DISTRIBUTION, SEASONAL MOVEMENTS, AND ABUNDANCE OF PACIFIC WHITE-SIDED DOLPHINS IN THE EASTERN NORTH PACIFIC*

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ABSTRACT

All relevant data available through 1979 on Pacific white-sided dolphins, *Lagenorhynchus obliquidens*, in the eastern North Pacific were examined for patterns of distribution, movements, and abundance. In waters east of longitude 180° white-sided dolphins occur from about latitude 20°N to latitude 61°N, on the continental shelf and offshore. They are present in the mouth of the Gulf of California and in inland marine waters of Washington, British Columbia, and Southeast Alaska, but apparently they do not usually enter the Bering Sea or regularly penetrate Prince William Sound. They appear to be continuously distributed across the temperate North Pacific. Seasonal movements cannot be unequivocally demonstrated in any area, although observed peaks in numbers suggest regular seasonal influxes into waters north of latitude 40°N in spring and summer and between latitudes 25°N and 30°N in fall. Evidence for seasonal presence is most convincing off Southern California, between latitudes 30°N and 35°N, where peak numbers occur inshore in November through April. No population estimate is possible with currently available data. On aerial surveys in the well-studied Southern California Bight, Pacific white-sided dolphins were observed to occur at a peak frequency of 1.42 individuals per nm flown; because perpendicular sighting distances were not recorded consistently for these sightings, we are unable to estimate survey strip-width or translate the frequency of individuals sighted into an estimate of density. In a region off Baja California, Pacific white-sided dolphins have been estimated to occur in densities up to 0.06 individuals per nm^2. They appear to be the second or third most abundant delphinid in Southern California waters in winter, after common dolphins and northern right whale dolphins. The Pacific white-sided dolphin may be the most abundant delphinid in the temperate eastern Pacific. The 1300 herds sighted averaged 88 individuals (s=366). Herds were significantly larger in southern

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(<30°N) and northern (>55°N) than in central (30°–55°N) portions of the range (one-way Anova, n=1268, F=3.69, P<0.01).

INTRODUCTION

The Pacific white-sided dolphin, *Lagenorhynchus obliquidens* (Fig. 1), is one of the most widely distributed delphinids in the eastern North Pacific. It has been reported from temperate waters between about latitude 23°N (Leatherwood and Reeves, 1978; Leatherwood, Reeves, Perrin, and Evans, 1982) and latitude 61°N (Scheffer, 1950), from the North American coast to at least the edge of the continental shelf.

Within their eastern North Pacific range, Pacific white-sided dolphins are a highly visible resource, interacting with human activities in various ways. An estimated 80 to 115 individuals have been live-captured for public display or research

