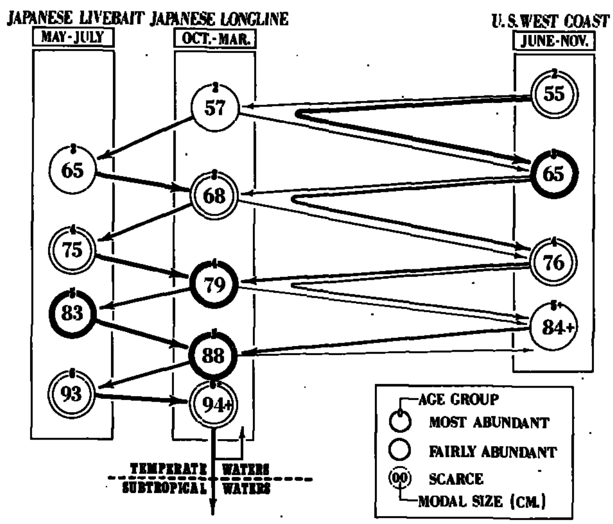


FIGURE 8.—Diagrammatic representation of albacore migration, by size (age) groups.

Figure 8 is a diagrammatic representation of the movements of albacore among the three fisheries. Since the sizes of the fish differ from one fishery to another (fig. 5), the migration of the albacore is hypothesized on the basis of size (age) groups. The approximate modal size for each year class in the catch is shown for each fishery. While it is not possible to describe quantitatively the movements among the fisheries, the following types or patterns of movements are the major elements in our suggested model of North Pacific albacore migrations:

I–a. This is the westward migration, in the fall, of 2-year-old (55 cm.) fish from the area of the American fishery. These albacore have been only partly recruited into the exploited stock at age 2; their recruitment will be completed when they are 3 years old. The majority of 2-year-olds do not get far enough west to reach the center of the Japanese winter longline fishery, and they may not even reach the eastern fringe of the developing winter longline grounds. In either case they do not migrate with the main body of southwesterly migrating fish in the longline fishery, but remain outside the area of any fishery until they return to the American fishery the following season as 3-year-olds.

I–b. The remaining 2-year-olds, those that do reach the center of the Japanese longline fishery, continue moving in a southwesterly direction between October and March and enter the Japanese livebait fishery in the spring as 3-year-olds. This group is apparently small, judging by the small numbers of 3-year-olds in the Japanese livebait catch.

II–a. The 3-year-olds (65 cm.), which are the major components of the American catch, may begin their westerly migration as early as August or September, but a significant portion of this group departs later in the season and does not reach the center of the Japanese longline fishery. These fish return to the American fishery the following summer as 4-year-olds.

II–b. The rest of the 3-year-olds, perhaps an equally significant portion, judging from the numbers of this year class in the American fishery and the Japanese longline fishery (fig. 5), enter the Japanese longline fishery by early winter. These fish continue westward to enter the Japanese livebait fishery the following spring as 4-year-olds.

III–a. The bulk of the third age group in the American catch, the 4-year-olds (76 cm.), migrate westward from the American fishery into the Japanese longline fishery and subsequently continue into the Japanese livebait fishery as 5-year-olds.

III–b. A small fraction of the 4-year-olds separates from the others and returns to the American fishery the following summer as 5-year-olds. This is only a small fraction, however, since 5-year-olds are an insignificant proportion of the American catch.

IV–a. Nearly all of the 5-year-old and older fish in the American fishery migrate into the Japanese livebait fishery by way of the Japanese longline fishery.

IV–b. A few of these older fish do separate and return to the American fishery. This is indicated by a tag recovery (table 1 and fig. 10, Recovery No. 14).

V–a. The Japanese livebait fishery is notably lacking in 2- and 3-year-old fish, which are fairly abundant in the American fishery. Such small fish, when present, may migrate into the American fishery after spending a part of the season in the longline fishery.

V–b. Of the more common sizes of fish in the Japanese livebait fishery, only the two youngest groups (the 4- and 5-year-olds) provide some fish which migrate into the American fishery. However, these are few, since by the time they enter the American fishery they are already 5- and 6-year-olds, and these age groups make an insignificant contribution to the American catch.

VI. The Japanese winter longline fishery receives fish from both the Japanese livebait fishery and the American fishery. From the longline fishery, the greater part of the albacore move into the Japanese livebait fishery, while the rest migrate east into the American fishery.

