APPARENT ABUNDANCE OF SOME PELAGIC MARINE FISHES OFF THE SOUTHERN AND CENTRAL CALIFORNIA COAST AS SURVEYED BY AN AIRBORNE MONITORING PROGRAM

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ABSTRACT

From September 1962 through December 1969, commercial aerial fish spotter pilots estimated tonnage of species observed during flights off the southern and central California coast. Observations of fish and the aircraft's flight route were recorded on special charts. These data were analyzed using 10-minute-longitude by 10-minute-latitude "block areas." A total of over 17,593 flight hours was involved, surveying 57,628 block areas—37,186 during the day and 20,442 during the night. Data from each block area were used to compute diurnal and nocturnal variation in apparent abundance and an annual index of apparent abundance.

Pacific bonito, *Sarda chiliensis*, and yellowtail, *Seriola dorsalis*, were observed in greater frequency and quantity during the day, and the northern anchovy, *Engraulis mordax;* jack mackerel, *Trachurus symmetricus*; and Pacific mackerel, *Scomber japonicus*, were observed in greater frequency and quantity during the night. Pacific barracuda, *Sphyraena argentea*, was observed in greater quantity at night but more frequently during the day.

Between 1963 and 1969 indexes of apparent abundance declined for jack mackerel, Pacific mackerel, Pacific sardine, Pacific bonito, Pacific barracuda, and yellowtail and increased slightly for the northern anchovy. The index closely follows estimates of total abundance for the Pacific mackerel, a species for which reliable estimates of total abundance are available. From observations of the catch trends in the bonito fishery, the index appears to be little affected by changes in economic demand. Its trends in apparent abundance are evident before they are reflected in catches and are useful in the evaluation of catch variations in underutilized resources.

In a search for more efficient fishing methods, many of the fisheries throughout the world that catch pelagic surface schooling species are using aircraft to locate and guide the fleet to the schools and in some cases to direct the catching operation (Cushing, Devold, Marr, and Kristjonsson, 1952). In some areas of the United States the services of the fish spotter are vital to the success of the commercial fleet which depends in part on the aircraft scouting the fishing grounds to obtain current information on the location of near-surface schooling fish (Squire, 1961). At times commercial aerial fish spotters assist the sport fishing fleet by advising them of the location of desirable marine game species.

Data obtainable by techniques of aerial observation have been used by fishery biologists to gain information on distribution and abundance of pelagic near-surface schooling fish.

Sette (1949) investigated the possibilities of aerial scouting for sardines off southern California in search of a method that would provide information useful in estimating abundance yet be free of the availability influence. Aerial scouting was conducted during the day, and commercial fishing was conducted at night. As a result the spotting data were deemed less reliable than those obtained from the commercial fishery.

Jones and Sund (1967), using commercial fish

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spotter aircraft in a search for tuna schools in the same area surveyed by a research vessel, found that the aircraft was about two and one half times more efficient than the vessel at locating fish schools. An evaluation of aircraft by the U.S. Navy, for making biological observations, indicated that for whales the frequency of sighting averaged about 20 times greater than that from ships (Levenson, 1968).

From 1956 to 1964 the California Department of Fish and Game conducted monthly survey flights along the California coast from San Francisco to Mexico. Data were published as flight reports in chart form showing the aircraft's flight track, areas surveyed, notes on species observed, and number of schools and their geographical location. Large variations in the number of schools visible over a short-time period appeared to limit the usefulness of the data, and the surveys were discontinued in 1964. The average number of schools sighted per flight was determined by Wood (1964),[3] and from these data a comparison was made of the relative abundance of northern anchovy, *Engraulis mordax*, schools for the period 1956 through 1963. Limitations on flights to nearshore areas during daylight and low search time in any one area restricted the potential of these surveys for determining the apparent abundance of the many pelagic species found off the California coast.

Fish spotter aircraft range over a large geographical area, and during these flights they may observe concentrations of several species of pelagic fish. Many times these fish are not caught for one or more reasons, such as fishing boats not equipped with proper nets, concentrations are small, species is not economically desirable, and fishing boats are not capable of reaching fish within a reasonable length of time. However, the fish spotters are able to identify these concentrations of fish.

Species commonly observed by the aerial fish spotters within the survey area were northern anchovy, jack mackerel, *Trachurus symmetricus;* Pacific bonito, *Sarda chiliensis;* Pacific mackerel, *Scomber japonicus;* Pacific sardine, *Sardinops sagax*; bluefin tuna, *Thunnus thynnus*; Pacific barracuda, *Sphyraena argentea*; white seabass, *Cynoscion nobilis*; and yellowtail, *Seriola dorsalis*.

The majority of fish spotting effort is directed toward the location and catching of jack mackerel, Pacific mackerel, Pacific bonito, Pacific sardine, and in recent years the northern anchovy. Of these five species the Pacific sardine and Pacific mackerel are most economically desirable with jack mackerel, Pacific bonito, and northern anchovy of descending importance.

To increase knowledge on the apparent abundance of pelagic near-surface marine life, the Tiburon Marine Laboratory initiated a pelagic fish monitoring program in cooperation with aerial fish spotter pilots who are active in spotting for the southern and central California coastal commercial fishery. These cooperators were individuals with specialized training and experience. When assisting the commercial fleet, fishing success is dependent upon accurate identification of schooling species by the spotters. They have considerable experience in estimating the weight of fish schools, and they are considered to be quite accurate in the estimation of weight.

There are a number of variables that affect the statistical accuracy of fish spotter data which are difficult to evaluate, such as individual difference in ability of pilots to locate fish, determine species, and estimate school size, and estimate total tonnage available in a fishing area. Variation in estimating school size probably has more effect on the data than the other variables. However, since at least five experienced observers were used in the program during each year, it was assumed that reasonable annual averages were obtained.

This report consists of an analysis of aerial fish spotter data for the period September 1962 through December 1969 to determine if, for the species commonly observed, it can be used to: (1) compute an accurate index of apparent abundance and (2) obtain a trend in the apparent abundance of pelagic near-surface species and in particular those of underutilized resources.

[3] Wood, R. 1964. Aerial surveys along the California coastline 1956 to 1963. Document V prepared for the Marine Research Committee meeting, March 6, 1964, San Pedro, Calif., 2 p. [Processed.]

METHODS AND PROCEDURES

Five fish spotter pilots were contracted to record observations of pelagic species, giving location, number of schools, estimated tonnage of each school or groups of schools, counts of large marine animals, and flight track for each survey flight. Two pilots usually covered the Santa Barbara Channel and Santa Barbara Islands north to Estero Bay and occasionally into Monterey Bay. The remaining three spotter pilots normally surveyed the area from west of Los Angeles to southwest of San Diego and occasionally offshore to San Clemente Island, Cortez Bank, and San Nicholas Island. Flight operations were conducted during daylight hours or on nights during the dark phase of the moon at elevations of 500 to 1,200 ft (152 to 365 m) above the sea surface.

TECHNIQUES OF OPERATION

Specific observation of a fish school has three phases: (1) distinguishing a school, (2) identifying the species, and (3) estimating weight of the school. The detection of near-surface schools during the day is dependent upon the pilot's ability to distinguish subtle color and light intensity differences in the water. Detection of schools at night is possible only during the dark period of the moon and depends on the pilot's ability to discern gradation of light intensity. Bioluminescence of planktonic organisms agitated by schooling fish indicates by a dull glow the location and size of the school. Species are identified during the day on the basis of a combination of two or more of the following characteristics: color of school or individual fish, shape of school, and behavior and size of individuals within the school. At night, species identification is based on shape of the luminous area and behavior of the schooling fish under undisturbed conditions, or by the behavior of the school after being subjected to a stimulus from an external source such as a flash from the aircraft's landing light.