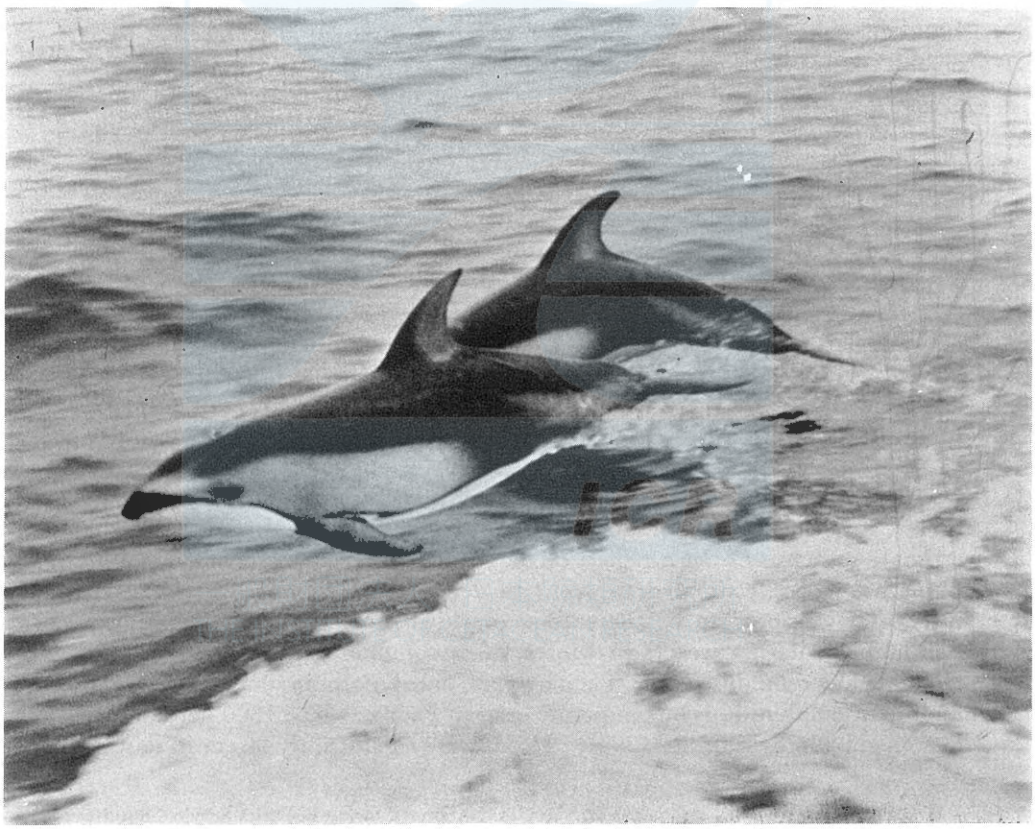

Fig. 1. Pacific white-sided dolphins "porpoising" beside a fishing vessel south of Adak, Alaska. The prominent bicolored dorsal fin, absence of a well demarcated beak, and striking pattern of black, gray, and white markings make these dolphins easy to recognize at sea [Photo courtesy of NMFS, National Marine Mammal Laboratory (NMML)].

since 1966 (Walker, 1975; National Marine Fisheries Service (NMFS), Washington, D. C., 1982, unpublished records; Reeves and Leatherwood, 1984). Small numbers have been taken incidentally in fishing operations for tuna, anchovy, and salmon in subtropical, midtemperate and northern temperate waters, respectively (U.S. Dept. of Commerce, 1981). These dolphins prey on commercially valuable fish and squid (Jones, 1981; Stroud, Fiscus, and Kajimura, 1981).

In 1979, under contract from the Southwest Fisheries Center, NMFS, a study was begun on the population biology and ecology of Pacific white-sided dolphins in the eastern North Pacific. This paper reports on distribution, seasonal movements, and abundance of the species in North Pacific waters east of longitude 180°, as surmised from all data available through 1979. Results of the remainder of the NMFS-sponsored study, addressing morphology, geographic variation, and general biology, will be published elsewhere by Leatherwood, William A. Walker and William F. Perrin.

BACKGROUND AND PREVIOUS LITERATURE

Gill (1865) initially described *L. obliquidens* from two specimens (U.S. National Museum Numbers 1963 and 3886) taken off the California coast. Scammon (1874), referring to those dolphins with which he had become acquainted while whaling in the eastern North Pacific, reported that " this species has a wider range and congregates in larger numbers than any other of the dolphin family." True (1889) gave the Pacific white-sided dolphin's distribution as the North Pacific Ocean, Puget Sound, and the coast of California. Subsequent accounts have added limited regional and seasonal information while restating the more generalized descriptions of range made by these early authors.

In the eastern North Pacific, individuals of *L. obliquidens* have been reported from the southern tip of Baja California (about latitude 23°N) northward along the coasts of California, Oregon, Washington, British Columbia, and Alaska to 61°N (Scheffer, 1950) and westward through the Gulf of Alaska and North Pacific to Amchitka Island (Scheffer and Slipp, 1948; Cowan and Guiguet, 1956; Brown and Norris, 1956; Pike, 1956, 1960; Norris and Prescott, 1961; Brownell, 1964; Fiscus and Niggol, 1965; Walker, 1975; Wahl, 1977; Barham, 1978; Leatherwood and Reeves, 1978; Everitt, Fiscus, and DeLong, 1979; Dohl, Norris, Guess, Bryant, and Honig, 1980; Consiglieri and Braham, 1982).