VII. The 6-year-olds (94 cm.) and older age groups in the winter longline fishery do not enter into either of the other two fisheries. A portion of these fish, having attained sexual maturity in temperate waters (albacore mature at around 90 cm.), move south into subtropical waters in the spring to form the reproductive unit of the North Pacific population (Ueyanagi, 1957; Otsu and Uchida, 1959). Since these older fish are always present in the winter longline fishery, it is apparent that at least some of them return north in the spring, possibly to the east of and beyond reach of the Japanese livebait fishery.

VIII. Most of the groups of fish exploited in the Japanese livebait fishery move from that fishery into the winter longline fishery and then back into the livebait fishery, thus remaining in the western North Pacific. Judging by the sizes of fish exploited, it is clear that only a small fraction of the fish in the livebait fishery migrate across the Pacific into the American fishery.

The above model is summarized in table 3, and the general pattern of migration of albacore in the North Pacific is illustrated in figure 9.

DISCUSSION

Data from tag recoveries support the model and thus the underlying hypothesis that there is a single population of albacore in the North Pacific

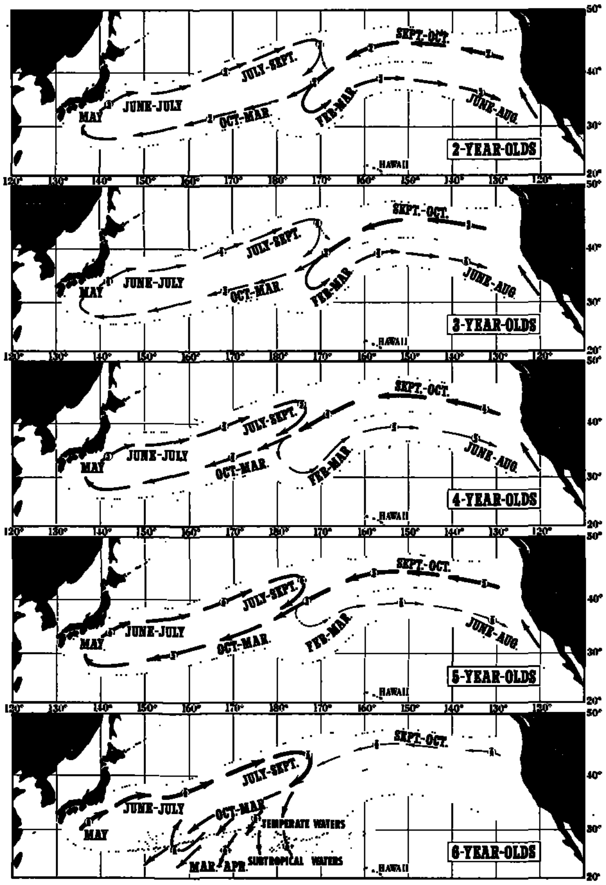


FIGURE 9.—Model of albacore migrations in the North Pacific Ocean, by age groups (ages encircled).

Ocean. In figure 10 and table 4 are shown the postulated migrations of each of the tagged fish recovered to date. The migration believed undertaken by each fish between tagging and recovery is related to one or more of the types of movement described in the preceding section and summarized in table 3.

There has not been any recovery of fish tagged as 2-year-olds in the American fishery, but this is understandable in view of their small number. Of 218 fish tagged by the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, in the general area of this fishery between longitudes 110° W. and 127° W., only 11 were 2-year-old fish. Judging from the fact that this age group is poorly represented in the Japanese longline fishery and that 3-year-olds are very scarce in the Japanese livebait fishery, it can be assumed that most of the fish return to the American fishery the following season and, along with new recruits, form the dominant 3-year-old age group (type I-a). The others probably constitute the 2-year-olds in the longline catch and the 3-year-olds in the following year's Japanese livebait catch (type I-b).

It has been hypothesized that a portion of the large adults occurring in the Japanese winter longline fishery move south during the spring into subtropical waters to form the reproductive part of the North Pacific population (Ueyanagi, 1957; Otsu and Uchida, 1959). We believe that it is fish from this group that appear in the Hawaiian longline fishery each year and contribute to an increase in landings beginning around April. However, since the annual landings of albacore in Hawaii are very small (between 10,000 and 21,000 pounds during the 1955–59 period), it is possible that the Hawaiian Islands are on the eastern fringe of this southward migration.