At first observations were recorded by the pilots on small portable tape recorders. This method was unsatisfactory, and recorders were replaced with three charts covering the coastal waters from the Coronado Islands, Mexico, north to Half Moon Bay, Calif. The charts were completed by the pilots after each flight and were submitted quarterly to the National Marine Fisheries Service. Figure 1 illustrates the type of information recorded by the fish spotter pilot.

PROCESSING OF OBSERVATION DATA

Each chart was overlayed with a 10-minute-longitude by 10-minute-latitude grid, numbered according to the California Department of Fish and Game "Block area" statistical system (Clark, 1935). With the gridded chart, the observation and flight track data could be conveniently tabulated and coded for subsequent computer analysis. California Department of Fish and Game statistical code numbers were assigned to each of the 27 species of marine animals observed. The computer output grouped data by species, year, week, block area, day or night observation, number of schools, tons per school, and tons per block area. The data for block areas were later combined into 11 larger grouped block areas or "zones" lettered A through K (Figures 2 and 3). These zones were selected to outline important geographical areas where fish were commonly observed.

The following criteria were used in tabulating the data from the flight charts:

1. Groups of schools which were indicated on the flight chart as covering more than one block area were listed for each block holding part of the group. For example, if one group of schools (10 schools, 15 tons per school, total 150 tons) overlapped two block areas equally, each area was credited with having 5 schools at 15 tons per school, equalling 75 tons per block area.

2. If only one school was shown overlapping two block areas, the school was assigned to the block area having the greatest portion of the school.

3. If a large area of fish was indicated involving more than two block areas and only a total tonnage estimate made, the tonnage was credited to the block areas in proportion to area outlined.

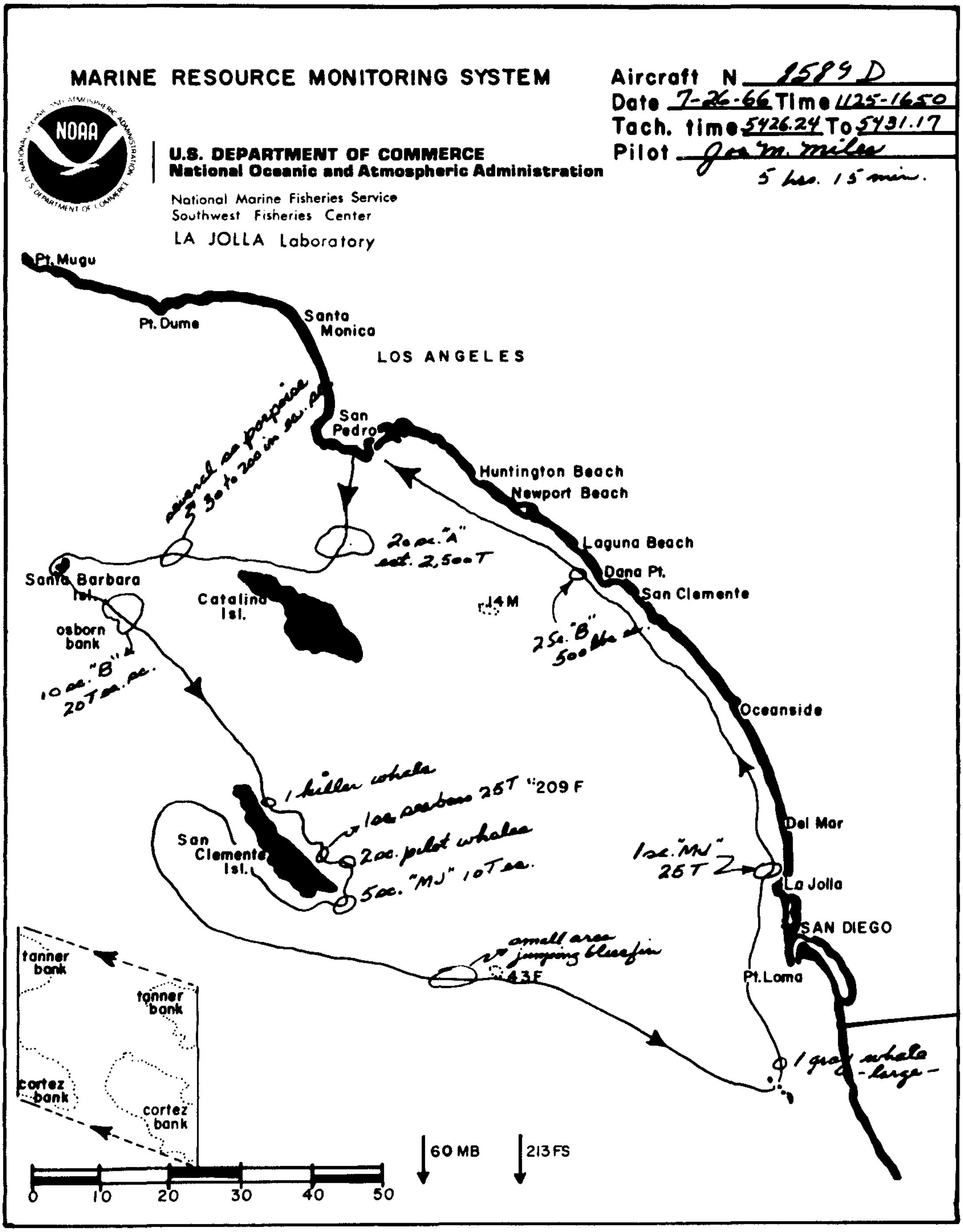

FIGURE 1.—Flight chart for southern California area showing typical flight track and fish and mammal observations. Block area grid is overlayed on chart for coding observations.

