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Results of a Tagging Program to Determine Migration Rates and Patterns for Black Marlin, *Makaira indica*, in the Southwest Pacific Ocean

JAMES L. SQUIRE, JR.[1] and DAPHNE V. NIELSEN[2]

ABSTRACT

Marine game fish anglers reported tagging a total of 2,576 black marlin, *Makaira indica*, from 1968 through 1978 near the Great Barrier Reef, north Queensland, Australia, as part of the National Marine Fisheries Service Cooperative Marine Game Fish Tagging Program—Pacific Area. Sixty tagged black marlin were recaptured during an 11-year period for a recapture rate of 2.3%. Average weight of black marlin tagged was estimated to be 175 kg (385 lb). Anglers tend to overestimate weight at time of tagging and short-term recaptures (0-60 days) indicate an average angler overestimate of 16 kg (35 lb) per marlin.

Sex was determined for 28 recaptures; 25 (89%) were reported as males and 3 (11%) reported as females. Average weight of males at recapture was 91 kg (195 lb), for females, 221 kg (488 lb).

Vector analysis of time, distance, and direction data for tag recovery locations indicated migration direction (vector mean bearing) and distance (vector mean distance from point of tagging) by periods of release time: 0-60 days, 121°/72 nmi, 61-120 days, 134°/446 nmi, 121-240 days, 097°/1,256 nmi.

The greatest distance (2,100 nmi) recorded from the point of tagging was for a black marlin recaptured northeast of New Zealand, 235 days after tagging. Black marlin tagged early in the north Queensland fishing season (September) tended to migrate away from the area of tagging at a lower rate for the first 0-60 day period than black marlin tagged in October, November, or later in the fishing season.

Tag recoveries were made near the tagging location 1, 2, and 4 years after tagging. Locations of recapture for these black marlin were calculated to be a vector mean distance of 58.3 nmi from the point of tagging. Longline high catch rate areas for black marlin indicate a monthly movement for the first 240 days of release time not unlike that observed by tagging. In the summer the centers of high catch rate show a south to southeast movement off the east coast of Australia from the tagging area, then a northward movement in the winter and spring to the New Guinea-Bismark Archipelago-Solomon Islands area. The amount of interchange with the Indo-Pacific and areas to the north is unclear, although emigration from the tagging area to north of New Guinea was recorded.

INTRODUCTION

Little is known about the migratory patterns for oceanic pelagic species such as tunas and billfish in the Pacific Ocean. Only a few species of tuna, such as yellowfin tuna, *Thunnus albacares*; albacore, *Thunnus alalunga*; bluefin tuna, *Thunnus thynnus*; and skipjack tuna, *Euthynnus pelamis*, have been tagged in sufficient numbers, usually by commercial methods (trolling, live-bait, or purse seining), to determine patterns and rates of migration. Billfish have a high economic value to the commercial longline fishery but are not caught at any one time in large numbers like the tunas. Therefore, the opportunity to tag and release these fishes is more limited.

The concept of using anglers to tag and release billfish, tunas, and other pelagic marine game species, was first developed by Frank J. Mather III of the Woods Hole Oceanographic Institution, Woods Hole, Mass. (WHOI). The "Cooperative Marine Game Fish Tagging Program" was first established by WHOI with a grant from the National Science Foundation for studies in the Atlantic Ocean. Since marine anglers frequently travel worldwide to fish for billfish, some tags issued for studies in the Atlantic were being used in the Pacific starting in 1954 to tag black marlin, *Makaira indica*, blue marlin, *Makaira nigricans*, striped marlin, *Tetrapturus audax*, sailfish, *Istiophorus platypterus*, shortbill spearfish, *Tetrapturus angustirostris*, and swordfish, *Xiphias gladius*. In 1961, the senior author made a cooperative agreement with Mather to support Pacific area tagging on behalf of the U.S. Fish and Wildlife Service, Pacific Marine Game Fish Research Center/Tiburon Marine Laboratory, Tiburon, Calif., later to become a laboratory of the National Marine Fisheries Service (NMFS). The Service then assumed responsibility for the Pacific program and has continued since that time to support the tagging efforts of marine game fish anglers for billfish and other pelagic game fish species.

The tagging results discussed in this paper are for tags furnished through 1978 by the NMFS and the WHOI. Beginning in 1976, increasing numbers of black marlin have been tagged with tags furnished by New South Wales State Fisheries, Sydney, Australia, and this agency has now assumed the primary role in support of the tagging program for black marlin off north Queensland, Australia. These records are not included in the analysis portion of this paper, with the exception that data for four recoveries (6.3% of the tag recoveries reported upon) of New South Wales State Fisheries (NSWF) tags have been used in the computation of mean vector bearing and distances, sex ratios, and estimated weight data.

TAGGING AND RECOVERY

The tagging data base of this study is that portion of the black marlin catch tagged and released by anglers off the northeast coast of Australia adjacent to the Great Barrier Reef, between lat.

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[1] Southwest Fisheries Center La Jolla Laboratory, National Marine Fisheries Service, NOAA, La Jolla, CA 92038.

[2] Cairns Game Fishing Club, Cairns, Queensland, 4870, Australia.

14° and 18°S. The major source for recoveries is the Pacific-wide Japanese and Korean commercial longline fishery catch, and, to a minor extent, the catch of Australian and New Zealand commercial and recreational fisheries. Few recoveries could be expected from the billfish recreational fishery since the numbers of billfish taken are small compared with the catch of the commercial longline fishery (avg. 9,100 fish, 1969-78, Japanese longline data). The recreational fishery operates in a relatively restricted seasonal and geographical area near the edge of the Great Barrier Reef where the resource is available and catchable, and high rod-and-reel catch rates can be obtained. Potential recovery areas by anglers are generally restricted to the major tagging areas. The longline fishery, however, samples over a large area of the ocean and it is possible that recoveries could be made throughout the year, sometimes at considerable distances from the location of tagging. The extensive Japanese longline fishery recovers the most tagged marlin.

Black marlin are distributed widely throughout the Pacific and Indian Oceans with some catches reported in the South Atlantic Ocean. Some of the better longline fishing areas for black marlin are in the east China Sea near Taiwan, off northwest Australia, the Arafura Sea, Sulu Sea, Celebes Sea, and the Coral Sea off northeast Australia. Of interest to this migration study is that no longline effort or catches of black marlin are reported north of Australia in the eastern Arafura Sea. Between Cape York, Australia, and Papua lies the Torres Strait, a large area having a water depth of < 20 m. This shallow area may inhibit the migration of black marlin between the Coral and Arafura Seas. The distribution of black marlin as inferred from catch rates from the Japanese longline fishery in the Pacific, Indian, and South Atlantic Oceans is given in Figure 1.

Black marlin have been an important resource to the Japanese commercial longline fishery in the western Pacific since the early 1950's. Catch levels of all fleets in the western Pacific are currently about 3,000 t (metric tons), approximately one-half the peak catch in 1957, with about 59% of the southwestern Pacific black marlin catch being taken in 1976 by Japanese longliners (FAO 1979).

While the longline fishery generally targets on the tunas, in certain areas of the Pacific they may target upon marlin, sailfish, swordfish, or both tunas and billfish. Billfish comprise about 18% of the total longline catch in the Pacific (Ueyanagi 1974). However, the ex-vessel value of some species of billfish, such as striped, blue, and black marlin, may be two or more times that of some tunas, making the fraction of billfish an important factor in determining the location of fishing effort. Black marlin appears to be a target species in the western Coral Sea near the tagging area during the spring and early summer months of September through January. The distribution of longline fishing effort and catch rates obtained in the areas to the south, west, and north of the tagging area, in months subsequent to tagging, is an important factor in evaluating tag recovery data.

METHODS AND EQUIPMENT

All black marlin tagged in the Pacific under the auspices of the Cooperative Marine Game Fish Tagging Program were caught by anglers using rod-and-reel, and were tagged and released by the angler or a member of the charter boat crew. Several types of tags were used in the 1960's, the principal type being the double barbed, all-plastic FM67 tag (Fig. 2). Other tags used in small numbers included the Type "A" tag, a metal-tipped tag similar to the "H" tag, and type "B" tag, a small, single-barbed plastic tag similar to tags currently being used for tunas (Fig. 2). Since 1970, the tag distributed has been the stainless steel dart tag ("H" type). This tag has a nylon monofilament line extending from the stainless steel barb, with a yellow polyvinyl tubing sleeve over the monofilament for printed information. Numbers and letters on the yellow polyvinyl sleeve are heat embossed in black, giving the tag's serial number and return and reward information. All tags furnished by the National Marine Fisheries Service were manufactured by the Floy Tag and Manufacturing Company, Seattle, Wash.

Each tag is attached to a postcard having the tag's serial number printed on it. After tagging a fish, the angler completes the information requested on the postcard such as tagging date,

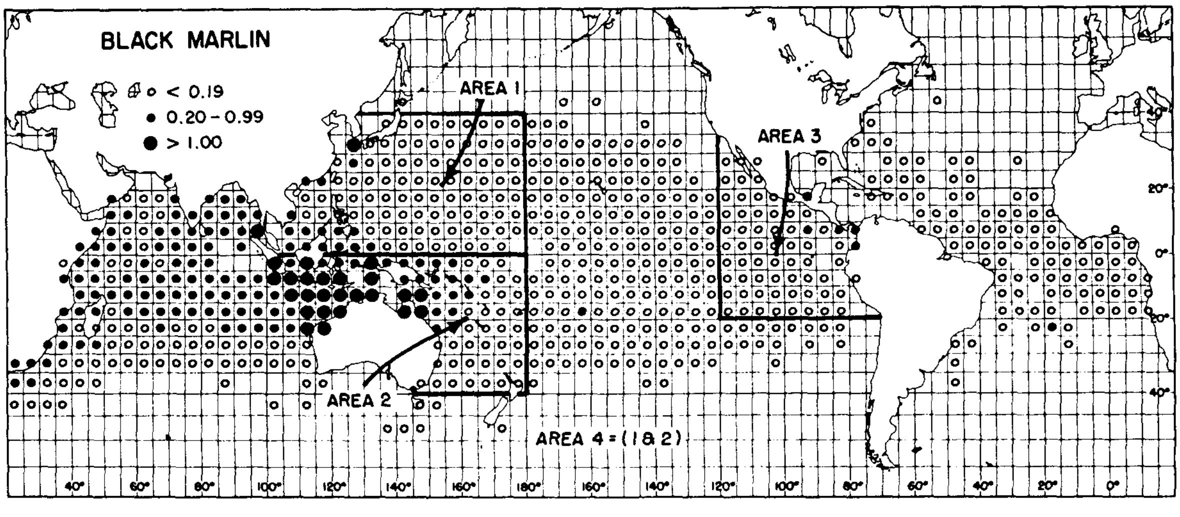


Figure 1.—Distribution of longline catch rates for black marlin in the Pacific Ocean as an indicator of resource distribution. Circles indicate mean catch rates (number of black marlin/1,000 hooks). Also shown are the boundaries of suggested black marlin stocks. From Shomura (1980).

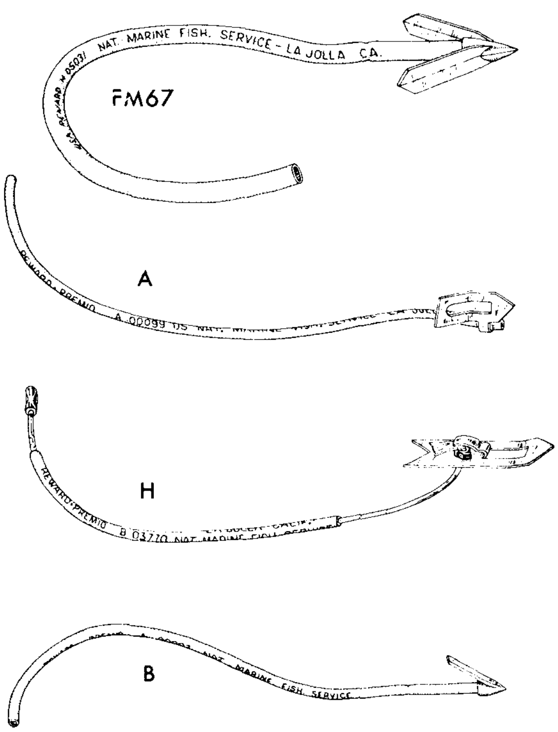


Figure 2.—Four types of dart tags used in the Pacific Ocean by the Cooperative Marine Game Fish Tagging Program.

location of tagging, species, estimate of fish's weight, tagger's name and address and returns it to the organization issuing the tag. Anglers who indicated a willingness to tag and release billfish were issued tagging equipment which consisted of a stainless steel applicator tip which must be mounted in a tagging pole, tags, instructions, and tagging flags for recognition of a billfish tagged and released. There was no charge for the tagging equipment.