Otsu and Uchida (1959) have suggested that the albacore occurring in Hawaiian waters are a segment of the North Pacific spawning population. They also agree with Ueyanagi (1957) that albacore spawning probably takes place in subtropical waters in the areas under the influence of the

TABLE 3.—*Summary of the model of albacore migrations in the North Pacific Ocean*

Type of movement	Pattern of movement among fisheries
I-a	U.S. west coast (2-year-olds) → midocean[1] —(most)→ U.S. west coast (3-year-olds)
I-b	U.S. west coast (2-year-olds) → Japanese longline → Japanese livebait (3-year-olds)
II-a	U.S. west coast (3-year-olds) → midocean → U.S. west coast (4-year-olds)
II-b	U.S. west coast (3-year-olds) → Japanese longline → Japanese livebait (4-year-olds)
III-a	U.S. west coast (4-year-olds) → Japanese longline —(most)→ Japanese livebait (5-year-olds)
III-b	U.S. west coast (4-year-olds) → midocean —(few)→ U.S. west coast (5-year-olds)
IV-a	U.S. west coast (5-year-olds and older) → Japanese longline —(most)→ Japanese livebait (6-year-olds and older)
IV-b	U.S. west coast (5-year-olds and older) → midocean —(few)→ U.S. west coast (6-year-olds and older)
V-a	Japanese livebait (2-, 3-year-olds) —(few)→ Japanese longline → U.S. west coast (3-, 4-year-olds)
V-b	Japanese livebait (4-, 5-year-olds) → Japanese longline —(few)→ U.S. west coast (5-, 6-year-olds)
VI	U.S. west coast (2-, 3-, 4-, 5+-year-olds) → Japanese longline (Mixing) ← Japanese livebait (3-, 4-, 5-, 6-year-olds)
VII	Japanese longline (6-year-olds and older) → Subtropical Convergence → Subtropical waters, spawning
VIII	U.S. west coast ⇄ Japanese longline (few) ⇄ Japanese livebait (most)

[1] This term refers to the general area between the center of the Japanese longline fishery and the U.S. west coast, and including the eastern fringe of the longline fishery.