In the western North Pacific these dolphins have been reported to occur from Taiwan northward along the coasts of Japan and Asia to the Kurile and Commander Islands (Okada and Hanaoka, 1939; Tomilin, 1957; Sleptsov, 1961; Nishiwaki, 1967; Mitchell, 1975). They have not been reported reliably from the Bering Sea (Nishiwaki, 1967; Consiglieri and Braham, 1982).

The statement that *L. obliquidens* " can be seen in the center of the North Pacific including the Hawaiian Islands " (Nishiwaki, 1967) has not been substantiated, although recent sightings at about latitude 40°N, longitude 180° (G. Naftel, Honolulu, Hawaii, personal communication) indicate that they do occur in the

pelagic mid-Pacific at temperate latitudes. Nishiwaki (1967) also claimed that Pacific white-sided dolphins are known from as far south as Panama in the eastern Pacific, but we are not aware of any confirmed records from south of 20°N. Their occurrence in partially enclosed areas, such as Osaka Bay (Kuroda, 1953), Puget Sound (Scheffer and Slipp, 1948), and the Inside Passage along the coast of British Columbia (Pike and MacAskie, 1969) is well documented. They have been reported to penetrate the Gulf of California to as far north as Gorda Bank (23°00′N, 109°30′W) (Leatherwood and Reeves, 1978; Leatherwood *et al.*, 1982). Although a skeleton was collected from Valdez, Alaska, in Prince William Sound (latitude 61°N) in 1901 (Scheffer, 1950), no Pacific white-sided dolphins were seen inside the Sound during recent extensive aerial and ship surveys (Hall, 1979).

Seasonal shifts in distribution have been reported. Pacific white-sided dolphins are said to be more common in coastal waters during fall and winter, moving offshore during spring and summer (Brown and Norris, 1956; Cowan and Guiguet, 1956; Norris and Prescott, 1961; Brownell, 1964; Pike and MacAskie, 1969; Barham, 1978; Leatherwood and Reeves, 1978; Everitt *et al.*, 1979; Dohl *et al.*, 1980). They are thought to occur only in warmer seasons in the northeastern Gulf of Alaska (Consiglieri and Braham, 1982) and to be more numerous in cooler seasons south of Point Conception, California (Leatherwood and Reeves, 1978). It has been suggested that such movements are related to changes in prey distribution (Norris and Prescott, 1961; Brownell, 1964; Barham, 1978) and water temperature (Leatherwood and Reeves, 1978; Dohl *et al.*, 1980).

Since Scheffer's (1950) summary of records along the North American coast, no comprehensive review of the Pacific white-sided dolphin's distribution and movements in the northeastern Pacific has appeared in the literature. The only published estimates of popluation size are Nishiwaki's (1972) statement that there are 30,000 to 50,000 in Japanese waters and Fox's (1977) estimate that about 24,000 inhabit an approximately 1.5 million km^2 area off California and Baja California. Leatherwood and Walker (1979) considered *L. obliquidens* one of the three most abundant delphinids, along with *Delphinus delphis* and *Lissodelphis borealis*, in Southern California waters during midwinter.

In this report we examine information available through 1979, from sightings and collections made north of latitude 15°S and east of longitude 180°, for patterns of distribution, movements, and abundance of the species in the eastern North Pacific.

MATERIALS AND METHODS

Records of sightings of Pacific white-sided dolphins in the eastern North Pacific for the years 1949 through 1979 were available from the literature and various unpublished sources. A complete file containing all the distribution data obtained for this report has been deposited with the Southwest Fisheries Center. Principal contributors are listed in Table 1, and their approximate areas of coverage are shown in Fig. 2. As in three previous efforts of this kind to investigate other

TABLE 1. PRINCIPAL SOURCES OF UNPUBLISHED RECORDS OF SIGHTINGS OF PACIFIC WHITE-SIDED DOLPHINS IN THE EASTERN NORTH PACIFIC (MODIFIED FROM DAHLHEIM, LEATHERWOOD AND PERRIN, 1982). THE NOTATIONS IN THE MIDDLE COLUMN INDICATE WHETHER, FOR PURPOSES OF THIS REPORT, THE LISTED PROGRAM'S SURVEY EFFORT HAS BEEN CHARACTERIZED SUBJECTIVELY (★), QUANTITATIVELY (+) OR NOT AT ALL (○).