When billfish are recovered, the recoverer receives a monetary reward upon sending in information on the tag number, species, date, and location of recovery. The recoverer sometimes adds information on water temperature at the time of recapture, length and weight measurements, sex, and gonad weight data.

RELEASE DATA

Cooperating marine game fish anglers and charter boat captains have tagged and released 2,885 black marlin in the Pacific Ocean using NMFS and WHOI tags since 1961. Of this number, 2,576 black marlin (89%) were tagged along the Great Barrier Reef off the north Queensland coast of Australia. The coordination of tagging for black marlin in this area was by the Cairns Game Fish Club, Cairns, Australia. Other locations in the Pacific where black marlin were reported to have been tagged were off the coasts of Panama and Hawaii, and near the southern tip of Baja California, Mexico.

The numbers of black marlin tagged in the north Queensland area are listed in Table 1 by year and tag type. Of the 2,576 black marlin tagged, 2,276 (88.0%) were tagged with "H" type tags and 305 (11.8%) with FM67 type tags. The remainder were tagged with "A" or "B" type tags.

Table 1.—Black marlin tagging off north Queensland, Australia, by year tagged and tag type, 1968-78.

		Tag types			
Year	Number tagged	A	H	FM67	B
1968	26			26	
1969	51			51	
1970	110			110	
1971	184		127	57	
1972	288		287	1	
1973	438		378	60	
1974	337	1	335		1
1975	411	1	409		1
1976	501		501		
1977	170		170		
1978	60		60		
Total	2,576	2	2,267	305	2

Figure 3 shows the distribution of tagging effort by year and average estimated weights as given by the angler, in relation to tagging locations along the outer islands and reefs of the Great Barrier Reef. September, October, and November are the major months for tagging black marlin, with percentages of 21.6, 49.0, and 24.1, respectively. The geographical area where the most black marlin were tagged was along the Great Barrier Reef from lat. 16°00′ to 16°30′S. This area includes the reefs known as Hope, Nicholas, Onyx, Spur, Opal, St. Crispin, Linden Bank, and Agincourt Reefs No. 1 and 2. Data given in Figure 3 indicate that from 1972 to 1974 tagging effort shifted northward off the Queensland area. This was probably due to the development near the outer reefs of floating or island facilities for the angler, allowing him easier access to waters distant from Cairns, Queensland.

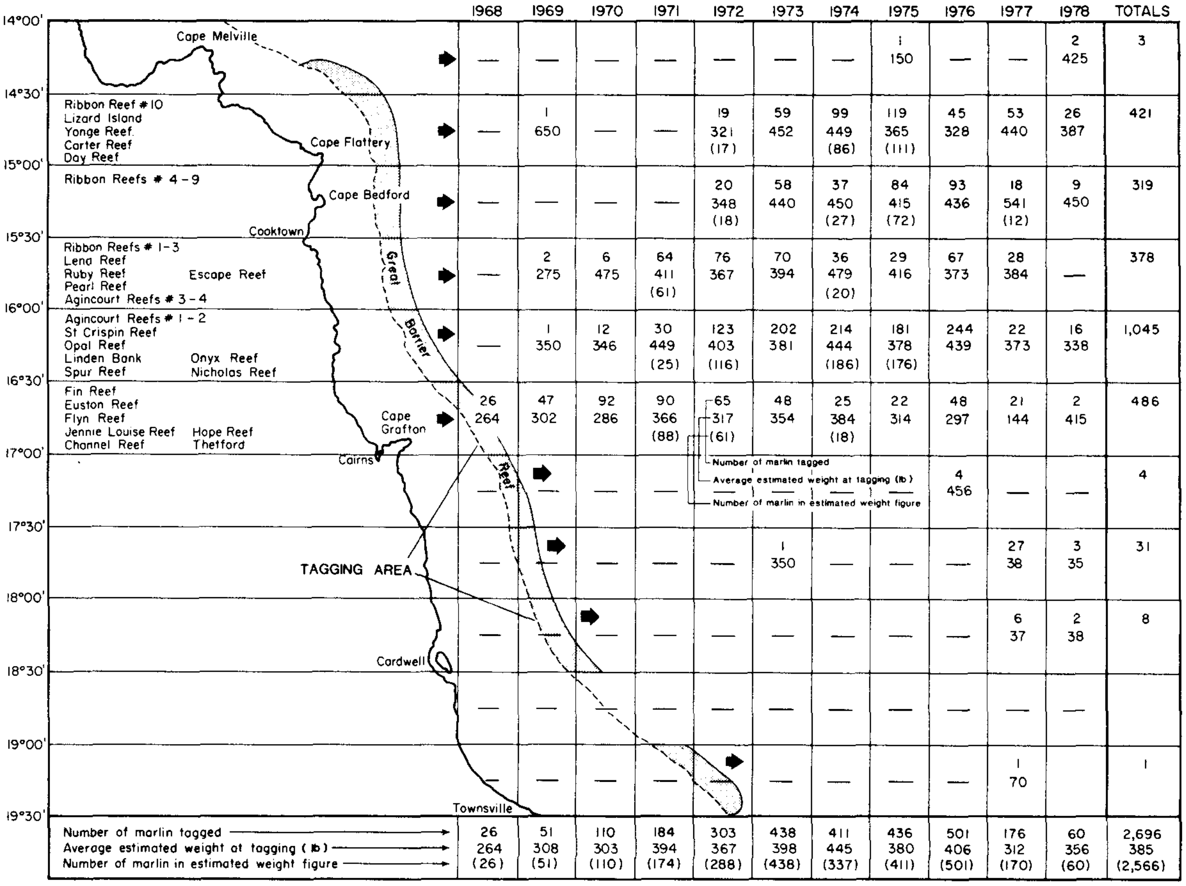
RECOVERIES

Of the 59 recaptures reported for black marlin tagged during the years 1968-78, 52 (88%) were recaptured by Japanese and Korean commercial longline fishing vessels, 4 (7%) by marine anglers, and 2 (3%) by Australian commercial fishermen (trawlers or netters); 1 (2%) was a beached marlin. Table 2 gives black marlin release, recapture, and biological data for those tagged with NMFS or WHOI tags. Data from four New South Wales State recoveries used elsewhere in the analysis are not listed in Table 2. Of the 59 returns, one return could not be matched to a tag report card.

RECOVERY RATES

A total of 2,576 black marlin was tagged off Queensland: 2,267 with the "H" type tags, 305 with the FM67, 2 with the "A" type, and 2 with the "B" type. Of these, 1.3% of the FM67 tags and 2.4% of the "H" tags were recovered, with an overall recovery rate of 2.3%. A breakdown of recovery rates for this area by year and by type of tag is given in Table 3.

Of the total of 189 black marlin reported tagged in other areas of the Pacific, 70 were tagged with FM67 type tags and 119 with "H" type tags. None has been reported recovered.



		1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	TOTALS
14°00'		—	—	—	—	—	—	—	1 150	—	—	2 425	3
14°30'	Ribbon Reef # 10 Lizard Island Yonge Reef Carter Reef Day Reef	—	1 650	—	—	19 321 (17)	59 452	99 449 (86)	119 365 (111)	45 328	53 440	26 387	421
15°00'	Ribbon Reefs # 4 - 9	—	—	—	—	20 348 (18)	58 440	37 450 (27)	84 415 (72)	93 436	18 541 (12)	9 450	319
15°30'	Ribbon Reefs # 1 - 3 Lena Reef Ruby Reef Escape Reef Pearl Reef Agincourt Reefs # 3 - 4	—	2 275	6 475	64 411 (61)	76 367	70 394	36 479 (20)	29 416	67 373	28 384	—	378
16°00'	Agincourt Reefs # 1 - 2 St Crispin Reef Opal Reef Linden Bank Onyx Reef Spur Reef Nicholas Reef	—	1 350	12 346	30 449 (25)	123 403 (116)	202 381	214 444 (186)	181 378 (176)	244 439	22 373	16 338	1,045
16°30'	Fin Reef Euston Reef Flyn Reef Jennie Louise Reef Hope Reef Channel Reef Thetford	26 264	47 302	92 286	90 366 (88)	65 317 (61)	48 354	25 384 (18)	22 314	48 297	21 144	2 415	486
17°00'		—	—	—	—	—	—	—	—	4 456	—	—	4
17°30'		—	—	—	—	—	1 350	—	—	—	27 38	3 35	31
18°00'		—	—	—	—	—	—	—	—	—	6 37	2 38	8
18°30'		—	—	—	—	—	—	—	—	—	—	—	
19°00'		—	—	—	—	—	—	—	—	—	1 70		1
	Number of marlin tagged	26	51	110	184	303	438	411	436	501	176	60	2,696
	Average estimated weight at tagging (lb)	264	308	303	394	367	398	445	380	406	312	356	385
	Number of marlin in estimated weight figure	(26)	(51)	(110)	(174)	(288)	(438)	(337)	(411)	(501)	(170)	(60)	(2,566)

Figure 3.—Locations of black marlin tagging immediate to the Great Barrier Reef off north Queensland, Australia, by 30' latitude areas, by year and number of black marlin tagged, and average estimated weight by anglers at time of tagging. Note—estimated weight may vary from actual weight, see text. (For conversion of pounds to kilograms, lb × 0.4536 = kg).

TAGGING AND RECOVERY WEIGHT DATA

Upon tagging a black marlin, one of the items requested from the angler was an estimate of the marlin's weight. The average weight estimated by angler at the time of tagging, for 2,566 marlin having weight data reported, was 175 kg (385 lb). Average estimated weights by year and by 30° latitude area off north Queensland are given on Figure 3. The largest recorded average weight by year was 202 kg (445 lb) in 1974. The largest number of marlin tagged, and the largest average weight of 186 kg (410 lb), occured at lat. 16°00′ to 16°30′S. This area includes Agincourt Reefs #1 and #2, Linden Bank, and St. Crispan, Opal, Spur, Onyx, and Nicholas Reefs.

Estimated tagging weight varied greatly with landing weight as seen by catches recorded at Cairns and Lizard Island weighing stations from 1 September to 31 December 1970-78 (Table 4). The average weight of black marlin from the landing records is 346 kg (762 lb). Estimates of weight at time of tagging averaged 175 kg (385 lb) or 171 kg (377 lb) less than the weights recorded at the weighing station.

The weight data on recaptured marlin were sometimes submitted with additional information on the recovery. In the case of the commercial longline fishery the weights were with the bill and a portion of the head removed at about the area of the eye orbit. The reported weight must therefore be increased by a factor of 1.1 (Ueyanagi[3]) to give the approximate "round weight" of the fish.

Fifty-one marlin had weight and/or length data accompanying information on the geographical location and time of recapture. Upon examination of the weight and length data for the recaptures, it was determined that for five marlin the data were inadequate to determine total weight. Of 46 black marlin recaptured by the commercial longline fishery, having angler estimated weight data at tagging, 30 were recaptured at total weight less than estimated by the angler, 15 at weights greater than estimated, and 1 at the same weight. The average angler overestimate of black marlin recaptured at tagging, when compared with the recapture

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[3] Shoji Ueyanagi, Far Seas Fisheries Research Laboratory, Japan Fisheries Agency, 1000 Orido, Shimizu, 424, Japan, pers. commun.

Table 2.—Black marlin release and recapture data, 1968-1978. Angler's Country - (U.S.) United States, (NZ) New Zealand, (A) Australia. Others as given.