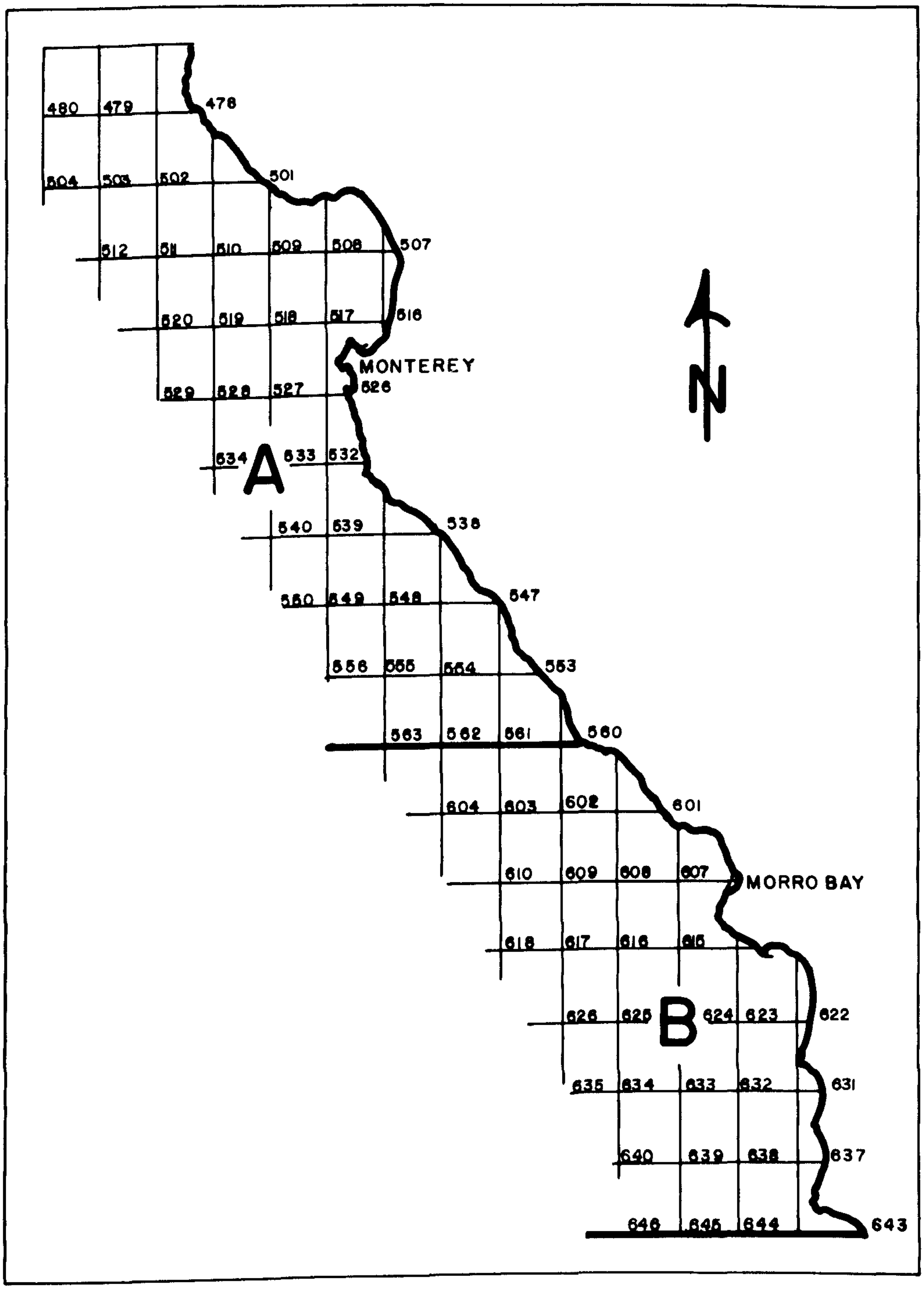

FIGURE 2.—Block areas grouped into zones (A-B), selected to outline the more important coastal fishing areas.

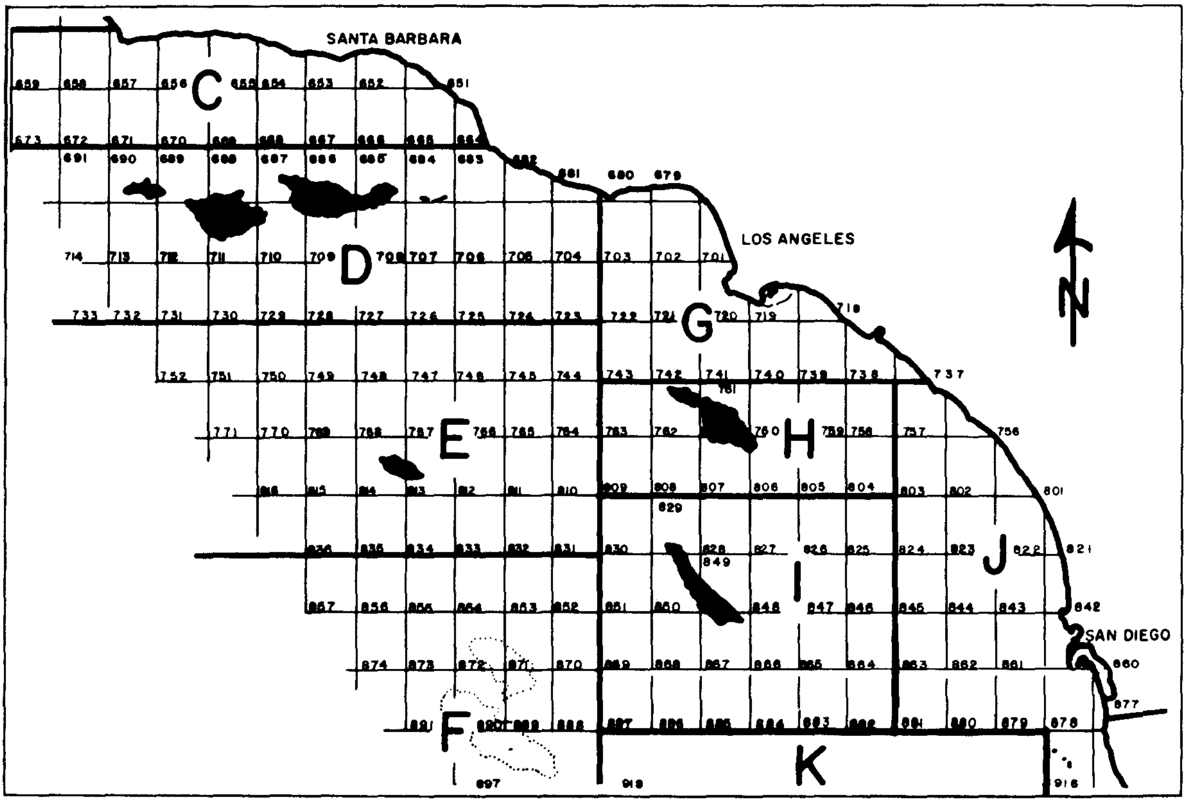

FIGURE 3.—Block areas grouped in zones (C-K), selected to outline the more important coastal fishing areas.

4. Whales, porpoises, and sharks were recorded as numbers of individuals observed.

5. When the flight track entered any portion of a block area, the block area was credited for the purpose of determining observation effort as having a "block area flight."

RESULTS

During survey flights, 20 species of fish were observed and identified. A number of other marine species (mammals, invertebrates) were observed and all are listed in Table 1.

DISTRIBUTION OF FLIGHT OBSERVATION EFFORT

A total of 17,593 flight hours were logged by spotter pilots during the survey period. The number of block area flights from September 1962 through the end of 1969 totaled 57,628 with 37,186 block areas surveyed during the day and 20,442 at night. Distribution of day and night block area flights by year and by zone is shown in Table 2.

NOCTURNAL AND DIURNAL VARIATION IN NUMBER OF SIGHTINGS AND TONNAGE

To determine criteria concerning the frequency of observation during the day and night for each of the species more commonly observed, the ratios in numbers of sightings and tonnages observed were calculated for the period September 1962 through December 1966. Information on the diurnal and nocturnal frequencies and magnitude of occurrence for each species is of importance in evaluating which observation (day

TABLE 1.—Species of fish and other marine animals observed during surveys.

Fish:
- Basking shark (*Cetorhinus maximus*)
- White shark (*Carcharodon carcharias*)
- Northern anchovy (*Engraulis mordax*)
- Pacific sardine (*Sardinops sagax*)
- Pacific bonito (*Sarda chiliensis*)
- Jack mackerel (*Trachurus symmetricus*)
- Pacific mackerel (*Scomber japonicus*)
- Pacific barracuda (*Sphyraena argentea*)
- Yellowtail (*Seriola dorsalis*)
- White seabass (*Cynoscion nobilis*)
- Bluefin tuna (*Thunnus thynnus*)
- Albacore tuna (*Thunnus alalunga*)
- Yellowfin tuna (*Thunnus albacares*)
- Skipjack tuna (*Katsuwonus pelamis*)
- Jacksmelt (*Atherinopsis californiensis*)
- Ocean sunfish (*Mola mola*)
- Striped bass (*Morone saxatilis*)
- Pacific saury (*Cololabis saira*)
- Swordfish (*Xiphias gladius*)
- Striped marlin (*Tetrapturus audax*)

Mammals:
- Gray whale
- Pilot whale
- Blackfish (killer whale)
- Porpoise and dolphin
- Seals and sea lions

Invertebrates:
- Squid
- Jellyfish

or night) might be the more significant in evaluating the trend of apparent abundance. These data were calculated during an earlier part of the study (1962-1966) to evaluate the method of using aerial fish spotter data.