Institution/Activity	Principal Area(s) Covered	Effort	Period(s) and Effort	Total No. Used
I. U.S. National Marine Fisheries Service				421
A. Southwest Fisheries Center				
1. Dolphin-tuna observer program and associated research cruises, 1968 through 1973.	Latitudes 35°N to 15°S, coast to approximately longitude 160°W.	★	Heavy effort nearshore Jan—Feb declining and moving seaward March through remainder of year. Some coastward research Qtr. 4.	
2. Dolphin-tuna observer program and associated research cruises, 1974 through 1979.	Latitudes 35°N to 15°S, coast to approximately longitude 160°W.	+	Same as above, but effort data available as number of ship survey hours per 5° square (see Fig. 3).	
3. Albacore observer program and associated research cruises, 1971 through 1979.	Latitudes 25°N to 46°N, within 250 nm of coast.	★	33 vessels, May through September, generally moving south to north through season.	
B. National Marine Mammal Laboratory				410
1. Pelagic fur seal program				
a. 1958 through 1979	Latitudes 32°N to 62°N, east of USA/USSR Convention line in Bering Sea, east of longitude 180° in remainder of Gulf of Alaska and N. Pacific.	○	Sporadic coverage, largely in summer, principally searching for and collecting fur seals. (See various reports of North Pacific Fur Seal Commission; Kajimura *et al.*, 1980; Stroud *et al.*, 1981). Effort characterized but summary unavailable in useable format.	
b. 1960's	Latitudes 21°N to 35°N, within 150 nm offshore and offshore Baja California as far as Islas Revillagigedos.	○	Cruises working north to south in winter and spring, January through April (Fiscus and Niggol, 1965; Rice 1963a, b; 1974). Effort characterized subjectively but summary unavailable in useable format for this report.	
2. Dall porpoise program 1978 and 1979	Southern Bering Sea and northern Pacific Ocean, near Aleutian Islands. Some cruises in Gulf of Alaska.	○	Observers aboard mother ships and research vessels much of summer. Sighting conditions often poor. Effort summaries described by Bouchet (1981) but unavailable in useable format for present report.	
3. Platforms of opportunity	All areas.	○	Coverage opportunistic, no effort data available.	

Continued . . .

TABLE 1. Continued.

Institution/Activity	Principal Area(s) Covered	Effort	Period(s) and Effort	Total No. Used
II. Naval Ocean Systems Center				140
A. Ship surveys 1965 through 1975	Within 150 nm of coast from latitudes 22°N to 35°N including Gulf of California. Some cruises north to Kodiak, Alaska in spring.	○	Effort data not consistently recorded. Cruises conducted all seasons, but principal effort winter and spring.	
B. Aerial surveys 1968 through 1975	Continental Shelf waters (Shore to longitude 121°W) between latitudes 31°30′N and 34°N (Southern California Bight).	+	Total 29,000 nm surveyed, all months. Effort data retained as transect lines by month (see Fig. 4).	
III. University of California				54
A. Scripps Institution of Oceanography—La Jolla	Principally within 100 nm of coast of California and Baja Calif. and in Gulf of California.	○	1950–1979—miscellaneous cruises with no indication of survey effort by area or season.	
B. Coastal Marine Laboratory Santa Cruz				
1. Ship surveys	Continental Shelf waters between latitudes 31°N and 34°N (Southern California Bight).	+	Effort available as total nm surveyed by month.	
2. Aerial surveys	Continental Shelf waters between latitudes 31°N and 34°N (Southern California Bight).	+	Effort available as total nm surveyed by month.	
IV. Smithsonian Institution Pacific Ocean Biological Survey	Latitudes 27°N to 35°N, coast to longitude 120°W.	○	1967–1968—unable to quantify effort by area or season.	47
Additional sources include: The University of Southern California, the Natural History Museum of Los Angeles County, San Diego Museum of Natural History, Marineland of the Pacific, Sea World, and numerous colleagues.				33* 196**

* unpublished. ** published.

small cetaceans of the eastern North Pacific (Leatherwood and Walker, 1979; Leatherwood, Perrin, Kirby, Hubbs, and Dahlheim, 1980; Dahlheim *et al.*, 1982), we pooled all acceptable data to describe overall distribution and to search for trends in distribution and abundance by season and latitude. Many of the sightings represented incidental observations from programs for which no measure of survey effort was available; such records were of limited value. Other incidental records came from programs for which survey effort could be subjectively described, e.g., in terms of general periods and areas of coverage. These records were somewhat more useful. The most important records, however, were those obtained from the following three programs which provided quantitative data on survey effort.