	Releases			Recaptures					Biological data			
Year	Date (SWFC No.)	Location	Tagger/Captain	Date	Location	Recovered by	Distance from point of tagging	Days at large	Estimated weight at release	Weight at recapture	Length	Sex
1968	3 Oct. (74)	Euston Reef	Mrs. B. Dyer/(A) C. Chambers	Jan. 1969	Narlinga Beach 20 mi. S. of Innisfail, Aust.	J. Giddins Innisfail, Aust.	55	95 (est.)	----	----	----	-
1969	2 Nov. (102)	Hope Reef	Bob Dyer/(A) C. Chambers	Oct. 1970	Lat. 15°30'S Long. 145°55'E	*Kompira maru* No. 28 (Japan)	60 N	364	84 kg (158 lbs)	60 kg^1 (132 lbs)	----	-
1971	11 Oct. (120)	Escape Reef	P. Van Vleck/(U.S.) P. Bristow	Apr. 17, 1972	Lat. 03°33'S Long. 166°03'E	*Jinam* No. 26 (Korea)	1,440 NE	180	23 kg (50 lbs)	42 kg^1 (92 lbs)	104.6 cm^2	-
1972	31 Aug. (134)	Hope Reef	H. Henze/(U.S.) P. Bristow	Oct. 31, 1972	Lat. 15°42'S Long. 146°06'E	*Tsurugi maru* (Japan)	50 E	61	91 kg (200 lbs)	----	173.0 cm^2	M
1972	10 Oct.) (135)	Linden Bank	V. Price/(U.S.) T. Curran	Nov. 10, 1972	Lat. 16°00'S Long. 146°00'E	*Kompira maru* No. 28 (Japan)	17 N	31	136 kg (300 lbs)	30 kg (68 lbs)	----	-
1970	13 Oct. (136)	Off Cairns, Aust.	P. Gay/(A) D. Wallace	Nov. 17, 1971	Lat. 15°30'S Long. 146°15'E	*Kompira maru* No. 28 (Japan)	83 NW	400	----	70 kg (154 lbs)	----	-
1972	10 Oct. (140)	Off Cairns, Aust.	D. Lyall/(A) K. Lyall	Nov. 10, 1972	Lat. 18°32'S Long. 148°36'E	*Genyō maru* (Japan)	145 SE	31	91 kg (200 lbs)	43 kg (95 lbs)	157 cm^2	M
1972	11 Sept. (141)	Near Ribbon Reefs	C. Simms/(U.S.) P. Bristow	Oct. 18, 1972	Lat. 14°45'S Long. 145°55'E	*Seiho maru* No. 58 (Japan)	15 N	37	68 kg (150 lbs)	68 kg (Est 150 lbs)	----	-
1972	25 Sept. (142)	Opal Reef	R. Schubot/(U.S.) D. Wallace	Nov. 22, 1972	Lat. 16°00'S Long. 146°12'E	*Seiwa maru* (Japan)	22 NE	58	68 kg (150 lbs)	----	172 cm^2	M
1972	19 Oct. (144)	Agincourt Reef	G. Bos/(U.S.) P. Wright	Mar. 9, 1973	Lat. 03°00'S Long. 144°00'E	*Fuku maru* No. 11 (Japan)	1,080 N	141	273 kg (600 lbs)	280 kg (616 lbs)	----	-
1973	3 Oct. (160)	Ruby Reef	J. Del Guericio/(U.S.) P. Bristow	Oct. 22, 1973	Lat. 18°09'S Long. 148°03'E	*Genyō maru* (Japan)	197 SE	19	91 kg (200 lbs)	62 kg (136 lbs)	175 cm	M
1973	6 Oct. (162)	Lena Reef	J. Del Guercio/(U.S) P. Bristow	Nov. 11, 1973	Lat. 15°28'S Long. 145°59'E	*Satsuma Seium maru* No. 2 (Japan)	13 NE	35	91 kg (200 lbs)	----	191 cm^2	-
1973	11 Oct. (163A)	Agincourt Reef	R. Vincent/(A) V. Vlassof	Nov. 1, 1973	Lat. 16°07'S Long. 146°16'E	*Fukushime maru* (Japan)	33 SE	21	182 kg (400 lbs)	84 kg (185 lbs)	192 cm^2	M
1973	4 Oct. (174)	Off Cairns	----	Nov. 12, 1973	Lat. 15°05'S Long. 146°10'E	*Haybusa maru* No. 3 (Japan)	90 N (est.)	39 (est.)	----	Est 50 kg (110 lbs)	Est 2 m	-
1974	10 Oct. (176)	Opal Reef	J. Gay/(A) D. Wallace	Nov. 24, 1974	Lat. 14°26'S Long. 145°44'E	*Yakushi maru* No. 38 (Japan)	120 N	35	68 kg (150 lbs)	63 kg (139 lbs)	235 cm	-
1973	5 Nov. (177)	Agincourt Reef #2	E. Gould/(U.S.) P. Bristow	Nov. 4, 1974	Lat. 17°23'S Long. 147°05'E	*Kana maru* (Japan)	110 SE	364	182 kg (400 lbs)	88 kg^1 (194 lbs)	192 cm^2	M 1,400 g^3

Table 2.—Continued.

	Releases			Recaptures					Biological data			
Year	Date (SWFC No.)	Location	Tagger/Captain	Date	Location	Recovered by	Distance from point of tagging	Days at large	Estimated weight at release	Weight at recapture	Length	Sex
1974	4 Nov. (178)	Linden Bank	T. Evans/(A) V. Vlassof	Nov. 16, 1974	Lat. 17°11'S Long. 147°99'E	Kana maru (Japan)	85 SE	12	91 kg (200 lbs)	98 kg (216 lbs)	193 cm[2]	M 2,100 g[3]
1974	12 Sept. (179)	Linden Bank	M. Florence/(A) L. Woodbridge	Nov. 6, 1974	Lat. 13"55'S Long. 145°11'E	Genyō maru (Japan)	150 N	55	----	82 kg[1] (180 lbs)	197 cm[2]	M
1973	8 Oct. (180)	No. 10 Ribbon Reef	J. Del Guercio/(U.S.) P. Bristow	Oct. 8, 1974	Lat. 16°01'S Long. 146°42'E	Ashyu maru (Japan)	95 SE	364	136 kg (300 lbs)	94 kg[1] (185 lbs)	184 cm[2]	M
1974	5 Oct. (181)	Onyx Reef	H. Nordaas/(U.S.) K. Klaproth	Oct. 26, 1974	Lat. 15°01'S Long. 145°57'E	Ashyu maru (Japan)	63 N	21	----	64 kg[1] (141 lbs)	180 cm[2]	M
1974	4 Oct. (182)	No. 9 Ribbon Reef	F. Inscho/(U.S.) P. Wright	Oct. 28, 1974	Lat. 13°40'S Long. 145°45'E	Wakatori maru (Japan)	72 N	24	68 kg (150 lbs)	60 kg (132 lbs)	174 cm[2]	-
1974	25 Sept. (183)	Agincourt Reef	H. Nordass/(U.S.) K. Klaproth	Dec. 26, 1974	Lat. 33°45'S Long. 151°22'E	N. Thompson near Long Reef, Sydney, Aust.	1,290 S	92	136 kg (300 lbs)	77 kg (169 lbs)	----	-
1974	14 Sept. (184)	No. 10 Ribbon Reef	S. Zuckerman/U.S.) P. Bristow	Nov. 18, 1974	Lat. 18°45'S Long. 150°10'E	Genyō maru (Japan)	351 SE	65	----	116 kg[1] (255 lbs)	206 cm[2]	M
1973	2 Sept. (185)	No. 2 Ribbon Reef	R. Meyer/(A) P. Bristow	Oct. 6, 1973	Lat. 16°18'S Long. 146°30'E	Funakawa maru (Japan)	70 SE	34	136 kg (300 lbs)	----	170 cm	-
1974	8 Oct. (203)	No. 10 Ribbon Reef	D. Phipps/(U.S.) L. Woodbridge	Nov. 7, 1974	Lat. 22°27'S Long. 154°33'E	Longliner (name unknown, Japan)	670 SE	30	45 kg (100 lbs)	52 kg (114 lbs)	----	-
1972	13 Sept. (204)	Off Cairns	M. Johnson (U.S.) D. Wallace	Apr. 30, 1975	Elizabeth Reef near Tutakakz, New Zealand	R. Dazeley/(-) S. Pritchard, Capt.	1,875 SE	959	159 kg (350 lbs)	147 kg (325 lbs)	108 cm[4]	-
1974	14 Sept. (205)	No. 6 Ribbon Reef	B. May/(U.S.) D. Wallace	Oct. 13, 1974	Lat. 15°30'S Long. 146°10'E	Etsuzan maru (Japan)	32 SE	29	114 kg (250 lbs)	60 kg[1] (132 lbs)	170 cm[2]	M
1973	19 Sept. (206)	Escape Reef	G. Matthews/(U.S.) P. Bristow	Oct. 28, 1974	Lat. 16°30'S Long. 146°45'E	Etsuzan maru (Japan)	60 SE	404	91 kg (250 lbs)	73 kg[1] (161 lbs)	184 cm[2]	M 650 g[3]
1974	2 Oct. (207)	No. 10 Ribbon Reef	R. Schubot/(U.S.) D. Wallace	Feb. 24, 1975	Lat. 31°03'S Long. 153°04'E near Korogora Pt. north of Sidney, Aust.	V. Jordan Hat Head, NSW, Aust.	1,200 S	145	114 kg (250 lbs)	76.2 kg (168 lbs)	2.58 m	-
1974	17 Oct. (208)	Thetford Reef	R. Griffin/(N.Z.) J. Crump	Jun. 9, 1975	Lat. 34°03'S Long. 175°56'W	Lein Ho No. 1 (Korea)	2,100 SE	235	36 kg (80 lbs)	45 kg (100 lbs)	----	F
1976	22 Sept. (219)	No. 10 Ribbon Reef	R. Schubot/(U.S.) D. Wallace	Oct. 15, 1976	No. 5 Ribbon Reef	E. Palmar, Angler P. Wright, Capt.	30 S	23	148 kg (325 lbs)	----	----	-

Table 2.—Continued.

		Releases		Recaptures					Biological data			
Year	Date (SWFC No.)	Location	Tagger/Captain	Date	Location	Recovered by	Distance from point of tagging	Days at large	Estimated weight at release	Weight at recapture	Length	Sex
1975	5 Oct. (220)	No. 10 Ribbon Reef	J. Del Guerico/(U.S.) P. Bristow	Oct. 10, 1976	Linden Band	M. Mather, Angler G. Mills, Capt.	87 S	370	136 kg (300 lbs)	Est 68 kg (150 lbs)	----	-
1974	10 Oct. (227)	Carter Reef	O. Phipps/(U.S.) L. Woodbridge	Nov. 10, 1974	Lat. 14°33'S Long. 145°48'E	Yakushi maru (Japan)	6 E	41	----	340 kg (749 lbs)	410 cm	-
1975	14 Sept. (228)	No. 10 Ribbon Reef	M. Cohn/(U.S.) P. Bristow	Oct. 8, 1975	Lat. 16°01'S Long. 146°16'E	Oyama maru (Japan)	78 S	24	68 kg (150 lbs)	----	177 cm	-
1975	13 Sept. (231)	No. 3 Ribbon Reef	I. Marr/(A) D. Hayes	Nov. 1, 1975	Lat. 17°12'S Long. 147 °02'E	Kaiei maru (Japan)	25 SE	49	114 kg (250 lbs)	89 kg (196 lbs)	----	-
1975	9 Oct. (233)	Jenny Louise	K. Klaproth/(A) M. Klaproth	Feb 6, 1976	Off Inyadde Pt. South of Jervis NSW Aust.	T & C Puglisi Ulladulla, NSW Aust.	1,320 S	120	114 kg (250 lbs)	67 kg (148 lbs)	2,660 mm[5] 2,380 mm[6]	-
1974	14 Nov. (234)	Linden Bank	D. Roux/(S. Africa) P. Wright	Oct. 20, 1975	Lat. 14°46'S Long. 146°03'E	Oyama maru (Japan)	100 N	349	176 kg (80 lbs)	----	163 cm	-
1974	18 Sept. (235)	No. 10 Ribbon Reef	F. Rice/(U.S.) D. Wallace	Oct. 31, 1975	Lat. --°13'S Long. 144°50'E	Oyama maru (Japan)	95 NW	408	125 kg (275 lbs)	----	184 cm	-
1974	27 Sept. (236)	Agincourt Reef	P. Furnell/(A) G. White	Dec. 5, 1975	Lat. 21°30'S Long. 155°19'E	Sagami maru (Japan)	665 SE	434	91 kg (200 lbs)	----	191 cm	F 1,100 g[3]
1975	6 Sept. (237)	No. 10 Ribbon Reef	D. Etheridge/(-) P. Wright	Oct. 12, 1976	Lat. 17°58'S Long. 147°30'E	Etsuzan maru (Japan)	220 SE	402	114 kg (250 lbs)	89 kg (196 lbs)	188 cm[2]	M
1975	30 Oct. (238)	No. 10 Ribbon Reef	E. Gould/(U.S.) G. Hallam	Oct. 31, 1976	Lat. 13°44'S Long. 144°44'E	Etsuzan maru (Japan)	90 NW	367	91 kg (200 lbs)	82 kg (180 lbs)	186 cm[2]	M
1974	11 Nov. (239)	Opal Reef	S. Lindsay, Jr./(U.S.) K. Klaproth	Nov. 31 1976	Lat. 13°38'S Long. 145°02'E	Etsuzan maru (Japan)	162 NW	733	136 kg (300 lbs)	82 kg (180 lbs)	185 cm[2]	M
1975	9 Oct. (240)	No. 10 Ribbon Reef	J. Del Guerico/(U.S.) P. Bristow	Nov. 10, 1976	Lat. 14°05'S Long. 145°21'E	Etsuzan maru (Japan)	49 NW	397	136 kg (300 lbs)	64 kg (141 lbs)	174 cm[2]	M 3,020 g[3]
1974	18 Nov. (241)	Opal Reef	H. Samuels/(A) D. Wallace	Nov. 10, 1976	Lat. 14°05'S Long. 145°21'E	Etsuzan maru (Japan)	126 NW	723	114 kg (250 lbs)	64 kg (141 lbs)	174 cm[2]	M 1,200 g[3]
1976	11 Nov. (242)	Linden Bank	A. Virsakis/(-) D. Wallace	Dec. 20, 1976	Lat. 20°00'S Long. 153°44'E	Sagami maru (Japan)	500 SE	45	91 kg (200 lbs)	----	177 cm	-
1976	21 Sept. (243)	No. 9 Ribbon Reef	H. Breyer/(U.S.) P. Bristow	Nov. 28, 1976	Lat. 16°50'S Long. 147°05'E	Kompira maru No. 8 (Japan)	138 SE	68	114 kg (250 lbs)	80 kg (176 lbs)	236 cm (TL,)	-
1975	26 Nov. (244)	Euston Reef	P. Whelan/(A) B. Apnich	Nov. 6, 1975	Lat. 13°58'S Long. 145°03'E	Kaiyo maru (Japan)	180 NE	346	102 kg (225 lbs)	87 kg (191 lbs)	188 cm[2]	M 2,500 g[3]