The total amount of fish estimated to have been seen by the aerial fish spotters during the period 1962-1966 was 5,289,521 tons of the following species: northern anchovy, 4,550,218 tons; jack mackerel, 335,794 tons; Pacific bonito, 238,247 tons; Pacific mackerel, 103,464 tons; and yellowtail, 1,955 tons.

Annual sightings of each species per block area flight were expressed as a percentage of all block area flights day and night (% day/% night) and are shown in Table 3. The ratio of diurnal and nocturnal sightings was obtained by dividing the percentage of day sightings by the percentage of night sightings. Ratio values greater than 1.00 indicate a greater number of sightings during day, less than 1.00 indicate greater number of sightings during the night.

To determine the day and night differences in the tonnage observed for each species, the

TABLE 2.—Observation effort (day/night) in block area flights by zone for the period September 1962 through 1969. [Data are presented in number of block area flights (day/night).]

Zone	1962	1963	1964	1965	1966	1967	1968	1969	Total
A	41/62	175/78	125/86	102/84	239/9	361/0	585/0	86/29	1,714/348
B	174/117	220/75	283/156	471/252	770/90	610/13	519/0	126/10	3,173/713
C	104/126	470/658	632/680	892/743	1,860/495	1,016/559	1,014/281	2,130/718	8,118/4,260
D	12/71	137/167	409/518	485/434	1,268/385	813/533	1,000/291	1,942/712	6,066/3,111
E	0/10	63/96	40/263	48/58	108/30	40/51	101/109	87/97	493/714
F	0/6	15/32	23/37	2/106	37/21	15/53	35/194	79/48	206/497
G	0/2	454/496	394/610	481/404	1,358/434	874/596	616/676	735/1,500	4,939/4,718
H	0/0	291/282	363/336	387/349	723/206	435/305	368/469	303/576	2,870/2,523
I	0/0	366/155	477/157	395/258	814/208	614/281	544/378	613/348	3,823/1,785
J	0/0	463/198	586/300	550/128	847/113	1,087/154	672/294	932/188	5,137/1,375
K	0/0	18/0	13/0	13/0	69/9	65/10	75/32	106/1	350/52
Total	331/394	2,672/2,237	3,336/3,143	3,826/2,816	8,120/2,000	5,936/2,555	5,826/3,070	7,139/4,227	37,186/20,442
Grand total	725	4,909	6,479	6,642	10,120	8,491	8,896	11,366	57,628

TABLE 3.—Annual sightings per block area flight in percentage (day/night) and day/night averages and ratios.

Species	1962	1963	1964	1965	1966	Day/night	
						Average	Ratio
Northern anchovy	3.3/21.6	8.7/19.7	7.8/21.5	4.9/11.8	5.4/25.0	6.0/19.9	0.30
Pacific bonito	6.3/ 6.3	7.3/ 5.1	9.7/ 3.4	8.3/ 1.7	6.3/ 2.5	7.5/ 3.8	1.99
Jack mackerel	0.3/ 1.0	3.5/ 9.9	5.0/ 6.7	3.3/ 6.2	1.8/ 5.7	2.7/ 6.1	0.47
Pacific mackerel	0.0/ 6.9	4.2/ 9.6	2.0/ 3.5	0.3/ 1.2	0.1/ 2.0	1.3/ 4.6	0.28
Pacific sardine	1.2/ 1.5	1.5/ 2.3	0.8/ 2.1	0.1/ 0.4	0.2/ 0.4	0.7/ 1.3	0.57
Yellowtail	0.0/ 0.0	1.0/ 0.4	0.2/ 0.0	0.2/ 0.0	0.2/ 0.0	0.3/ 0.0	4.00
Pacific barracuda	1.8/ 0.0	0.9/ 0.6	0.5/ 0.6	0.7/ 0.0	0.2/ 0.1	0.8/ 0.2	3.15

amount observed (day or night) in each zone was divided by the number of block area flights (day or night) within the zone. The average number of tons observed per block area flight for each zone, the average number of tons observed for all zones combined, and ratios of day and night tonnages observed are shown in Table 4. Ratios were obtained by dividing the tons per block area flight (day) by tons per block area flight (night). Therefore, ratios greater than 1.00 indicate greater tonnage during the day, less than 1.00 indicate greater tonnage during the night.

AVERAGE WEIGHT OF FISH SCHOOLS

Average weight of schools was computed for the period September 1962 through December 1966 from all data having estimates of individual schools by weight. As previously indicated, some tonnages were given by areas, not by numbers of schools and tonnages of each school. The average tonnage per school is listed for each species in Table 5.

INDEX OF ANNUAL APPARENT ABUNDANCE

An index of annual apparent abundance was calculated for observations during day and night for each zone and for all zones combined from September 1962 through December 1969 for the northern anchovy, Pacific bonito, jack mackerel, Pacific mackerel, Pacific sardine, yellowtail, and Pacific barracuda. Marr (1951) defined the term apparent abundance as "abundance as affected by availability, or the absolute number of fish accessible to a fishery." This definition of apparent abundance most nearly describes the type of index calculated in this paper.

For convenience in calculating this index, four arbitrary tonnage ranges were selected for each species. Tonnage ranges for each species were selected to cover the entire range of observed tonnages that may occur in any one block area. The midpoint tonnage of each range was divided by 100 for the northern anchovy and by 10 for Pacific bonito, jack mackerel, Pacific mackerel, and Pacific sardine to provide a tonnage range value (X) of convenient size to be used in the

TABLE 4.—Day/night differences in tonnage and ratios observed based on average tons observed per block area flight in each zone for the period September 1962-1966.

Species and zone	Tons/block area flight day/night	Day/night ratio
Northern anchovy		
Zone A	478.8/636.1	0.75
B	148.5/832.2	0.17
C	45.4/386.4	0.11
D	32.6/337.5	0.09
E	9.8/214.0	0.04
F	3.9/ 39.2	0.01
G	105.0/197.3	0.53
H	64.4/ 75.8	0.84
I	10.8/ 92.3	0.11
J	32.6/237.1	0.13
K	13.5/ 11.1	1.21
Average—all zones	79.8/299.7	0.26
Pacific bonito		
Zone A	0.6/ 0.0	--
B	0.5/ 0.2	2.50
C	15.8/ 7.6	2.00
D	12.8/ 2.1	6.09
E	44.5/ 0.1	445.00
F	0.6/ 0.0	--
G	5.8/ 0.9	6.44
H	5.5/ 2.2	2.50
I	7.0/ 0.8	8.75
J	27.6/ 11.3	2.44
K	0.2/ 0.0	--
Average—all zones	10.9/ 2.3	4.73
Jack mackerel		
Zone A	41.7/ 12.2	3.48
B	25.3/ 44.8	0.56
C	2.5/ 6.0	0.41
D	9.2/ 34.6	0.27
E	2.5/ 19.2	0.13
F	8.0/169.4	0.04
G	2.3/ 6.1	0.37
H	1.7/ 8.2	0.20
I	5.8/ 17.0	0.34
J	4.0/ 11.5	0.34
K	0.0/ 0.0	--
Average—all zones	7.7/ 18.4	0.41
Pacific mackerel		
Zone A	0.0/ 0.0	--
B	0.0/ 1.1	0.00
C	0.8/ 5.7	0.14
D	2.5/ 3.8	0.65
E	0.5/ 6.4	0.07
F	50.1/ 50.3	0.99
G	2.0/ 2.0	1.00
H	11.1/ 5.9	1.88
I	1.7/ 2.4	0.70
J	2.7/ 8.4	0.32
K	3.2/ 0.0	--
Average—all zones	2.6/ 5.2	0.50
Pacific sardine		
Zone A	9.5/ 4.5	2.11
B	0.6/ 3.9	0.15
C	0.1/ 0.1	1.00
D	0.2/ 0.2	1.00
E	3.0/ 57.4	0.05
F	16.6/ 6.1	2.72
G	0.2/ 1.2	0.16
H	0.2/ 7.0	0.02
I	0.0/ 0.0	--
J	0.1/ 1.1	0.90
K	0.0/ 0.0	--
Average—all zones	0.7/ 4.1	0.17
Yellowtail	(Note, small number of observations, zone data omitted.)	
Average—all zones	0.09/0.02	4.50
Pacific barracuda	(Note, small number of observations, zone data omitted.)	
Average—all zones	0.06/0.29	0.20