Southwest Fisheries Center (SWFC), NMFS

Scientific observers aboard American tuna vessels and U.S. government re-

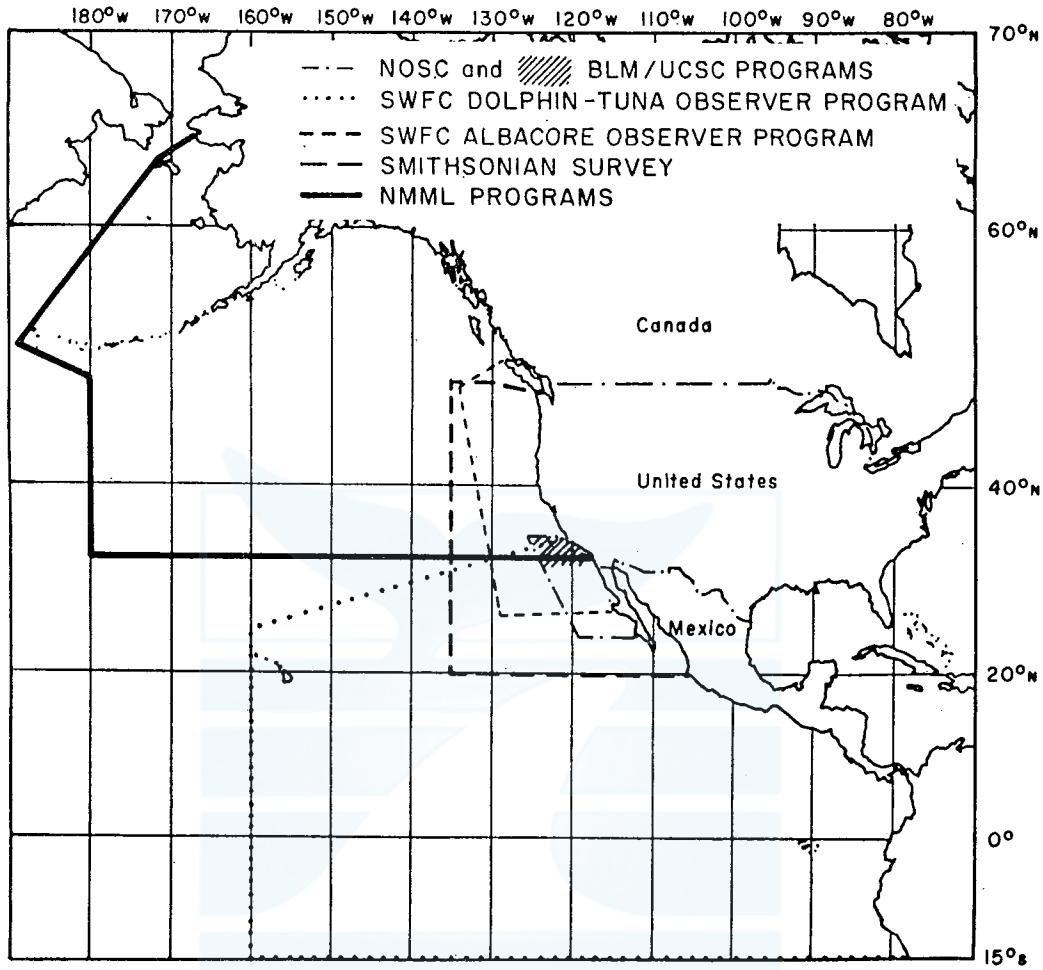

Fig. 2. Approximate areas covered by the principal programs providing sightings of Pacific white-sided dolphins (modified from Leatherwood *et al.*, 1980).

search vessels operating in the eastern tropical Pacific have supplied sightings made in the area from about latitudes 15°S to 35°N, between the shore and about longitude 160°W (Table 1). Sightings from this program were subjected to critical scrutiny using methods explained in detail by Leatherwood (1978). Unverifiable sightings were discarded. Effort (time during which a NMFS marine mammal observer was on watch) was calculated as number of hours of watch within each 5-degree block (Fig. 3). All minutes in a watch series were assigned to the 5-degree block in which the watch series began. Additional information concerning the protocol for data collection in this program is available in the NMFS Observer's Handbook (unpubl. manuscr., SWFC, La Jolla).