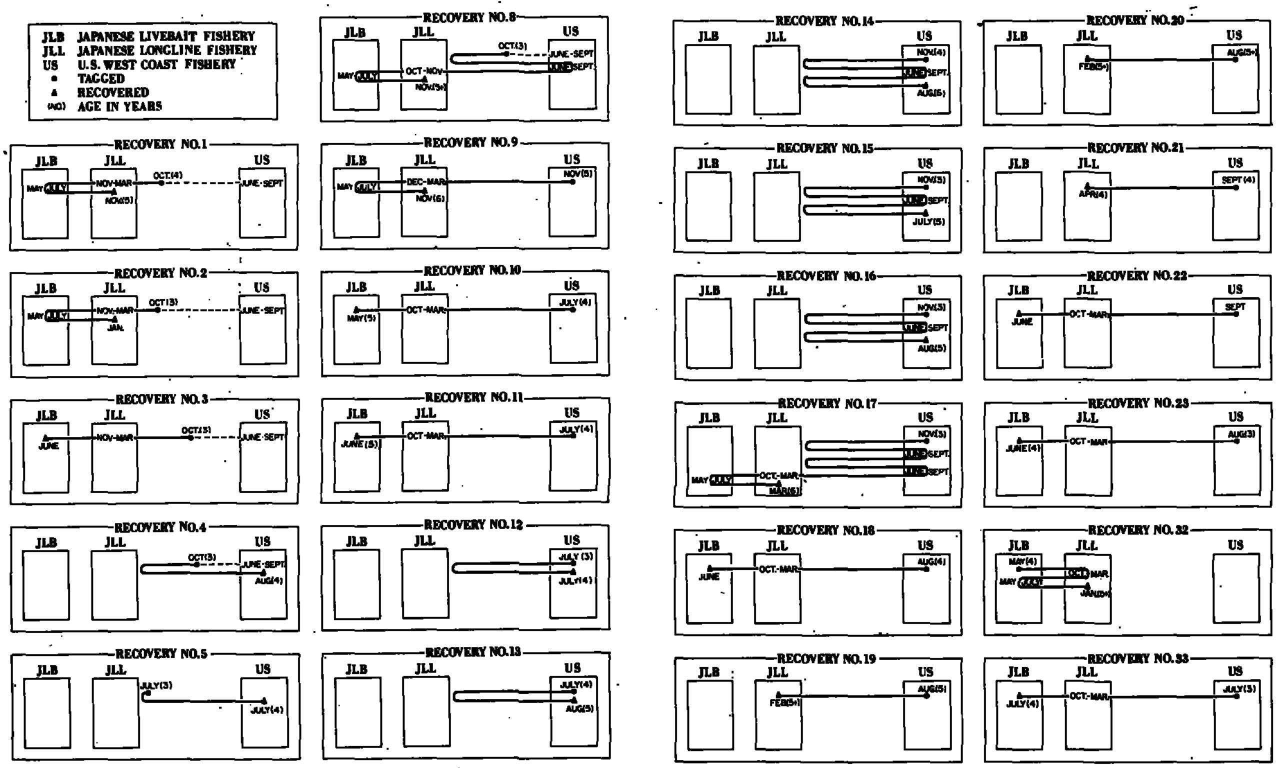


FIGURE 10.—Diagrammatic representation of the postulated migrations of albacore between tagging and recovery (see table 4).

North Equatorial Current. It seems a reasonable hypothesis that spawning occurs during the summer in subtropical waters (the exact spawning grounds have not yet been defined), and that the larval and early juvenile stages are spent in these waters. The collection of young albacore from stomach contents of predator species (Yabe et al., 1958) indicates the occurrence of these stages in subtropical waters. At a later stage, perhaps when the fish are about a year old, they migrate into temperate waters but do not immediately join the exploited stock (Suda, 1958).

As stated previously the Japanese livebait fishery occasionally encounters 1-year-old fish (about 35 cm.). There have been similar occurrences of small fish in the American fishery, for example, during the summer of 1954, when the fishery was reportedly characterized by the appearance of small fish (personal communications, Inter-American Tropical Tuna Commission). Such small fish are probably abundant generally throughout temperate waters, but are not available to the commercial fisheries until they reach the age of 2 or 3.

The virtual absence of 2-year-olds in the Japanese livebait catch, and the relatively small number of this age group in the longline fishery, seem to indicate that recruitment into the exploited stock occurs primarily in the American fishery. This apparent concentration of recruitment in the eastern Pacific may be exaggerated by gear selectivity, as the longline gear used in the central Pacific would not be expected to sample such small fish effectively for several reasons. This objection would not hold, however, in the Japanese livebait fishery, and so it is apparent that the major portion of the recruitment is taking place in the eastern rather than the western North Pacific.

In general, our model indicates a greater volume of migration of the commerical sizes of albacore in the westerly direction, from the American fishery into the Japanese fisheries, than vice versa. At the same time, it indicates that a significant portion of the fish entering the American fishery does not migrate directly into the Japanese fisheries, but instead is exploited over 3 or 4 seasons in the American fishery. Furthermore, the sizes

TABLE 4.—*Postulated migration of albacore between tagging and recovery*

[Each recovery is related to a "type of movement," shown in table 3.]