Table 2. — Continued.

Releases				Recaptures					Biological data			
Year	Date (SWFC No.)	Location	Tagger/Captain	Date	Location	Recovered by	Distance from point of tagging	Days at large	Estimated weight at release	Weight at recapture	Length	Sex
1976	4 Nov. (245)	Opal Reef	J. Pilkington/(A) N. Jackson	Nov. 7, 1976	Lat. 15°38'S Long. 146°10'E	*Yakusi maru* No. 38 (Japan)	36 NE	3	227 kg (500 lbs)	65 kg (143 lbs)	215 cm	-
1976	15 Sept. (246)	No. 7 Ribbon Reef	D. Sheperdson/(A) P. Wright	Nov. 10, 1976	Lat. 16°37'S Long. 146°40'E	*Yakushi maru* No. 38 (Japan)	98 SE	56	112 kg (247 lbs)	95 kg (209 lbs)	305 cm	-
1976	22 Oct. (255)	No. 3 Ribbon Reef	C. Phipps/(U.S.) L. Woodbridge	Dec. 9, 1977	Lat. 18°35'S Long. 148°07'E	*Kompira maru* No. 8 (Japan)	200 SE	413	91 kg (200 lbs)	----	----	-
1976	6 Dec. (256)	Linden Bank	H. Nordass/(U.S.) K. Klaproth	Oct. 16, 1977	Lat. 15°35'S Long. 146°04'E	*Kompira maru* No. 8 (Japan)	38 NW	416	----	102 kg (224 lbs)	275 cm	-
--	Tag #18030 (257)	----	----	Oct. 23, 1977	Lat. 16°05'S Long. 146°40'E	*Aomori maru*	----	----	----	138 kg[1] (304 lbs)	220 cm	M
1976	15 Oct. (258)	Opal Reef	R. Mulholland/(-) D. Hayes	Oct. 17, 1977	Lat. 16°03'S Long. 146°13'E	*Funakawa maru* (Japan)	18 NE	367	91 kg (200 lbs)	----	183 cm	M
1976	28 Sept. (259)	No. 2 Ribbon Reef	D. Schubot/(U.S.) D. Wallace	Nov. 5, 1977	Lat. 15°35'S Long. 146°18'E	*Ashu maru* (Japan)	32 NE	327	80 kg (175 lbs)	72 kg[1] (158 lbs)	178 cm	M
1975	7 Nov. (260)	Opal Reef	P. Marvin/(U.S.) D. Wallace	Nov. 24, 1977	Lat. 17°43'S Long. 147°26'E	*Fukuyoshi maru* No. 25 (Japan)	128 SE	747	91 kg (200 lbs)	Est 75 kg (165 lbs)	----	-
1973	29 Oct. (261)	No. 10 Ribbon Reef	E. Gould/(U.S.) P. Bristow	Oct. 22, 1977	Lat. 14°21'S Long. 145°46'E	*Oyama maru* (Japan)	25 N	1,453	136 kg (300 lbs)	----	205 cm	M
1977	20 Sept. (269)	No. 1 Ribbon Reef	R. Estrada/(Ecuador) P. Bristow	Oct. 9, 1977	Lat. 15°28'S Long. 146°05'E	*Fukuichi maru* (Japan)	20 NW	19	68 kg (150 lbs)	60 kg (132 lbs)	205 cm	-
1976	3 Oct. (281)	No. 5 Ribbon Reef	A. Remley/(A) G. Hallam	Oct. 31, 1978	Lat. 16°31'S Long. 146°50'E	*Yakushi maru* No. 7 (Japan)	90 SE	758	250 kg (550 lbs)	115 kg (253 lbs)	2.5 m	-
1977	29 Sept. (282)	Linden Bank	C. Edwards/(A) W. Edwards	Nov. 6 , 1978	Lat. 17°00'S Long. 147°30'E	*Yakushi maru* No. 7 (Japan)	91 SE	403	136 kg (300 lbs)	120 kg (264 lbs)	2.5 m	-

[1] Gilled and gutted.

[2] Eye orbit (posterior) to fork.

[3] Gonad weight.

[4] Fork to anterior portion of jaw (lower).

[5] Bill tip to fork.

[6] Lower jaw tip to fork.

Table 3.—Tag return rates by year and tag type for black marlin tagged off north Queensland, Australia, as part of the Cooperative Marine Game Fish Tagging Program—Pacific Area (NMFS/WHOI). (For tagging 1968-78.) Total tag recovery rate (%): FM67 305T/4R = 1.3%; H 2,267T/56R = 2.4% (1 H tag recovered, tagging date unknown); no recoveries for either A or B tags.

Year	Type	No. tagged	No. recovered	Recovery rate (%)
1968	FM67	26	1	3.8
	H	0		
	A	0		
	B	0		
1969	FM67	51	1	1.9
	H	0		
	A	0		
	B	0		
1970	FM67	110	1	0.9
	H	0		
	A	0		
	B	0		
1971	FM67	57	1	1.7
	H	127	1	0.8
	A	0		
	B	0		
1972	FM67	1	0	0.0
	H	287	7	2.4
	A	0		
	B	0		
1973	FM67	60	0	0.0
	H	378	9	2.4
	A	0		
	B	0		
1974	FM67	0		
	H	335	17	5.1
	A	1	0	0.0
	B	1	0	0.0
1975	FM67	0		
	H	409	9	2.2
	A	1	0	0.0
	B	1	0	0.0
1976	FM67	0		
	H	501	10	2.0
	A	0		
	B	0		
1977	FM67	0		
	H	170	2	1.2
	A	0		
	B	0		
1978	FM67	0		
	H	60	0	0.0
	A	0		
	B	0		
		2,576	59	

Table 4.—Black marlin weights as recorded by year, 1 September through 31 December 1970-78, at Cairns and Lizard Island, Queensland, Australia.

	Number	Total weight		Average		Heaviest		Lightest	
Year	marlin	kg	lb	kg	lb	kg	lb	kg	lb
1970	47	12,271	27,053	261	575	558	1,231	35	77
1971	69	21,078	46,468	305	673	514	1,133	40	89
1972	107	34,177	75,346	319	704	576	1,271	78	172
1973	134	46,000	101,411	343	756	654	1,442	20	45
1974	64	22,775	50,210	356	784	535	1,180	98	215
1975	78	28,023	61,778	359	792	620	1,367	99	218
1976	59	22,043	48,596	373	823	583	1,286	84	186
1977	49	21,273	46,899	434	957	600	1,323	110	243
1978	37	15,036	33,149	406	896	616	1,358	118	261
Total	644	222,676	490,910						
	= 346 kg (762 lb) average								

weight for a release time of 0-60 d, was 16 kg (35 lb). For recaptures made 61-120 d after release, the average angler overestimate at tagging was 21 kg (46 lb). Estimated weights at tagging and recapture were compared within release time periods, and the results listed in Table 5. These calculations assume no growth, therefore an increase in recapture weight vs. weight at tagging would be expected as time progressed. However, the average recaptured weight decreased when compared with estimated weight at tagging during periods 0-60 and 61-120 d after release.

Table 5.—Average weights of black marlin as estimated by the angler at time of tagging and compared with weights reported upon recovery: estimated tagging weight vs. recorded weights by time periods.

Period	No. of fish	Average weight	
		kg	lb
0-60 d	16	[1]+20.6	[1]+45.5
61-120 d	4	[1]+41.9	[1]+92.5
121-240 d	5	[2]−2.7	[2]−6.0
241-365 d	7	[2]−3.8	[2]−8.4
366d-2 yr	9	[1]+19.5	[1]+43.0
2-3 yr	3	[1]+14.3	[1]+31.6
3-4 yr	1	[1]+36.2	[2]−80.0

[1] Overestimate (+), fish recovered at weights < reported tagged.

[2] Underestimate (−), fish recovered at weights > reported tagged.

SEX RATIO OF RECAPTURED MARLIN

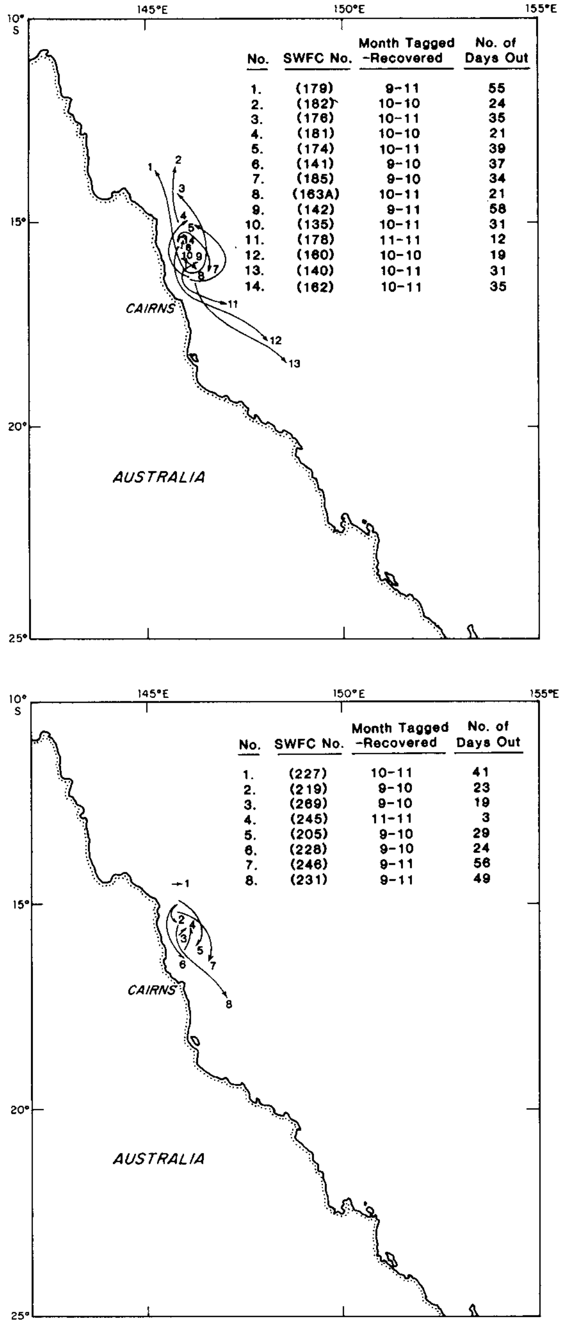
Some longline vessel crews recorded the sex of tagged black marlin upon recapture. One angler also gave this information on a recaptured marlin. Sex information was given for 28 recoveries including two recaptures from black marlin tagged with NSWF tags, and of this number, 25 (89%) were reported as males and 3 (11%) as females. The average weight of the 25 males recovered was 91 kg (193 lb), and 221 kg (449 lb) for the three females. The average weight for the small sample of females recovered was determined from black marlin weighing 45 kg (100 lb), 95 kg (209 lb), and 479 kg (1,056 lb).