TABLE 5.—Average weight per school (data from September 1962 through December 1966).

Species	Total tons / No. schools obs.	=	Avg. tons/school
Northern anchovy	192,047.5 / 5,261	=	36.5
Pacific sardine	5,140.5 / 194	=	26.5
Jack mackerel	44,545 / 1,846	=	24.1
Skipjack tuna	260 / 14	=	18.6
Albacore	73 / 4	=	18.2
Bluefin tuna	7,092 / 396	=	17.9
Pacific bonito	38,435 / 2,244	=	17.1
Pacific mackerel	10,948 / 649	=	16.9
Yellowtail	754.5 / 53	=	14.2
White seabass	234 / 47	=	4.9
Pacific barracuda	834.5 / 184	=	4.5

index formula. Midpoints were not reduced for Pacific barracuda and yellowtail. Range of observed tonnage and X values are shown in Table 6.

The following formula was used to calculate annual indexes of apparent abundance, day and night, for each species by zone and the day/night index of annual average apparent abundance for each species.

Index of apparent abundance

$$= \frac{\sum N_1X_1 + N_2X_2 + N_3X_3 + N_4X_4}{N_t}$$

where: $N_{1,2,3,4}$ = number of block area flights in which the species occurred at value $X_{1,2,3,4}$.

$X_{1,2,3,4}$ = tonnage range values.

N_t = total number of block area flights in the zone during the year.

Day and night indexes of apparent abundance for each zone and the annual average day/night indexes of apparent abundance for all zones are listed in Table 7.

DISCUSSION AND SUMMARY

A direct, precise measure of total abundance is most desirable for the management of pelagic marine species. However, at the present time and into the foreseeable future, this degree of accuracy in the measurement of total abundance cannot be attained. Therefore, pelagic resource mangement will be required to rely on an indirect measure of total abundance. Some observations on the relation between the index of apparent abundance and changes in estimates of total abundance can be made. For the years 1963 through 1969, either separately or combined, some data are available giving estimates of total abundance, spawning biomass, or indexes of abundance for such species as the northern anchovy, Pacific mackerel, Pacific sardine, jack mackerel, and Pacific bonito. However, all such estimates were calculated from data obtained from such measures as catch, effort, catch composition, fecundity, and egg and larval counts. No direct measurements of total abundance were

TABLE 6.—Range of tonnage and tonnage range values (X).

Species	Observed tonnage	X
Anchovy	0-400	2
	400-1,000	7
	1,000-10,000	55
	10,000-20,000	150
Pacific bonito	0-50	2.5
	50-150	10
	150-1,000	57.5
	1,000-5,000	300
Jack mackerel	0-50	2.5
	50-300	17.5
	300-1,000	65.5
	1,000-2,000	150
Pacific mackerel	0-20	1
	20-100	6
	100-250	17.6
	250-500	37.5
Pacific sardine	0-100	5
	100-500	30
	500-2,000	125
	2,000-4,000	300
Pacific barracuda	0-10	5
	10-30	20
	30-80	55
	80-160	120
Yellowtail	0-5	2.5
	5-10	7.5
	10-30	20
	30-60	45

TABLE 7.—Annual average indexes of apparent abundance for both day and night observations. Dash (--) indicates no flight observations in zone. Indexes given as day/night.