Recovery No.	Type of movement	Postulated migration [1]
1	III-a, VIII	US (June–Sept.) → MO (tagged) (Oct.) (78.2 cm.) → JLL (Nov.–Mar.) → JLB (May–July) → JLL (recovered) (Nov.) (size unknown)
2	II-b, VIII	US (June–Sept.) → MO (tagged) (Oct.) (68 cm.) → JLL (Nov.)–Mar.) → JLB (May–July) → JLL (recovered) (Jan.) (size unknown)
3	II-b	US (June–Sept.) → MO (tagged) (Oct.) (63.4 cm.) → JLL (Nov.–Mar.) → JLB (recovered) (June) (size unknown)
4	II-a	US (June–Sept.) → MO (tagged) (Oct.) (59.9 cm.) → US (recovered) (Aug.) (72.3 cm.)
5	II-a	MO (tagged) (July) (68.4 cm.) → MO (Oct.–Mar.) → US (recovered) (July) (78.0 cm.)
6		Tagged and recovered in American fishery during same season.
7		Tagged and recovered in American fishery during same season.
8	II-a, III-a, VIII	US (June–Sept.) → MO (tagged) (Oct.) (65.1 cm.) → US (June–Sept.) → JLL (Oct.–Mar.) → JLB (May–July) → JLL (recovered) (Nov.) (94.8 cm.)
9	IV-a, VIII	US (tagged) (Nov.) (85.2 cm.) → JLL (Dec.–Mar.) → JLB (May–July) → JLL (recovered) (Nov.) (97.5 cm.)
10	II-a	US (tagged) (July) (78 cm.) → JLL (Oct.–Mar.) → JLB (recovered) (May) (85.2 cm.)
11	III-a	US (tagged) (July) (75 cm.) → JLL (Oct.–Mar.) → JLB (recovered) (June) (size unknown)
12	II-a	US (tagged) (July) (65 cm.) → MO (Oct.–Mar.) → US (recovered) (July) (77.3 cm.)
13	III-b	US (tagged) (July) (75 cm.) → MO (Oct.–Mar.) → US (recovered) (Aug.) (84.5 cm.)
14	II-b, IV-b	US (tagged) (Nov.) (79.4 cm.) → MO (Dec.–Mar.) → US (June–Sept.) → MO (Oct.–Mar.) → US (recovered) (Aug.) (92.6 cm.)
15	II-a, III-b	US (tagged) (Nov.) (68.6 cm.) → MO (Dec.–Mar.) → US (June–Sept.) → MO (Oct.–Mar.) → US (recovered) (July) (86.4 cm.)
16	II-a, III-b	US (tagged) (Nov.) (65.9 cm.) → MO (Dec.–Mar.) → US (June–Sept.) → MO (Oct.–Mar.) → US (recovered) (Aug.) (81.2 cm.)
17	II-a, III-b, IV-a, VIII	US (tagged) (Nov.) (60.8 cm.) → MO (Dec.–Mar.) → US (June–Sept.) → MO (Oct.–Mar.) → US (June–Sept.) → JLL (Oct.–Mar.) → JLB (May–July) → JLL (recovered) (Mar.) (90 cm.)
18	III-a	US (tagged) (Aug.) (76.0 cm.) → JLL (Oct.–Mar.) → JLB (recovered) (June) (size unknown)
19	IV-a	US (tagged) (Aug.) (84 cm.) → JLL (recovered) (Feb.) (88 cm.)
20	IV-a	US (tagged) (Aug.) (91 cm.) → JLL (recovered) (Feb.) (93 cm.)
21	III-a	US (tagged) (Sept.) (size unknown) → JLL (recovered) (Apr.) (ca. 75 cm.)
22		US (tagged) (Sept.) (size unknown) → JLL (Oct.–Mar.) → JLB (recovered) (June) (size unknown)
23	II-b	US (tagged) (Aug.) (size unknown) → JLL (Oct.–Mar.) → JLB (recovered) (June) (75.7 cm.)
24–31		Tagged and recovered in livebait fishery during same season.
32	VIII	JLB (tagged) (May) (ca. 70 cm.) → JLL (Oct.–Mar.) → JLB (May–July) → JLL (recovered) (Jan.) (ca. 92 cm.)
33	II-b	US (tagged) (July) (67 cm.) → JLL (Oct.–Mar.) → JLB (recovered) (July) (size unknown)
34–35		Tagged and recovered in American fishery during same season.

[1] US=American fishery; JLL=Japanese longline fishery; JLB=Japanese livebait fishery; MO=midocean between Japanese longline fishery and U.S. west coast, or on eastern fringe of Japanese longline fishery.

of fish commonly exploited by the Japanese livebait fishery (4-, 5-, and 6-year-olds) are such that only a small percentage would appear later in the American fishery. This is, to a large extent, also true of the Japanese longline fishery, which takes largely the 4-, 5-, and 6-year-old fish.

It is therefore easy to understand why tagging in the Japanese livebait fishery has not resulted in any recoveries in the American fishery. The chances of such recoveries are slim because of the small number of fish of these older age groups appearing in the American catch. Tagging of the less common smaller fish in the livebait or longline fisheries should increase the chances of recoveries in the American fishery.

SUMMARY

1. A model of the migration of albacore in the North Pacific Ocean is proposed on the basis of tag recovery data, age and growth information, and distribution and size frequency data from various fisheries. This model is consistent with the hypothesis that there is a single population of albacore in the North Pacific Ocean.