MIGRATORY PATTERNS AND RATES

Black marlin occur throughout the Pacific Ocean between about lat. 40°N and 45°S, but their population density, as measured by the Japanese longline catch rate data, is low except in certain geographical areas. The stock structure of black marlin is not fully understood. Isolated high catch-rate areas are observed in the western and eastern Pacific. It has been suggested that two stocks (eastern/western) or three stocks (eastern/northwestern/northeastern) may be present (Shomura 1980). There is a strong possibility of mixing between black marlin stocks in the Indian Ocean, Indo-Pacific, and the western Pacific.

Figures 4-8 show plots of black marlin tag and recovery locations, grouped by release time periods. All recoveries >500 nmi from the tagging location off the Great Barrier Reef, Queensland, Australia, regardless of release time period, are shown in Figure 9. Information on recovery number, month of tagging, and number of days from release to recovery are included in these figures and lines connecting the tagging and recapture points do not indicate the exact migratory path of the tagged fish.

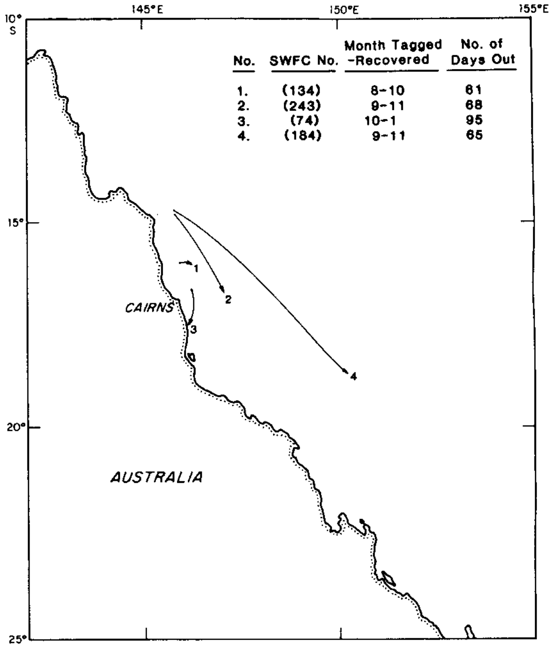
When these recovery distances over time (as measured by days from release to recapture) are presented, it can be seen that



No.	SWFC No.	Month Tagged -Recovered	No. of Days Out
1.	(179)	9-11	55
2.	(182)	10-10	24
3.	(176)	10-11	35
4.	(181)	10-10	21
5.	(174)	10-11	39
6.	(141)	9-10	37
7.	(185)	9-10	34
8.	(163A)	10-11	21
9.	(142)	9-11	58
10.	(135)	10-11	31
11.	(178)	11-11	12
12.	(160)	10-10	19
13.	(140)	10-11	31
14.	(162)	10-11	35

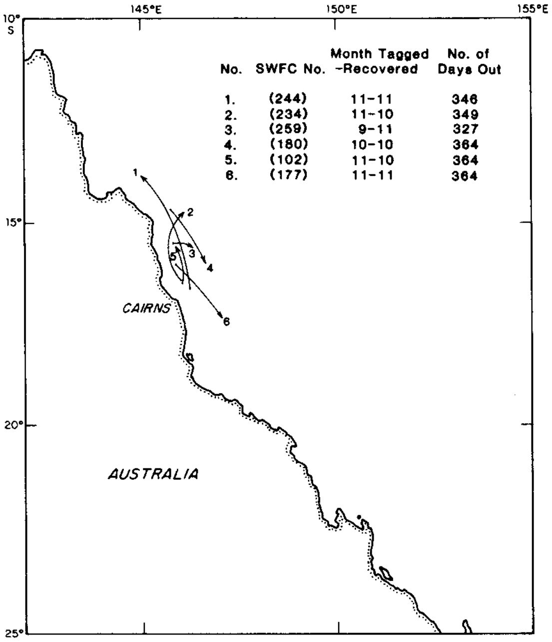
No.	SWFC No.	Month Tagged -Recovered	No. of Days Out
1.	(227)	10-11	41
2.	(219)	9-10	23
3.	(269)	9-10	19
4.	(245)	11-11	3
5.	(205)	9-10	29
6.	(228)	9-10	24
7.	(246)	9-11	56
8.	(231)	9-11	49

Figure 4.—Tag and recovery locations, 0-60 d time at large. Lines indicate point of tagging and recovery only.



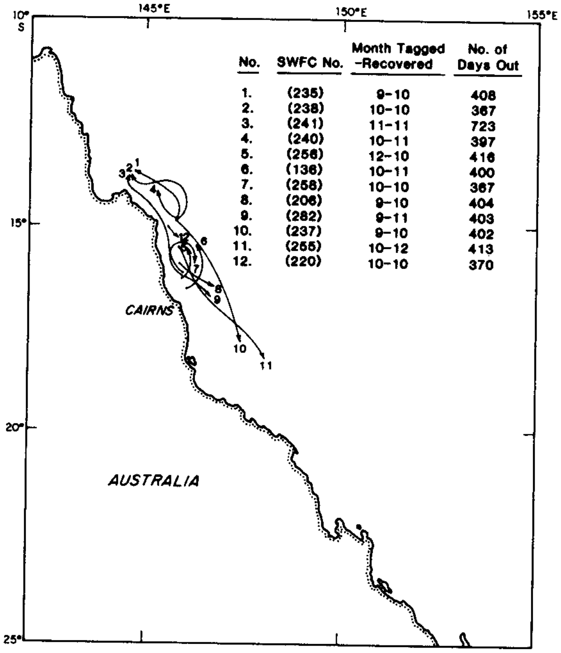
No.	SWFC No.	Month Tagged -Recovered	No. of Days Out
1.	(134)	8-10	61
2.	(243)	9-11	68
3.	(74)	10-1	95
4.	(184)	9-11	65

Figure 5.—Tag and recovery locations, 61-120 d time at large. Lines indicate point of tagging and recovery only.



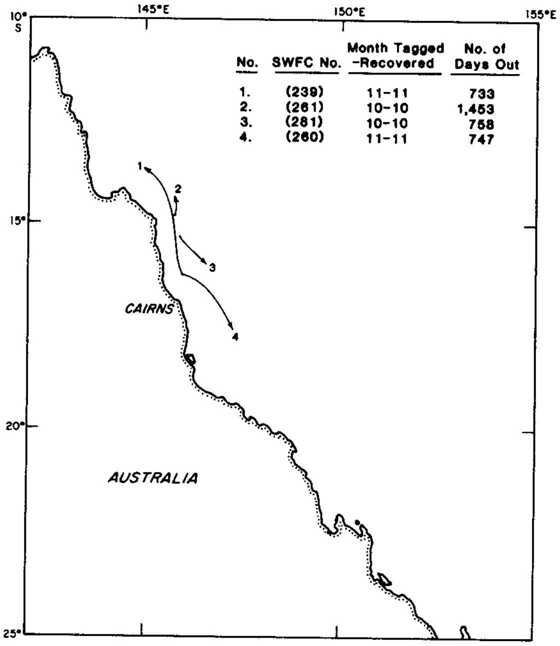
No.	SWFC No.	Month Tagged -Recovered	No. of Days Out
1.	(244)	11-11	346
2.	(234)	11-10	349
3.	(259)	9-11	327
4.	(180)	10-10	364
5.	(102)	11-10	364
6.	(177)	11-11	364

Figure 6.—Tag and recovery locations, 241-365 d time at large. Lines indicate point of tagging and recovery only.



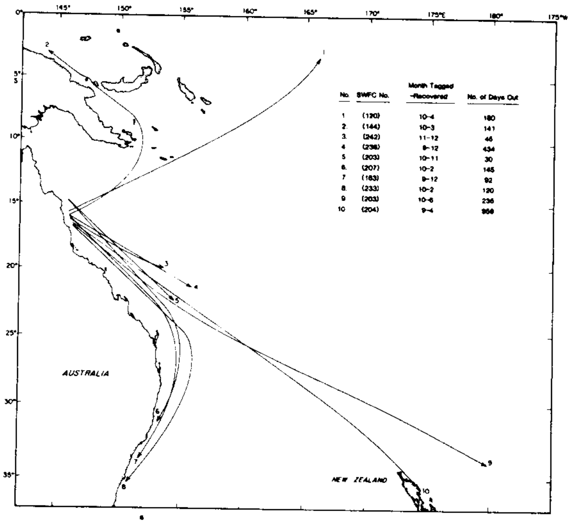
No.	SWFC No.	Month Tagged -Recovered	No. of Days Out
1.	(235)	9-10	408
2.	(238)	10-10	367
3.	(241)	11-11	723
4.	(240)	10-11	397
5.	(256)	12-10	416
6.	(136)	10-11	400
7.	(258)	10-10	367
8.	(206)	9-10	404
9.	(282)	9-11	403
10.	(237)	9-10	402
11.	(255)	10-12	413
12.	(220)	10-10	370

Figure 7.—Tag and recovery locations, 366d-2 yr time at large. Lines indicate point of tagging and recovery only.



No.	SWFC No.	Month Tagged -Recovered	No. of Days Out
1.	(239)	11-11	733
2.	(261)	10-10	1,453
3.	(281)	10-10	758
4.	(260)	11-11	747

Figure 8.—Tag and recovery locations, 2 to 3 yr and 3 to 4 yr time at large. Lines indicate point of tagging and recovery only.



No.	SWFC No.	Month Tagged -Recovered	No. of Days Out
1	(120)	10-4	180
2.	(144)	10-3	141
3.	(242)	11-12	46
4	(236)	9-12	434
5	(203)	10-11	30
6.	(207)	10-2	145
7	(183)	9-12	92
8.	(233)	10-2	120
9	(203)	10-6	236
10	(204)	9-4	958

Figure 9.—All recoveries 500 nmi or greater from location of tagging. Lines indicate point of tagging and recovery only.

average distances of tagging to recapture points increase from time of tagging for at least the first 180 d of time at large. A regression was calculated for recaptures made within the first 235 d from time of release. Recapture distances by number of days from release are given in Figure 10. The greatest recorded distance between tagging and recapture was 2,100 nmi, 235 d after release. Recaptures made near the tagging area (within 210 nmi) were common 1 and 2 yr after tagging (17 at 1 yr, 4 at 2 yr) and one recapture at nearly 4 yr after release (1,453 d or 3.98 yr).