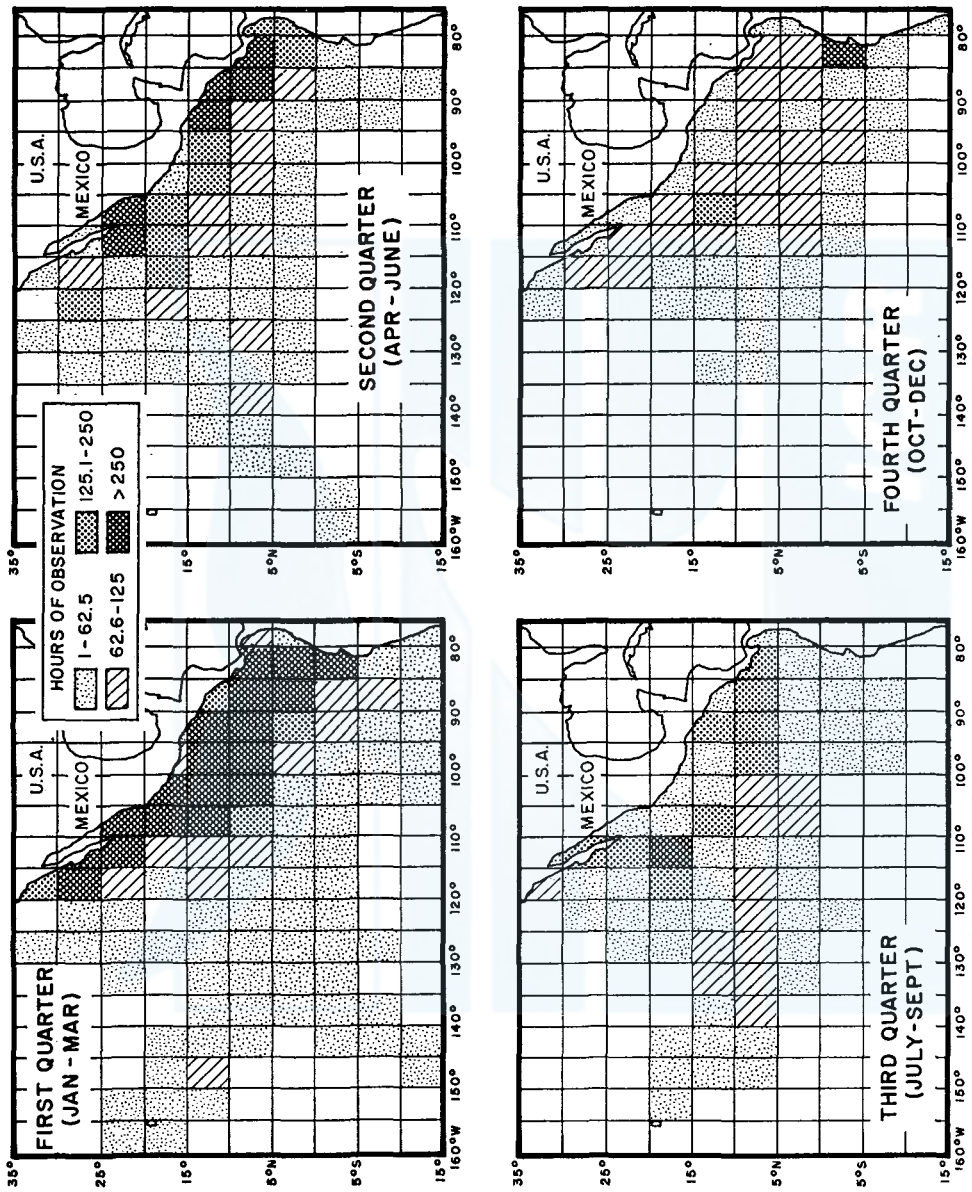

Fig. 3. Ship survey effort by NMFS dolphin-tuna observer program, 1974 to 1979, by quarter.