Zone	1962	1963	1964	1965	1966	1967	1968	1969
				Northern anchovy				
A	0.51/1.22	10.98/13.28	0.80/7.32	2.51/2.48	2.02/ 6.33	1.15/ --	0.28/ --	0.00/ 0.00
B	3.25/3.18	6.17/13.02	4.08/3.08	1.85/5.75	0.29/15.31	0.28/ 0.30	0.73/ --	0.03/ 0.00
C	0.05/0.99	0.40/ 2.70	0.90/2.85	1.82/8.63	0.27/ 2.79	2.91/ 3.03	0.05/ 1.76	0.87/ 1.93
D	0.00/2.97	1.24/10.02	0.23/4.75	0.48/3.67	0.14/ 6.73	0.63/ 5.12	0.05/ 3.24	0.41/ 1.96
E	--/0.00	0.00/ 1.05	0.00/3.14	0.00/0.12	1.09/ 0.23	3.15/ 0.11	0.18/ 0.12	0.32/ 0.67
F	--/0.00	3.66/ 1.71	5.75/0.37	0.00/0.58	0.00/ 2.61	0.00/ 0.00	0.00/ 0.60	0.00/ 0.00
G	--/1.00	0.51/ 1.81	0.54/6.21	1.42/3.23	2.24/ 1.78	2.40/ 8.32	0.55/ 2.11	5.01/ 8.57
H	--/--	0.14/ 0.12	0.38/1.00	0.05/1.90	2.28/ 1.43	5.45/ 1.60	0.65/ 0.58	6.35/ 3.26
I	--/--	0.14/ 0.00	0.05/0.11	0.02/0.34	0.28/ 2.53	2.87/ 0.71	0.18/ 0.21	0.78/ 0.49
J	--/--	0.78/ 0.67	0.85/6.08	0.00/0.00	0.45/ 1.55	0.16/20.16	0.52/ 1.11	0.55/ 3.39
K	--/--	0.00/ --	0.00/--	0.00/--	0.00/ 0.22	0.00/ 0.70	2.44/ 0.06	0.00/ 0.00
Average all zones	1.79/1.99	1.64/ 2.99	1.03/3.90	0.96/4.18	0.84/ 3.62	1.78/ 4.30	0.33/ 1.46	1.30/ 4.35
				Pacific bonito				
A	0.00/0.00	0.00/ 0.00	0.50/0.00	0.00/0.00	0.04/ 0.00	0.07/ --	0.00/ --	0.00/ 0.00
B	0.01/0.00	0.00/ 0.01	0.06/0.01	0.02/0.00	0.43/ 0.00	0.01/ 0.00	0.00/ --	0.00/ 0.00
C	0.62/0.25	3.63/ 1.51	2.40/0.82	2.18/0.40	1.38/ 0.83	0.51/ 1.02	0.36/ 1.36	0.29/ 0.27
D	0.83/0.63	0.65/ 1.88	1.40/0.12	0.85/0.10	1.27/ 0.54	0.38/ 0.80	0.53/ 0.15	0.24/ 0.23
E	--/0.00	0.02/ 1.15	0.50/0.00	6.81/0.00	4.30/ 0.00	0.00/ 0.00	0.00/ 0.02	0.00/ 0.00
F	--/0.00	0.00/ 0.00	0.43/0.00	0.00/0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
G	--/0.00	0.31/ 0.37	0.30/0.00	0.50/0.01	1.19/ 0.16	0.67/ 0.39	0.12/ 0.13	0.12/ 0.16
H	--/--	0.85/ 0.22	2.12/0.53	2.06/0.32	0.03/ 0.00	0.00/ 0.02	0.68/ 0.24	0.09/ 0.06
I	--/--	0.00/ 0.45	3.46/0.54	0.40/0.13	0.06/ 0.02	0.12/ 0.00	0.02/ 0.03	0.02/ 0.05
J	--/--	3.67/ 0.23	1.10/0.06	1.71/0.46	4.96/ 0.11	3.27/ 0.12	1.70/ 0.69	0.64/ 0.51
K	--/--	0.13/ --	0.00/--	0.00/--	0.00/ 0.00	45.73/ 0.00	0.26/ 0.00	0.75/ 0.00
Average all zones	0.23/0.19	1.62/ 0.58	1.62/0.28	1.26/0.19	1.34/ 0.35	1.35/ 0.34	0.43/ 0.35	0.26/ 0.18
				Jack mackerel				
A	0.00/0.08	1.81/ 0.00	8.32/2.89	0.78/ 1.67	4.29/25.72	0.81/ --	0.91/ --	0.03/ 0.00
B	0.02/0.00	3.48/ 1.37	6.65/6.67	1.03/ 1.22	0.74/ 8.78	0.78/ 1.34	0.70/ --	0.00/ 0.00
C	1.59/0.45	0.96/ 0.49	0.83/0.56	0.14/ 0.33	0.06/ 0.03	0.04/ 0.33	0.13/ 0.02	0.11/ 0.17
D	0.00/1.45	1.79/13.77	2.72/5.36	1.44/ 1.40	0.24/ 1.62	0.41/ 0.24	0.21/ 0.20	0.15/ 0.33
E	--/0.00	0.27/ 4.74	0.93/2.31	0.72/ 1.55	0.16/ 7.38	0.00/ 2.15	0.24/ 4.09	0.00/ 4.41
F	--/2.91	11.16/39.70	1.63/2.31	0.00/17.41	0.00/27.91	0.00/38.84	10.87/27.77	3.50/13.08
G	--/0.00	1.23/ 1.76	0.64/0.99	0.02/ 0.29	0.00/ 1.05	0.00/ 0.10	0.02/ 0.00	0.13/ 0.26
H	--/--	0.56/ 1.34	0.01/1.11	0.71/ 0.43	0.04/ 2.18	0.01/ 0.33	0.00/ 0.26	0.00/ 0.59
I	--/--	2.11/ 5.53	0.17/1.86	1.35/ 0.75	0.19/ 2.37	0.04/ 3.27	0.00/ 1.27	0.04/ 1.58
J	--/--	0.67/ 0.54	0.72/1.51	0.86/ 0.96	0.00/ 0.06	0.00/ 0.03	0.08/ 1.07	0.06/ 0.30
K	--/--	0.00/ --	0.00/--	0.00/ --	0.00/ 0.00	0.00/ 1.75	0.00/ 1.09	0.00/ 0.00
Average all zones	0.51/0.46	1.41/ 2.98	1.62/2.18	0.71/ 1.36	0.28/ 1.94	0.20/ 1.41	0.30/ 2.25	0.11/ 0.65
				Pacific mackerel				
A	0.00/ 0.00	0.00/ 0.00	0.00/0.00	0.00/ 0.00	0.00/ 0.00	0.00/ --	0.00/ --	0.00/ 0.00
B	0.30/ 0.03	0.00/ 1.56	0.00/0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ --	0.00/ 0.00
C	0.00/ 3.15	0.23/ 0.37	0.03/0.30	0.04/ 0.28	0.01/ 0.35	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
D	0.50/ 0.30	1.41/ 2.20	0.49/0.23	0.05/ 0.08	0.00/ 0.01	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
E	--/ 3.75	0.43/ 0.67	0.02/0.74	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.03	0.00/ 0.00
F	--/ 0.00	5.40/ 6.59	3.15/3.62	0.00/ 0.23	0.00/ 2.95	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
G	--/18.75	0.79/ 0.46	0.78/0.13	0.00/ 0.44	0.00/ 0.04	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
H	--/ --	2.19/ 1.62	0.14/0.36	0.00/ 0.02	0.00/ 0.02	0.00/ 0.00	0.00/ 0.00	0.00/ 0.03
I	--/ --	0.76/ 0.40	0.01/0.53	0.00/ 0.11	0.00/ 0.09	0.00/ 0.02	0.00/ 0.00	0.00/ 0.04
J	--/ --	0.83/ 1.44	0.75/0.29	0.00/ 0.36	0.00/ 0.06	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
K	--/ --	1.94/ --	0.00/--	0.00/ --	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
Average all zones	0.17/ 1.26	0.79/ 0.91	0.33/0.33	0.01/ 0.19	0.00/ 0.14	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00

TABLE 7.—Continued.

Zone	1962	1963	1964	1965	1966	1967	1968	1969
				Pacific sardine				
A	0.00/ 0.00	1.40/ 3.78	1.22/0.05	0.04/ 0.00	0.00/ 0.00	0.00/ --	0.00/ --	0.00/ 0.00
B	0.05/ 2.13	0.31/ 0.00	0.26/1.63	0.00/ 0.00	0.00/ 0.38	0.00/ 0.00	0.00/ --	0.00/ 0.00
C	0.04/ 0.00	0.02/ 0.00	0.00/0.05	0.07/ 0.02	0.00/ 0.00	0.00/ 0.03	0.00/ 0.00	0.00/ 0.00
D	0.00/ 0.28	0.07/ 2.36	0.23/0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
E	--/12.50	2.22/ 0.83	1.75/7.87	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
F	--/ 0.00	0.00/ 0.00	13.47/1.62	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
G	--/ 0.00	0.08/ 0.30	0.17/0.13	0.03/ 0.00	0.00/ 0.09	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
H	--/--	0.06/ 0.67	0.00/2.27	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.02	0.00/ 0.00
I	--/--	0.00/ 0.00	0.00/0.00	0.00/ 0.00	0.00/ 0.02	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
J	--/--	0.12/ 0.05	0.22/0.01	0.00/ 1.09	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
K	--/--	0.00/ --	0.00/--	0.00/ --	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
Average all zones	0.04/ 1.00	0.22/ 0.50	0.27/1.03	0.02/ 0.05	0.00/ 0.04	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
				Pacific barracuda				
A	0.00/ 0.00	0.00/ 0.00	0.00/0.00	0.00/ 0.00	0.00/ 0.00	0.00/ --	0.00/ --	0.00/ 0.00
B	0.00/ 0.00	0.00/ 0.00	0.00/0.00	0.00/ 0.00	0.24/ 0.00	0.00/ 0.00	0.00/ --	0.00/ 0.00
C	0.00/ 0.00	0.34/ 0.43	0.45/0.48	0.25/ 0.00	0.02/ 0.00	0.02/ 0.00	0.03/ 0.01	0.04/ 0.00
D	0.00/ 0.00	0.00/ 0.00	0.00/0.01	0.00/ 0.00	0.01/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
E	--/ 0.00	0.00/ 0.00	0.00/0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
F	--/ 0.00	0.00/ 0.00	0.00/0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
G	--/ 0.00	0.00/ 0.11	0.00/0.00	0.02/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
H	--/ --	0.00/ 0.00	0.00/0.00	0.00/ 0.00	0.00/ 0.00	0.11/ 0.00	0.00/ 0.00	0.00/ 0.00
I	--/ --	0.00/ 0.00	0.00/0.31	0.40/ 0.00	0.02/ 0.00	0.01/ 0.00	0.00/ 0.00	0.00/ 0.00
J	--/ --	0.15/ 0.00	0.00/0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.04/ 0.00
K	--/ --	0.04/ --	0.00/--	0.00/ --	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
Average all zones	0.00/ 0.00	0.08/ 0.15	0.08/0.12	0.10/ 0.00	0.03/ 0.00	0.00/ 0.00	0.01/ 0.00	0.02/ 0.00
				Yellowtail				
A	0.00/ 0.00	0.00/ 0.00	0.00/0.00	0.00/ 0.00	0.00/ 0.00	0.00/ --	0.00/ --	0.00/ 0.00
B	0.00/ 0.00	0.00/ 0.00	0.00/0.00	0.00/ 0.00	0.07/ 0.00	0.00/ 0.00	0.00/ --	0.00/ 0.00
C	0.00/ 0.00	0.03/ 0.04	0.00/0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
D	0.00/ 0.00	0.36/ 0.00	0.00/0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
E	--/ 0.00	0.00/ 0.00	0.00/0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
F	--/ 0.00	0.00/ 0.00	0.00/0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
G	--/ 0.00	0.00/ 0.00	0.00/0.00	0.01/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
H	--/ --	0.00/ 0.00	0.00/0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
I	--/ --	0.55/ 0.64	0.13/0.04	0.34/ 0.07	0.39/ 0.00	0.09/ 0.00	0.00/ 0.00	0.00/ 0.00
J	--/ --	0.63/ 0.10	0.00/0.00	0.16/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
K	--/ --	0.00/ --	0.00/--	0.00/ --	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
Average all zones	0.00/ 0.00	0.19/ 0.06	0.01/0.00	0.06/ 0.00	0.04/ 0.00	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00