The average migration rate in nautical miles per day (nmi/d) away from the location of tagging, for selected time periods subsequent to tagging, was calculated using two methods from data derived from time, straight line distance, and true bearing angle measurements from the tagging point to the recapture point. Of particular interest are the data obtained from recaptures within the first three time periods selected (0-60, 61-120, and 121-240 d) since these data may better define the average migration rate of black marlin away from a high population density (as reflected in CPUE) and reported spawning area. The greatest observed migration rate for any black marlin recaptured was 22.3 nmi/d, an average attained during a release time of 30 d. Average movement was calculated in nautical miles per day for the first three time periods, then multiplied by the average number of days within the period in relation to zero day, or start of the first time period, to obtain the approximate average distance of migration:

Days	*Midpoint in time*	*Avg. nmi/d*	*To period midpoint*
0-60	30	3.65	109.5 nmi
61-120	40	6.08	547.2 nmi
121-240	180	7.70	1,386.0 nmi

The percentage of recaptures by month of tagging was August 30%, September 30%, October 49%, November 17%, and December 2%. Recaptures made within the first period (0-60 d) were examined to determine the migration rate for black marlin tagged in September (9 fish recaptured), October (13 fish recaptured), and November (3 fish recaptured). No black marlin tagged in

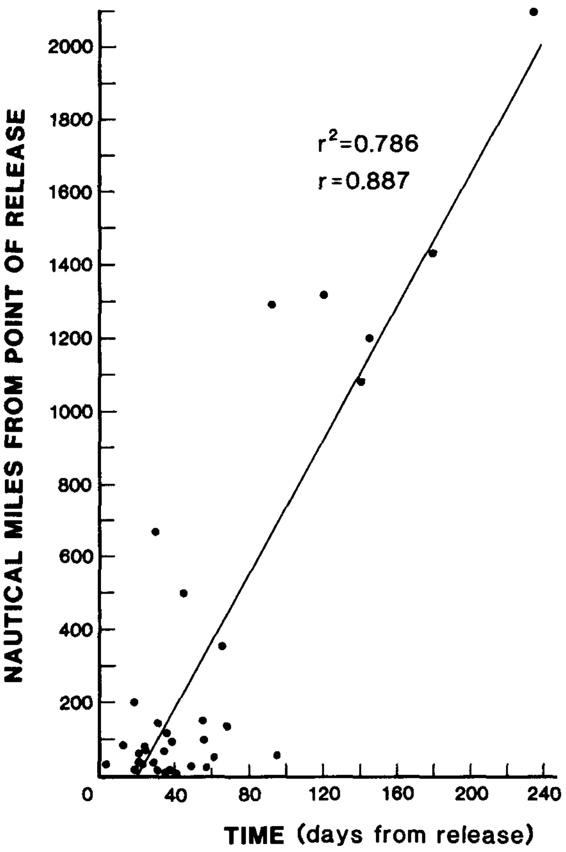


Figure 10.—Regression plot of black marlin recovery distances, by number of days at large.

August or December were recaptured within the first 60 d from release. The average rate of movement during the first 60 d from release for black marlin tagged in September was 1.46 nmi/d; October, 4.58 nmi/d; and November, 10.06 nmi/d. The average rate increased 3.1 times from September to October, and 2.2 times from October to November, with the November rate being 6.9 times that recorded for September. An increasing average rate of movement (nmi/d) was shown for black marlin tagged during the later part of the season. This may indicate that black marlin frequenting the general area of tagging early in the season may not migrate out of the area as rapidly as those black marlin tagged later in the season.

Vector analysis used distance and directional data determined by examination of tagging and recovery locations (straight-line distance), time of release (number of days), and direction (number of degrees, true bearing) from tagging point to recovery point. Vector mean bearings and distances were calculated 0-730 d in five time periods as shown in Figure 11. This analysis indicated a reduced rate of movement for the first time period after tagging (0-60 d) compared with the two following time periods (61-120 and 121-240 d). For the second period an acceleration of movement of 6.2 times the first period was noted. A reduced rate of movement of mean vector distance of 2.8 times the second period was observed for the third period (121-240 d).

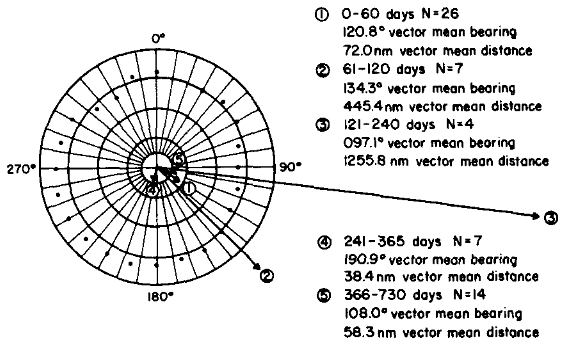


Figure 11.—Vector mean bearings and distances for five recovery periods: 0-60 d, 61-120 d, 121-240 d, 241-365 d, and 366-730 d.

Arcs showing mileage limits were plotted, using both the average distance traveled from tagging to recovery per day by period, times the midpoint for each time period; the vector mean distance for each period is given in Figure 12. The differences between the plots of average nautical miles per day and the vector mean distance are relatively small. Vector mileage arcs are smaller due to the method of calculation. The black marlin covering the most distance from the point of tagging (2,100 nmi in 235 d) to the recapture site northeast of New Zealand (see Fig. 12) had an average daily rate of travel of 8.94 nmi.

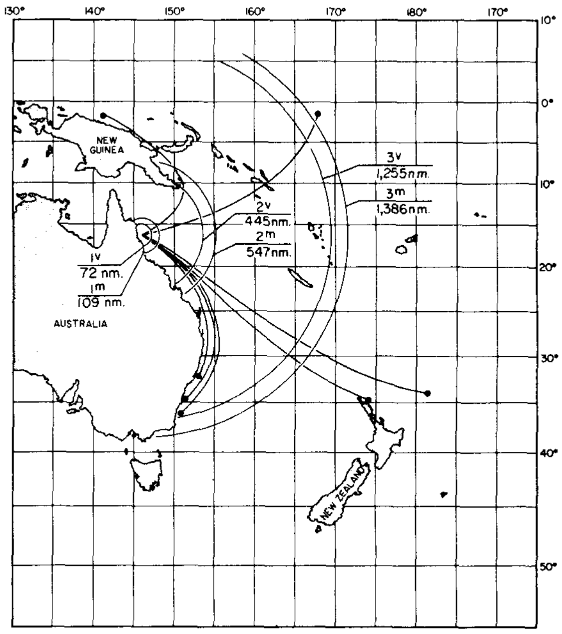


Figure 12.—Nautical mile arcs for average distance traveled from tagging to recovery by time periods, (1 = 0-60 d, avg. 30 d; 2 = 61-120 d, avg. 90 d; 3 = 121-240 d, avg. 180 d). V is the vector mean distance for each period, m is the measured distance. Only long distance recoveries (< 500 nmi) are also shown.

Studies by Ueyanagi (1960) indicate that a black marlin may spawn in the northwestern Coral Sea in early summer (November). Recaptures are reported in the spring and early summer near the point of tagging about 1, 2, 3, and 4 yr after tagging. This would indicate that at least some of these black marlin tagged show a returning migration trend toward a suspected spawning area.

Geographical areas fished by commercial longline gear vary in amount of fishing effort expended and changes in longline effort may affect the number of recoveries and recovery location. From 1965 to 1975, black marlin catch rates from the Japanese longline fishery in many areas of the southwest Pacific averaged 2.1-5.1 + and >5.1 fish/1,000 hooks effective hooking effort (Suzuki and Honma 1977); peak hooking rates were recorded near the tagging area off north Queensland from October through December. The distribution of longline effort and CPUE should be reflected in the distribution of recovery locations for black marlin tagged in the western Coral Sea. The effective effort for black marlin fished in the Coral Sea is high. The effectiveness index (*E*) of the effort on black marlin (effective hook/nominal hooks) exceeds 1.0 in 19 of 24 yr (1952-75) as reported by Suzuki and Honma (1977).

Figure 13 outlines the 10-yr average level of Japanese longline fishing effort by 5° longitude and 5° latitude for the Coral Sea and adjacent areas from 1968 to 1977 (Anonymous 1970-79). Extensive longline fishing effort is evident north of the Solomon Islands, east of Queensland, and off the southeast coast of Victoria, Australia, and off the eastern coast of New Zealand. A substantial amount of longline effort was expended off the Great Barrier Reef area (north Queensland) from lat. 20°S northward. No longline effort is reported in the eastern Arafura Sea and Torres Strait between Cape York and Papua. Fishing effort isolines also indicate an area of reduced effort extending from near New Caledonia eastward, centering on about lat. 20°S. The effort levels for the 5° areas given in Figure 13 for the period 1968-77 are indicated by numbers of hooks fished × 10^4. The strata of hook effort, levels 1-3, representing 9-99, 100-199, and 200 or greater × 10^4, respectively, were averaged for the 1968-77 period.

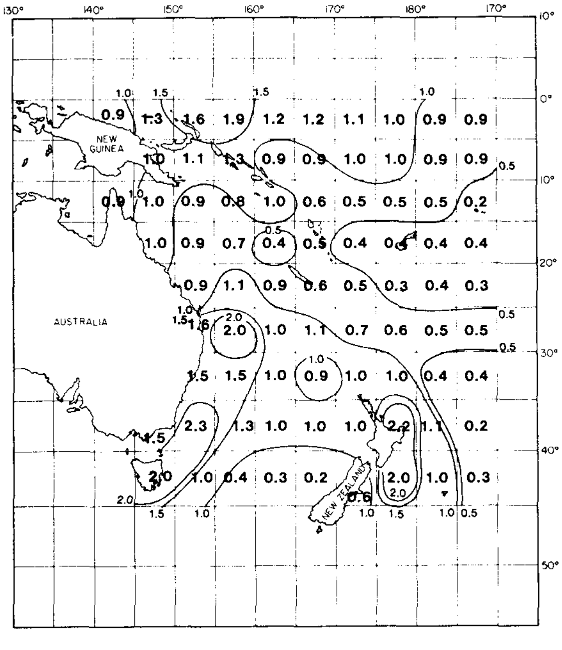


Figure 13.—Average distribution of Japanese longline fishing effort for 1968-77 by 5° longitude × latitude areas from Japanese Fishery Agency data. Effort levels for the 10-yr period were determined by averaging effort level 0-99, 100-199, 200 or greater × 10^4 hooks in terms of 1 = 0-99, 2 = 100-199, and 3 = 200 or greater × 10^4 hooks.

The distributions of longline fishing CPUE for black marlin as a measure of apparent abundance in the area from near northern New Zealand, and near the New Guinea-Solomon Islands are shown in Figure 14a, b, c (from Suzuki and Honma 1977).

A review of CPUE for June-August (Fig.14a) shows CPUE levels of 0.6-2.0 black marlin/1,000 hooks are common in the New Guinea-Bismark Archipelago-Solomon Islands area throughout the winter months. Average effort levels are high in this area, 100-199 hooks × 10^4 per 5° longitude × 5° latitude area. In September-November (Fig. 14a, b) the tagging area has a high CPUE. The first indications of a poleward shift of high CPUE areas for black marlin, in the range of 0.6-2.0 fish/1,000 hooks along the western coast of the Coral Sea, occurs during September. By examining the changes in CPUE for the area off north Queensland during and after the months of September, October, and November, some insight into the shift of high black marlin CPUE away from the tagging areas can be observed. High catch rates (≥5.1 black marlin/1,000 hooks) are common in the western Coral Sea from lat. 10° to 20°S in October and November. The high CPUE areas for September-November are near long. 150°E × lat. 15°S and have a hook effort of <99 hooks × 10^4 per 5° longitude × 5° latitude area. In December (Fig. 14b), increasing catch rates are observed south to about lat. 25°S. These higher catch rates are observed to the west within a latitudinal band of lat. 15° to 20°S. Longline hook effort level is < 99 hooks × 10^4 per 5° longitude × 5° latitude area. In January (Fig. 14b), catch rates increase along the Australian coast to about lat. 35°S. Catch rates per 5° square are lower than those observed previously off the north Queensland area (lat. 10° to 20°S), but remain in the range of 2.1-5.0 black marlin/1,000 hooks. The center of high black marlin CPUE is in an area having an effort level of < 99 hooks × 10^4 per 5° longitude × 5° latitude. By February (Fig. 14c), black marlin CPUE in the lat.15° to 20°S area has decreased to 0.5 black marlin/1,000 hooks. The high CPUE areas continue to be off the Queensland and New South Wales coast, from lat. 20° to 35°S. Average effort levels in the high CPUE areas for February are at a higher level than during the previous months, ≥100 hooks per 5° longitude × 5° latitude area but < 199 hooks × 10^4 per 5° area. CPUE patterns for March (Fig. 14c) change considerably, with higher CPUE areas noted north of lat. 15°S, and reduction in high CPUE areas to the south. Catch rates averaged 0.6-2.0 black marlin/1,000 hooks per 5° longitude × 5° latitude area. Effort levels in the higher CPUE areas are less than averages observed for high CPUE areas in February, and average ≤ 99 hooks × 10^4 per 5° longitude × 5° latitude area. Most catches in April (Fig. 14c) are being made north of lat. 20°S. Catches average 0.6-2.0 fish/hooks per 5° longitude × 5° latitude area. A further retraction of high CPUE areas from latitudes south of 15°S is evident in May (Fig. 14c). Some catches at levels of 0.6-2.0 black marlin/1,000 hooks are observed for areas east of the Queensland coast, but the center area of high CPUE is in the New Guinea-Bismark Archipelago-Solomon Islands area. Average effort levels are higher in this area and are between 100 and 199 hooks × 10^4 per 5° longitude × 5° latitude square.