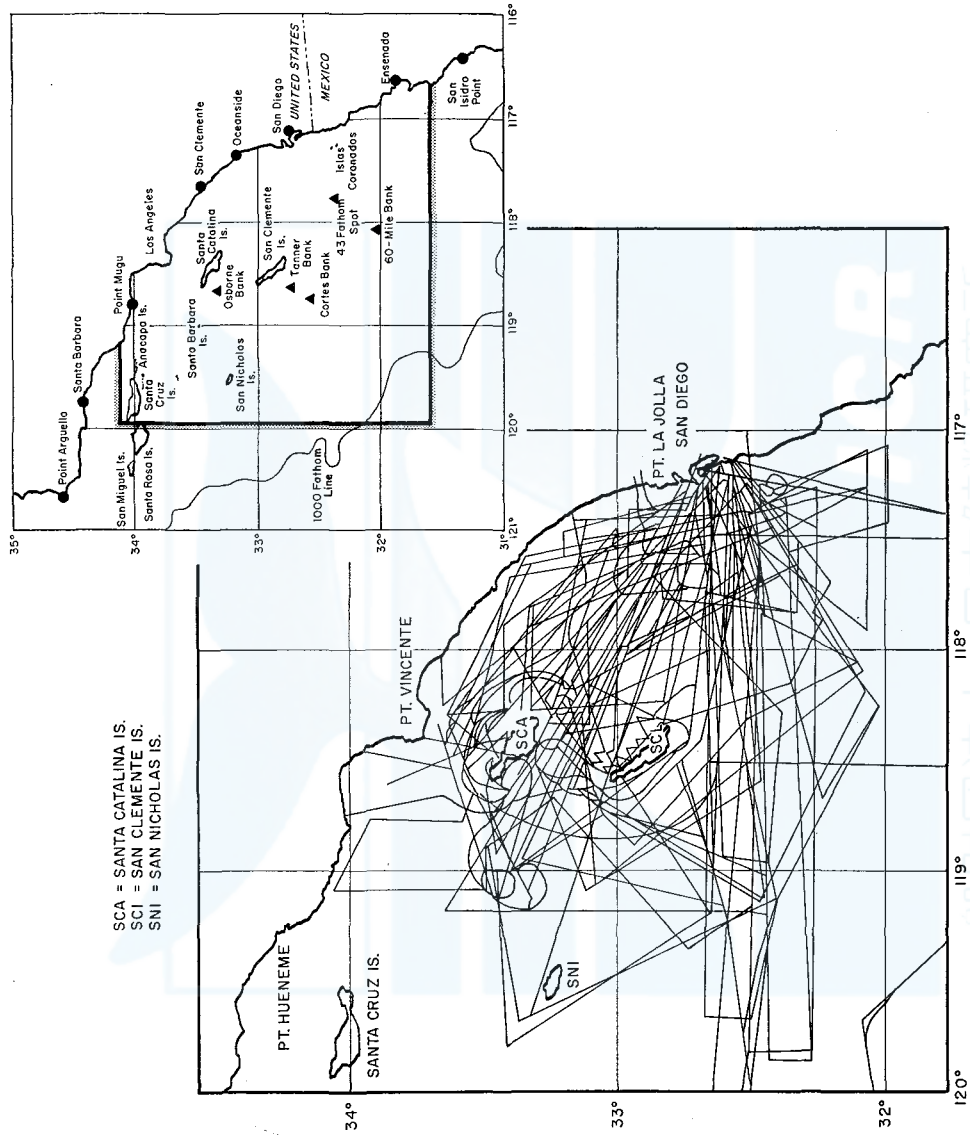

Fig. 4. Area covered by Naval Ocean Systems Center (NOSC) aerial surveys, 1968 through 1976. The lower left figure shows principal transects flown.