made which would provide a precise count of the population size.

From data for 1962 through 1966 the diurnal/nocturnal ratios in tonnage observed and in sightings indicate that the northern anchovy, jack mackerel, Pacific mackerel, and Pacific sardine were observed more frequently and in greater quantities at night. Pacific bonito and yellowtail were observed more frequently and in greater quantities during the day. However, Pacific barracuda were observed in greater quantity at night but more frequently during the day.

Indexes of apparent abundance for day and night observations and variations in total commercial catch (Lyles, 1963, 1964, 1965, 1966; Keilman and Allan, 1969) during the years 1963 through 1969 are shown in Figures 4 through 7. The records for 1962 were incomplete (program initiated in September 1962) and were not considered in the discussion of the index.

In consideration of the day/night ratios, the indexes reflect the following:

Pacific sardine (Figure 4)—The Pacific sardine is observed in greater quantity and more frequently during the night; therefore, the night index should provide a better measure of the sardine's apparent abundance. The night index declined from 0.50 in 1963 to an index of less than 0.00 in 1969. Some positive index values of less than 0.005 will be recorded as 0.00.

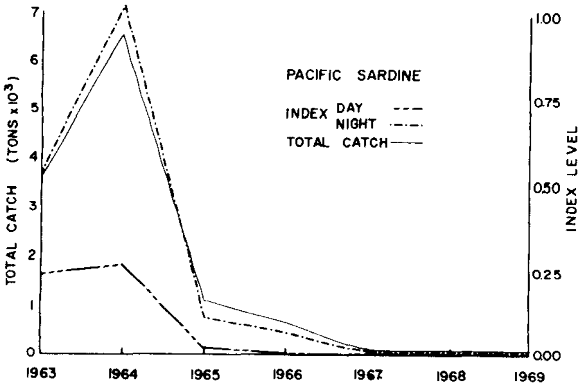

FIGURE 4.—Total catch and average index value for the Pacific sardine.

Pacific mackerel (Figure 5)—Data show that Pacific mackerel are observed in greater frequency and abundance during the night; therefore, the night index should be a better indicator of apparent abundance. The night index declined sharply from 0.91 in 1963 to 0.14 in 1966 and continued the decline to less than 0.00 in 1969.

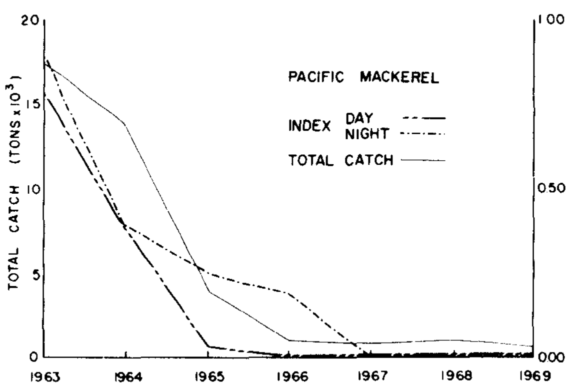

FIGURE 5.—Total catch, average index values for the Pacific mackerel.

Jack mackerel (Figure 6)—Observation of data show that jack mackerel is sighted more frequently and in greater abundance during the night; therefore, the night index should be the best measure of apparent abundance. The night index declined from 2.98 in 1963 to 1.36 in 1965; however, the index level showed an increase in 1968 to 2.25 and a sharp decline in 1969 to 0.65.

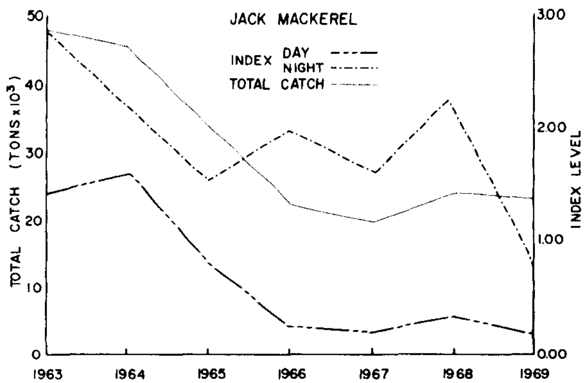

FIGURE 6.—Total catch and average index values for the jack mackerel.

Pacific bonito (Figure 7)—Bonito are observed in greater frequency and abundance during the day; therefore, the day index better represents any changes in apparent abundance. The day index showed only a slight decline during the 1963-1967 period, declining from 1.62 to 1.34. However, since 1967 the index has declined rapidly to a low in 1969 of 0.18.

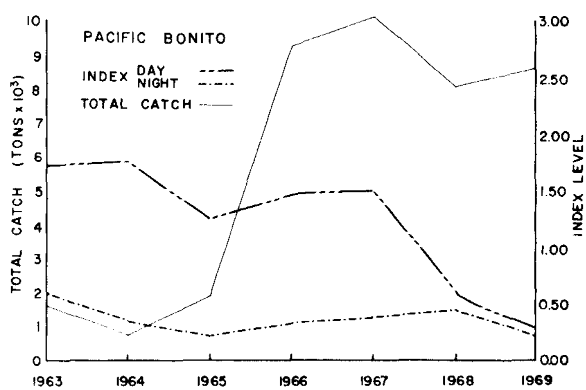

FIGURE 7.—Total catch and average index values for the Pacific bonito.