a

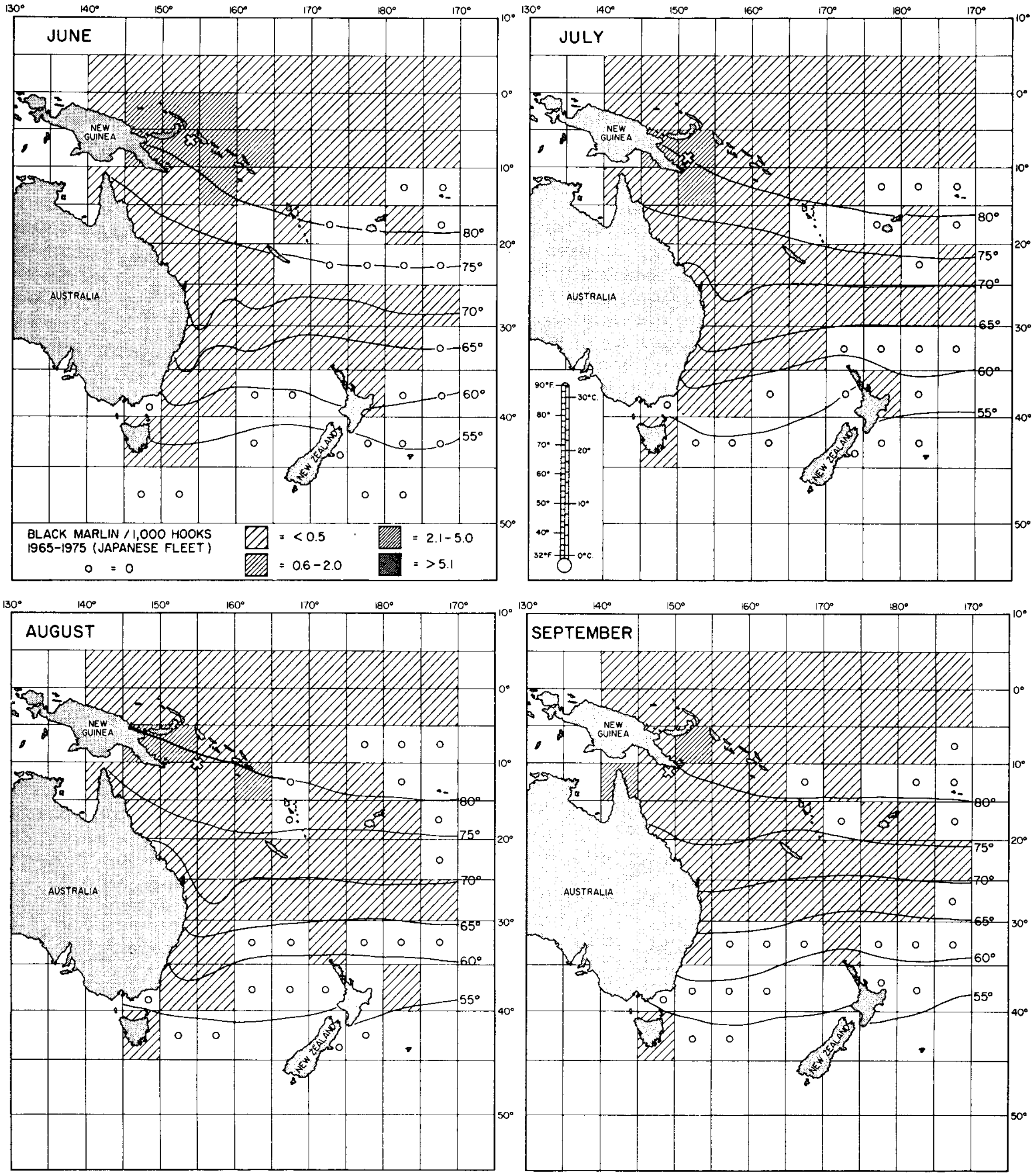


Figure 14.—Distribution of average hook rates for black marlin per 1,000 hooks effective effort (from Suzuki and Honma 1977): a. June-September. b. October-January. c. February-May.

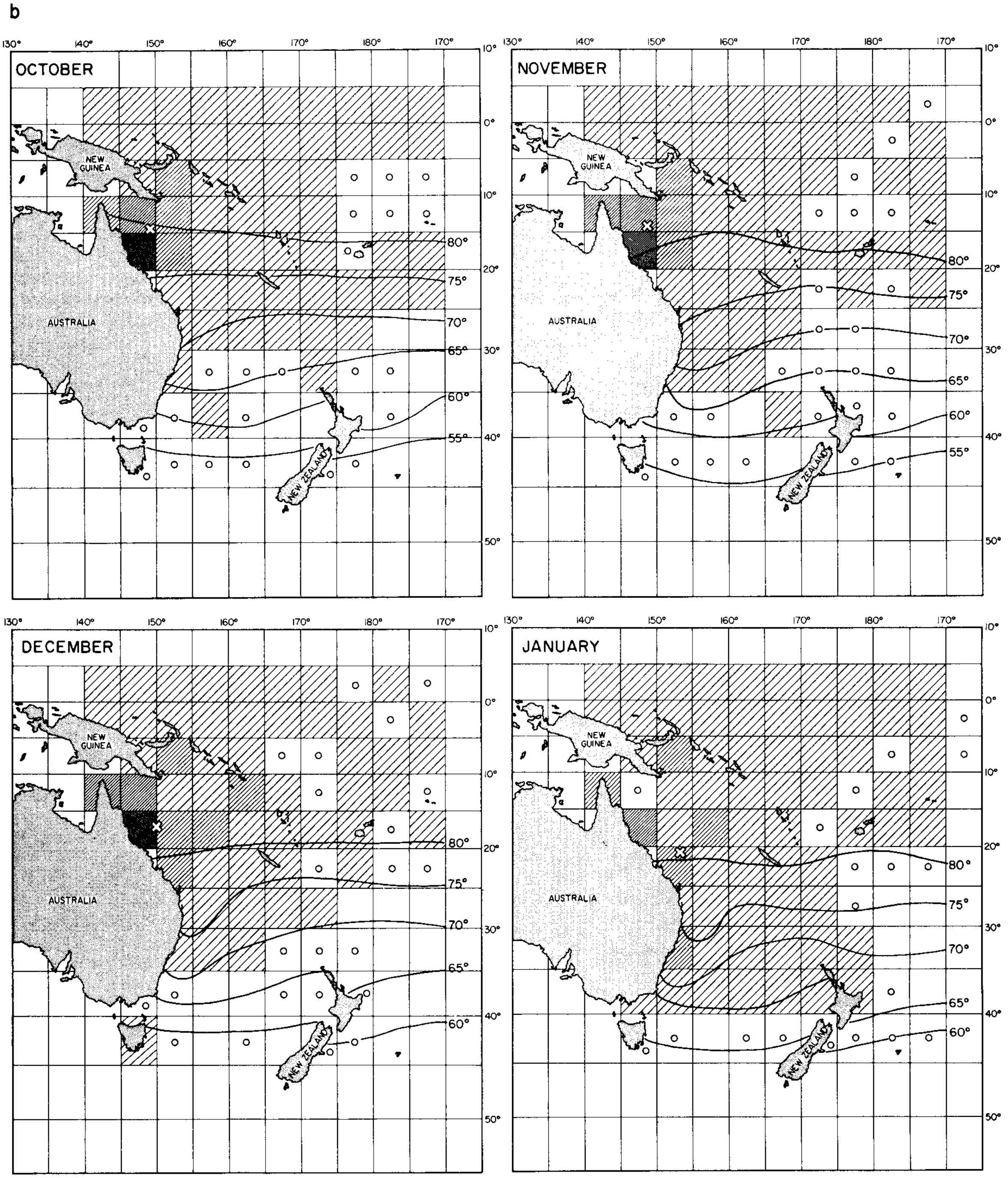


Figure 14.—*Continued.*

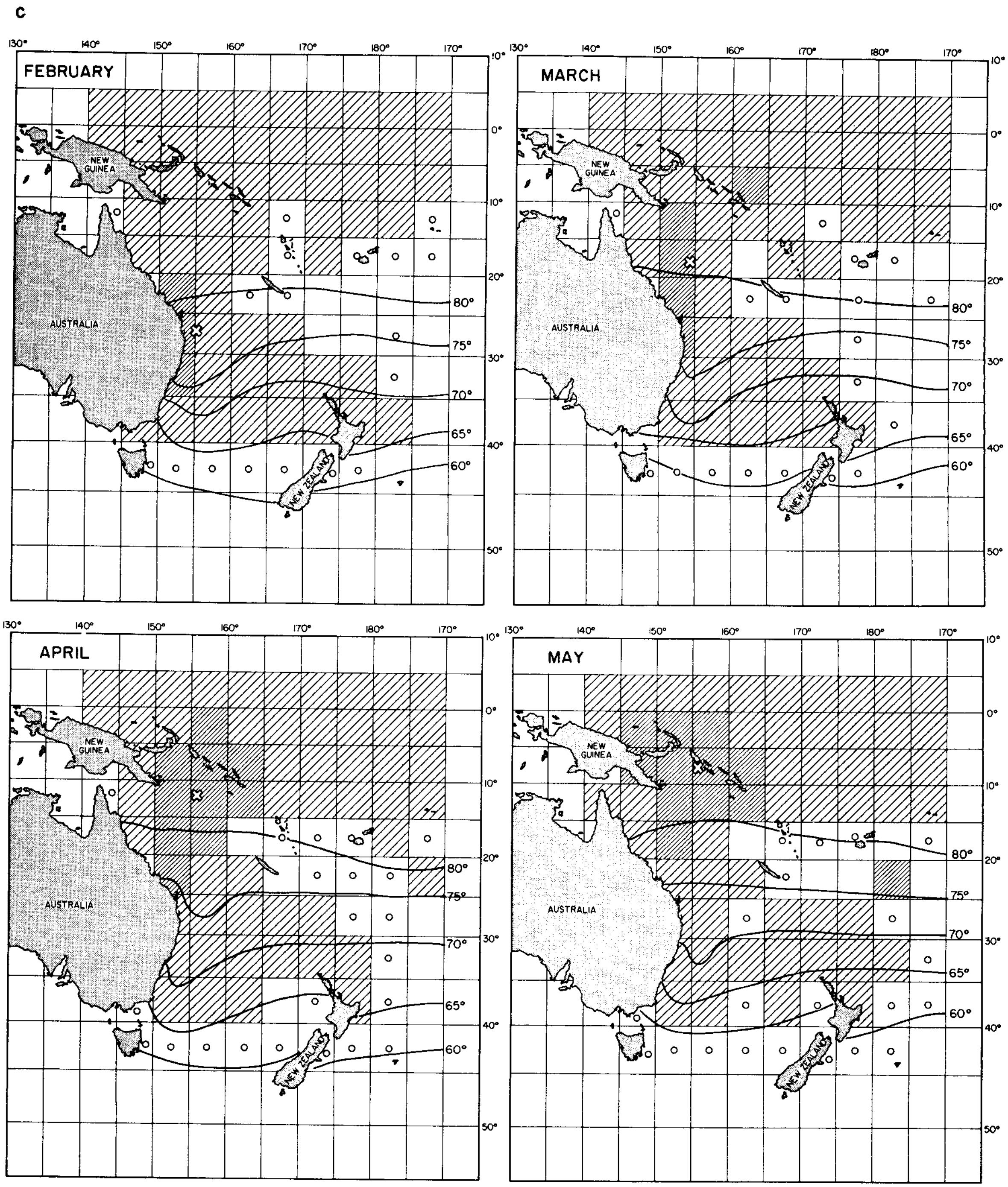


Figure 14.—*Continued.*

Low CPUE levels of black marlin, < 0.5 marlin/1,000 hooks, are common throughout most of the southwest Pacific from lat. 30°S northward during every month of the year. The southerly limit in the summer through fall (January-May) is about lat. 40°S. The only area commonly showing a low CPUE level throughout the year is the area from New Caledonia east, in a latitudinal band of lat. 10° to 20°S. A retraction of the low CPUE levels to the northwest from the New Zealand area is observed in October through December. CPUE data indicate that minor catches of black marlin could be expected in many areas of the southwest Pacific in most months.