2. The migration of albacore within the areas of the three major fisheries is in general reflected by the seasonal shifting of the respective fishing grounds. The Japanese livebait fishery begins off southern Japan in late April or May and gradually moves in the north and northeasterly directions. In July the fishery rapidly declines

as the fish move offshore from central Japan in an easterly direction.

The Japanese longline fishery begins in October with its center of abundance located in midocean between longitudes 170° E. and 180°, and along latitude 38° N. The fishery generally shifts in a southwesterly direction with the advance of the season. At the end of the season, in March, the center of concentration is located around 30° N., 140° E.

The American fishery begins off Baja California in June and gradually shifts north along the coast, as well as offshore, as the season progresses.

3. Tag recoveries have shown transpacific movements of albacore from the American fishery into the Japanese longline and livebait fisheries and from midocean into both the American and Japanese fisheries. Tagging in the Japanese livebait fishery has produced one recapture in the longline fishery.

4. The three North Pacific fisheries exploit different sizes of fish. Assuming that the first year's growth of albacore is about 30 cm., it is postulated that the fish are 2-years-old (about 50 cm.) when they first enter the commercial fisheries. On this basis it is shown that the Japanese livebait fishery takes four groups, which are approximately 3-, 4-, 5-, and 6-year-old fish, with modal lengths of 65, 75, 83, and 93 cm. Five-year-old fish are usually the principal component of the catch. The catches in the winter longline fishery are composed of 2- to 8- or 9-year-old fish, with modal lengths of approximately 57, 68, 79, 88, 94 cm., and larger. The 4- and 5-year-old fish are most numerous in the catch. The American fishery usually exploits 2-, 3-, and 4-year-old fish (55, 65, 76 cm.), but small numbers of older age groups (5- and 6-year-olds) also appear in the catches. The 3-year-old fish are generally most abundant. These differences in sizes among the fisheries are considered in developing the model of albacore migration.

5. It is postulated that albacore undertake no more than one transpacific migration within a 1-year period.

6. The model of the migration of albacore among the fisheries is briefly as follows: a varying portion of the 2-, 3-, and 4-year-old fish and nearly all of the older fish in the American fishery migrate westward into the Japanese longline fishery, and subsequently into the Japanese livebait fishery the following spring. The remainder either do not reach, or may possibly enter the fringe of the Japanese longline fishery, and return to the American fishery the following summer. Consequently, some of the fish may be available to the American fishery for as many as four or five seasons (fig. 8).

The Japanese livebait fishery is notably lacking in 2- and 3-year-old fish. Such small fish, when present, may migrate into the American fishery after spending a part of the season in the winter longline fishery. Of the more common sizes in the livebait fishery, only the 4- and 5-year-old groups provide some fish that enter the American fishery the following summer, but these are few since 5- and 6-year-old fish comprise only a very small proportion in the American catch. The bulk of the fish from the livebait fishery migrate into the longline fishery in the fall and return to the livebait fishery the following spring.

Fish enter the winter longline fishery from both the American fishery and the Japanese livebait fishery. A large part of these fish migrate southwestward in the winter longline fishery, and subsequently enter the livebait fishery in the spring, while a few separate and migrate into the American fishery by summer.

A portion of the large adults occurring in the Japanese winter longline fishery (6-year-olds and older) move south during the spring into subtropical waters, where they make up the reproductive unit of the North Pacific population.

7. It is hypothesized that spawning occurs in subtropical waters during the summer, and that the larval and early juvenile stages are spent in these waters. When about a year old, the fish migrate into temperate waters, but they do not immediately join the exploited stock. The albacore are generally not available to commercial fisheries until they reach the age of 2 or 3.

8. It appears that most of the recruitment into the exploited stock takes place in the eastern rather than the western North Pacific. There is a greater volume of migration of the commercial sizes of albacore in the westerly direction from the American fishery into the Japanese fisheries, than vice versa.

ACKNOWLEDGMENTS

Permission to use unpublished Japanese data on albacore tag recoveries was kindly granted us by Hiroshi Nakamura, Director, Nankai Regional Fisheries Research Laboratory, Kochi, Japan; and use of data of the Fish Commission of Oregon was authorized by Robert J. Ayers, Aquatic Biologist. We wish to express our deep appreciation to them, as well as to the many American and Japanese fishermen who reported these tag recoveries. We wish to express our appreciation also to Tamotsu Nakata, scientific illustrator, for skillfully portraying the complex migratory movements described in the text.

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