Northern anchovy (Figure 8)—Data indicate that the northern anchovy is observed more frequently and in abundance during the night; therefore, the night index should better reflect the apparent abundance of this species. The night index increased from 2.99 in 1963 to 4.30 in 1967, declined in 1968 to 1.46, and increased to a high level of 4.35 in 1969.

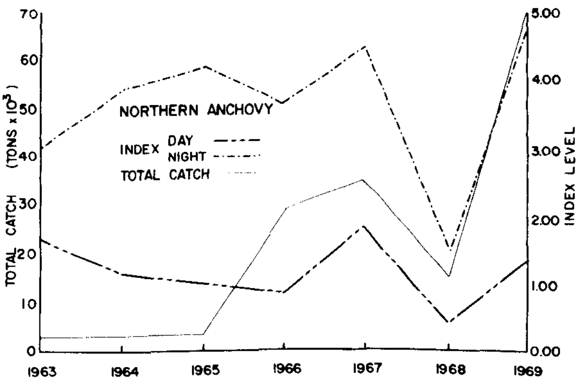

FIGURE 8.—Total catch and average index values for the northern anchovy.

Yellowtail and barracuda—Indexes have declined for both species (see Table 7); however, the frequency of observation was low, and no comparisons can be made with trends in abundance.

The relation between the trend of the apparent abundance index and of the trend of abundance estimates, where available, are discussed for the following species:

Pacific sardine—During the period 1963-1969, the Pacific sardine population continued to decline to a very low level, and the population is now at a fraction of that calculated for the 1930's and 1940's. Since no recent annual estimates are available (latest is 190,000 tons for 1959), a direct comparison of the estimates of total abundance with the index of apparent abundance cannot be made; however, the trend of the index follows closely the downward trend of the commercial catch.

Pacific mackerel—The Pacific mackerel fishery in southern California has been the subject of comprehensive research by the California Department of Fish and Game for many years. For purposes of comparison between trends of the index and population estimates, the more recent data for Pacific mackerel provides the best source of comparative statistics.

The Pacific mackerel catch has declined to a low level in recent years, and the trend of the index follows closely the catch decline (see Figure 5). Population estimates have been calculated by a number of workers. Blunt and Parrish (1969) summarized the knowledge of this fishery and reported estimates of total spawning biomass of 160 million pounds in 1963. Blunt[3] (personal communication) computed revised estimates for California waters using a modification of the Murphy method (Murphy, 1966). Revised figures indicate a spawning biomass of 64.5 thousand tons in 1962 and 78.5 thousand tons in 1963 reducing to less than 5,000 tons in 1968, an 84% or more, decline from 1963. The night index follows this 84% decline in estimated spawning biomass with an 89% index decline from 1.26 in 1963 to 0.14 in 1966 and to less than 0.00 in 1968.

Jack mackerel—Jack mackerel total abundance estimates are derived from egg and larval surveys. Ahlstrom (1968) estimated the adult spawning population in 1951-1954 for the California area to be between 1.4 and 2.4 million tons and that the resource was "much to moderately underutilized." In 1968 he estimated the population level to be approximately the same as was found in the earlier years.

The commercial fishery has experienced a substantial decline in catch over the past years and has extended its fishing grounds further offshore. Ahlstrom (1968) indicated the spawning population is centered in the oceanic waters. Blunt (1969) reported that in this offshore area the population is comprised of mature adults, some reaching the age of 30 years. The young fish remain inshore until 3 to 6 years old and then inhabit the offshore waters where they are outside the range of the normal fishery. The night aerial index shows a decline in apparent abun-

[3] C. E. Blunt, Jr., California Department of Fish ano Game, Marine Resources Brancsh, 1416 Ninth St., Sacramento, CA 95814.

dance of these inshore younger fish, and this decline follows the downward catch trend.

Pacific bonito—The Pacific bonito has been abundant in southern California waters since the advent of the "warm years" of 1957-1958. Its northward latitudinal range into southern California waters is influenced by environmental conditions (Radovich, 1963). Figures on total abundance are not available. However, an index of abundance off southern California was developed from party boat catches by Radovich (1963). It is believed that party boat catches reflect the bonito's general abundance off southern California within certain limits. These limits were not defined and are due to the anglers preference for fishing more desirable species such as barracuda, yellowtail, albacore, etc., when they are available rather than fishing for bonito. Blunt (personal communication; see footnote 3) continued Radovich's study and calculated an index based on catch per angler day for the years 1962 through 1968. Values are as follows: 1962, (1.7), 1963 (1.5), 1964 (2.4), 1965 (1.4), 1966 (0.9), 1967 (0.6), 1968 (1.4). The highest party boat index level was in 1964. The index shows an increase for 1968 and differs from the index of apparent abundance; however, this index has shown an overall decrease since 1964.

The day index of apparent abundance shows an overall decrease from 1963 through 1969. The Pacific bonito is classed as "much underutilized" by Ahlstrom (1968). Due to economic factors and a decline in catches of jack and Pacific mackerel, the catch of bonito increased sharply in 1966 and 1967 with only a slight reduction in catch during 1968 and 1969. In contrast to this increase in catch level, the index of apparent abundance has shown a substantial decrease from 1.26 in 1965 to 0.26 in 1969. A considerable reduction in catch was experienced in 1970 (Lester A. Keilman, personal communication) as the total catch declined to 4,600 tons, about one-half the 1969 catch.

Northern anchovy—Studies by Ahlstrom (1968) estimated a total population of 1.8 to 2.3 million tons in 1958, increasing to 4.5 to 5.6 million tons in 1968. This estimate was based on data from larval counts and shows a population increase of approximately 8.6 times during the period 1951 through 1968. No total population estimates for the successive years 1963 through 1969 are available; however, Ahlstrom does state that the larval counts show that the population is somewhat variable from year to year and that the population reached a plateau in about 1962. Since annual abundance estimates are not available for the years 1963 through 1969, a direct comparison with the aerial spotter index cannot be made. The northern anchovy has increased substantially in abundance during the past decade and is classed as an underutilized species (Ahlstrom, 1968). Since it has been subjected only to minor fishery, except in 1969, it is generally agreed that the population level continued to be at high level throughout the years 1963-1969. The trend of the night aerial index of apparent abundance shows an overall increase during the years 1963 through 1969. The only significant change in apparent abundance was in 1968 when the index declined sharply; however, in 1969 it again increased to a high level.

Wide fluctuations in anchovy relative abundance were noted by Wood (1964, see footnote 2) during aerial surveys from 1956 to 1963. Future observations will determine if this paralleling of catch and apparent abundance will continue. Since the survey area covers an area common to the anchovy, trends in the annual index should be of use in evaluating catch variations and reflect the trend of total abundance in this underutilized resource.

In summary, for the geographical area normally surveyed by the aerial fish spotter, the author believes these data represent a reasonable index of apparent abundance. Like all other measures presently available, the true relation of the index of apparent abundance to total abundance for each species cannot be determined. However, from all data available concerning the Pacific mackerel, a species for which considerable and more reliable data on the adult population are available, the trend of the index follows the downward trend of the total abundance estimate. The index shows little effect from fluctuations in economic demand, as shown in data for the Pacific bonito. Trends in the abundance level of the Pacific bonito within the survey area are evident before they are reflected in catches, and it appears to be a useful index in the evaluation of catch variations and long-term trends in total abundance in underutilized pelagic surface schooling resources.

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The studies of Dr. Oscar E. Sette in the late 1940's must be recognized as one of the earliest applications of scientific aerial fish observations in the continuing search for new methods and techniques for obtaining abundance estimates of pelagic fishery resources.

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