To better define the changes in areas of high CPUE, the approximate center of high CPUE was estimated and its geographical position by month is given in Figure 15. A progressive southward movement of high CPUE areas from the tagging area is observed for December and January, reaching its southern-most limit by February. A substantial geographical shift in high CPUE center from about lat. 28° to 18°S has occured. In April, the shift is northeastward to the Solomon Islands area (lat. 10°S). CPUE center moves northwestward to about lat. 5°S in May and June. The southward movement is again evident in July-September, shifting the high CPUE center from lat. 5°S to about lat. 10° to 11°S between New Guinea and the Solomon Islands.

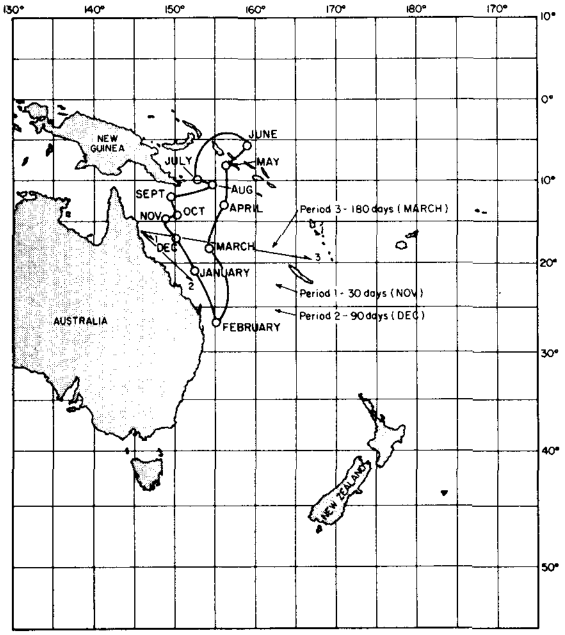


Figure 15.—Monthly movements of the approximate center (as determined by eye-fit) of high longline CPUE for black marlin as observed in Figure 14a, b, c.

DISCUSSION AND SUMMARY

The north Queensland, Australia, area is one of the most productive locations in the Pacific for anglers using rod-and-reel to catch black marlin. The excellent fishing attracts anglers from about the world, as indicated by the several countries represented in the tag recovery summary (see Table 2). An important factor was that many of the anglers and charterboat operators in this area were willing to tag and release black marlin. The number of black marlin tagged off north Queensland (2,576) is the sum of tag report forms returned by cooperating anglers. This represents a minimum number of fish tagged, since some report forms are not returned to the tagging agency (Squire 1974). The extent of nonreporting of releases is assumed to be minimal in this area because of the excellent management of the tagging effort by the Cairns Game Fishing Club which distributed the tagging equipment and maintained accurate records.

Of the black marlin reported tagged during 1968-78, 60 tags were returned for an overall return rate of 2.3%. The maximum return rate was observed in 1974, 5.1% for 335 marlin tagged with H-type tags. This is a greater return rate than the 0.9% rate experienced for striped marlin tagged by anglers in the northeastern Pacific (Squire 1974). For recapture data having information on sex, 89% were reported to be males.

The average weight of black marlin, as estimated at the time of tagging, was approximately 175 kg (385 lb) each. Table 5 indicates that substantial overestimates of black marlin weight at tagging were recorded. The ability of an angler to estimate accurately the weight of a large fish such as a black marlin actively swimming in the water is subject to considerable error. The data presented indicate that a reasonable level of accuracy (one that might produce growth rate data or allow estimates of annual average size) is not possible without the application of correction values. Estimated weight data, given by average weight per year (Fig. 3), indicate that estimated weights peaked in 1974 at 201 kg (445 lb)/fish. Average shoreside landing weights, as recorded by the Cairns Game Fishing Club, are about twice the estimated average weight of tagged fish (Table 4). This would indicate that the fish being landed for weighing are the large ones, and are not representative of the average weight of all marlin caught. Landing larger marlin, rather than tagging and releasing them, would tend to bias the average estimated tagging weight lower. Figure 3 also shows an increase in tagging effort northward along the Great Barrier Reef to latitudes < 15°30′S from the area immediate to Cairns, Australia (lat. 17°S). This increase in tagging is evident in the latitudinal band 15°30′ to 14°30′S, beginning in 1972.

The fish recaptured at 1, 2, and 3 yr after tagging, were recaptured relatively close to the point of tagging. Fish released about 1 yr earlier were recovered a mean distance of 38.4 nmi, and 2 yr earlier, at 58.3 nmi, from the point of tagging. The recovery of tagged fish at annual increments near the tagging location indicates that there is a tendency for at least some tagged black marlin to return to the northwestern Coral Sea.

To better define seasonal migratory patterns, tagging effort should be distributed throughout the species range. In most cases where tagging of oceanic species is conducted, the ideal distribution is not achieved. The tagging effort reported on in this paper is from one portion of the black marlin distributional range in the western Pacific and the associated Indo-Pacific area (Fig. 1). Black marlin are presumed to spawn in the Coral Sea between October and December (Ueyanagi 1960), and tagging takes place at this time at or near the spawning area. Black marlin are usually caught by anglers in proximity to the outer edge of the Great Barrier Reef, and most tagging takes place in this area. The commercial longline fishing operations take place offshore from the tagging area. The tagging area is within the high black marlin CPUE area for commercial longline gear during the September-December period (see Fig. 14a, b, c) and is also within an area of moderately high longline effort (see Fig. 13). Because of the commercial longline effort in this area, a number of short-term (0-60 d) recoveries were obtained. Of importance in evaluating the tag return data for migratory patterns is the relationship between a shift of the high CPUE areas and the frequency of recoveries in these areas. Recoveries about 6 mo, and 1 or more years after tagging, are most important, if one is to assume a seasonal migratory pattern exists.

Most of the tag and recovery geographical plots given in Figures 5 to 10 tend to give the impression that all migration is radiating outward from a geographically localized point of tagging, and that the tagging location is the "center" of distribution; this is not the case. Black marlin are tagged in an area as they migrate through it at varying rates and directions.

Emigration from the area of tagging during the first few months appears, for most recoveries, to be toward the south-southeast. An overall mid-point average for the first 0-60 d of release ($\bar{x}$ = 30 d) was 109 nmi; for period 2, 61-120 d ($\bar{x}$ = 90 d), 547 nmi; and for period 3, 121-240 d ($\bar{x}$ = 180 d), 1,386 nmi. Arc distances given in Figure 12 show that, based on average distance/time (180 d and 1,386 nmi), the average distance of migration would be from about southern New South Wales, just east of the New Hebrides, northeast to midway between Solomon Island and the Gilbert Islands to the Equator. The longest distance recorded was to the southeast of the tagging area, east of New Zealand (2,100 nmi, or 8.9 nmi/d). For black marlin recovered 121-240 d after tagging, the average rate was 7.7 nmi/d and in the time period of 180 d the average distance traveled at that rate would be 1,386 nmi. However, this sample, having a release time of 0-240 d, represents only 13.5% of the total recoveries. Based on average migration rate data, black marlin tagged early in the season (September) tended to migrate away from the point of tagging at a lower average rate for the first time period (0-60 d) than black marlin tagged in October, November, or later in the fishing season. This may be because the tagging areas are in or near the spawning area, and the behavior of black marlin in this area earlier in the spawning season may be different from those entering later in the season.

Data obtained from this study indicate that black marlin tagged in the western Coral Sea do not undergo short-term trans-Pacific migrations, although some interchange over time with the eastern Pacific is possible. The degree of interchange with the Indo-Pacific is unclear. Emigration from the tagging area to north of New Guinea was recorded; however, no recoveries were recorded to the east in the Arafura, Banda, or Timor Seas or the eastern Indian Ocean.

Some tentative estimate of the central tendency of migration direction and rate can be made using the vector analysis (Fig. 11), the graphic plots of tag and recovery points (Figs. 4 to 9), and movements of high CPUE areas over time (Fig. 14a, b, c), in relation to the geographical distribution of longline effort levels in the southwest Pacific (Fig. 13). Figure 15 gives the approximate geographical centers of high longline CPUE by month as observed in data presented in Figure 14a, b, c. Inspection of the longline CPUE rates for the 5° areas and plots of geographical location indicate south or southeast movement from the tagging area in the summer and then a northward movement of high CPUE areas to the New Guinea-Bismark Archipelago-Solomon Islands area in the winter. Vector mean bearing and distance data from tag results were plotted in Figure 11 and indicate direction and distance of migration away from the tagging area for 30, 90, and 180 d from October, the month having the most tagging activity (49%).

Monthly average sea surface temperature isotherms are shown in Figure 14a, b, c. High longline CPUE areas for black marlin are located in close relation to the 26.7°C (80°F) average isotherm during most months of the year. High CPUE areas are related to lower temperatures and are found between the 23.9°C (75°F) and 26.7°C (80°F) isotherms only in February off the Queensland and New South Wales coasts. Latitudinal warming and cooling as reflected in sea surface temperature may be a measure of other physical or biological environmental parameters that may be important to black marlin distribution.

From the results of tagging (emigration rates and directions), inspection of average longline effort, and CPUE, a diagramatic description of black marlin migration in the southwestern Pacific can be hypothesized (Fig. 16). The tagging results indicate that the migratory rates and patterns of black marlin are highly variable. There is, however, a central tendency of movement of tagged fish not unlike that expected from observations of the movements of CPUE trends. Black marlin were observed to move southward from the tagging area toward southeastern Australia and New Zealand in late summer, then northeast toward the Gilbert Islands, and to northeast of New Guinea in the winter, returning to the western Coral Sea in the spring and early summer. The interchange rate of the population found in the Coral Sea, with the population of the Indo-Pacific area, is unclear. The relationship of the Coral Sea population to that in the central Pacific and other areas in the western Pacific is also not defined. Though no recoveries have been made in these areas, some population interchange could be expected.

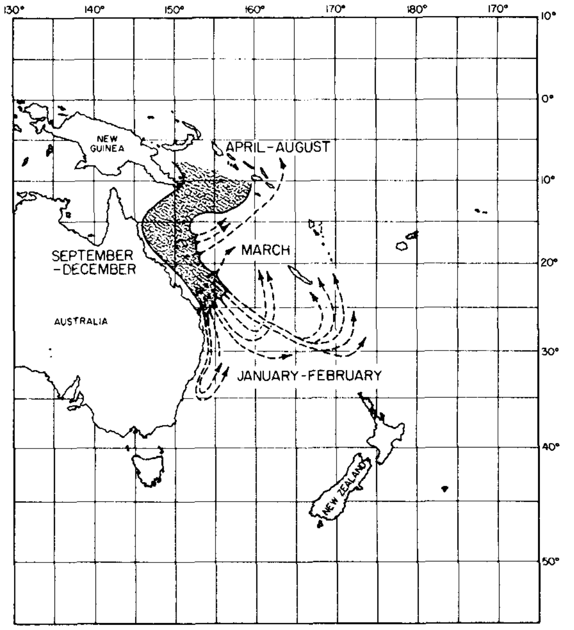


Figure 16.—A hypothetical description of black marlin migration in the southwest Pacific Ocean.

ACKNOWLEDGMENTS

The cooperation of the marine anglers who caught, tagged, and released black marlin made this study possible. We wish to convey our appreciation to the marine anglers, and to the Japanese and Korean commercial longline fleet captains and crews who recaptured tagged marlin and returned the tags.

Many of the recoveries were returned through either the Far Seas Fisheries Research Laboratory, Shimizu, Japan, or the Kanagawa Prefectural Fisheries Experimental Station, Joga Shima, Kanagawa Prefecture, Japan. We are grateful to scientists Eiji Hanamoto of the Kanagawa Fisheries Experimental Station, and Shoji Ueyanagi, Susumu Kume, and Shoji Kikawa of the Far Seas Fisheries Research Laboratory for their assistance in return of marlin tags and information used in the analysis. The interest of the charterboat captain in learning more about the resource on which he fishes often results in the marlin being tagged, although the anglers are credited for tagging and releasing the marlin. To the charterboat fleet off Cairns and nearby areas, our sincerest appreciation.

The Cairns Game Fishing Club provided excellent control of tagging equipment and maintained complete and accurate records of tagged fish throughout the years, thereby making the tagging analysis more accurate. Their precision handling of the program is appreciated.

To Julian Pepperell of New South Wales State Fisheries, who furnished a portion of the data used in this analysis, our sincere appreciation. The efforts of Norman Bartoo and Richard Evans (SWFC) in statistical analysis of the data are acknowledged. To others such as the International Game Fish Association and marine game fish anglers throughout the world who gave their support, we thank you.

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