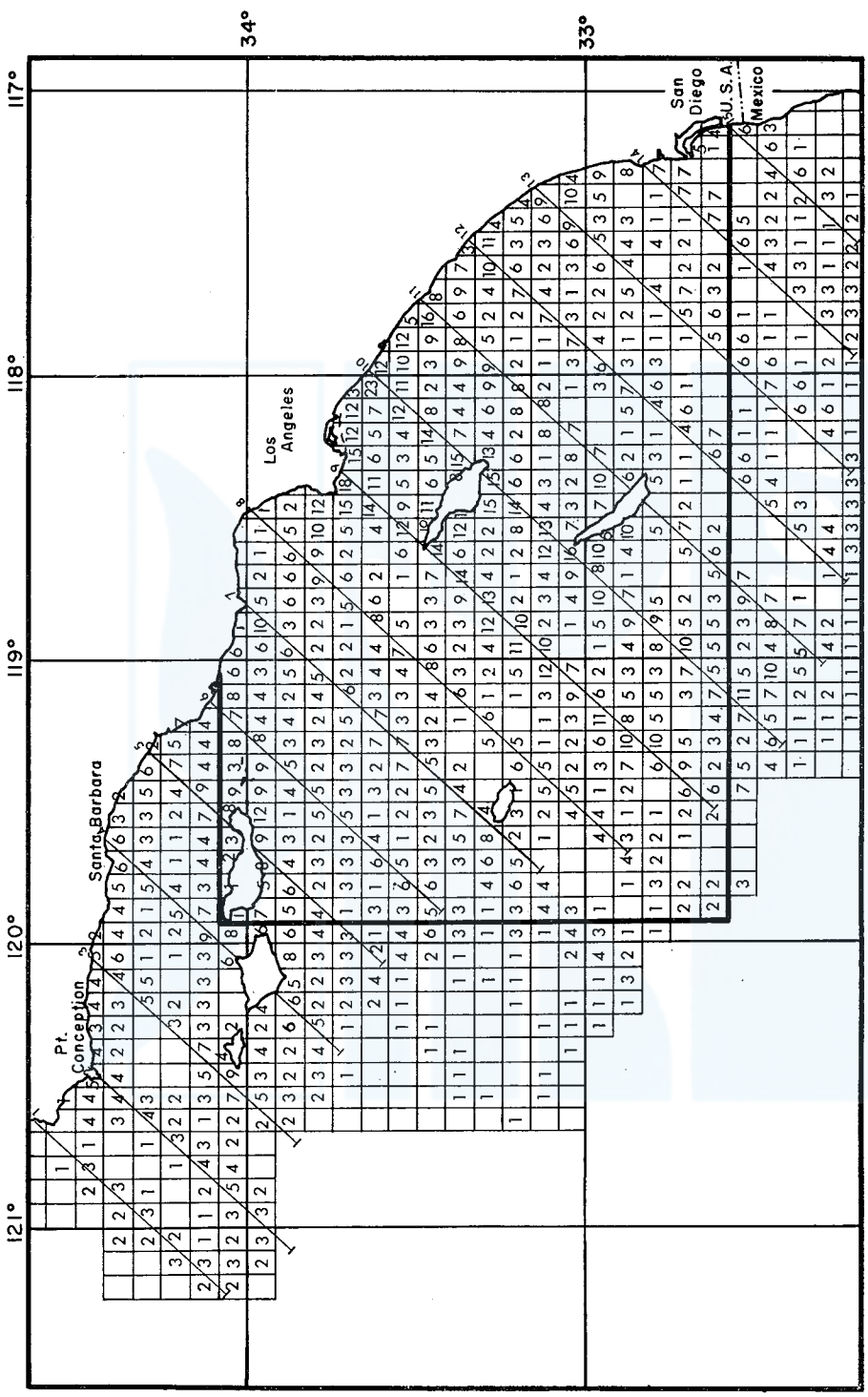

Fig. 5. Aerial survey effort by UCSC, May 1975 through March 1976. Numbers in 5-degree blocks denote number of times that area was surveyed by air during the study period. The blocked area corresponds to the area covered by NOSC aerial surveys, 1968 to 1976 (see Fig. 3). The diagonal lines are the UCSC transects (from Dohl *et al.*, 1980).

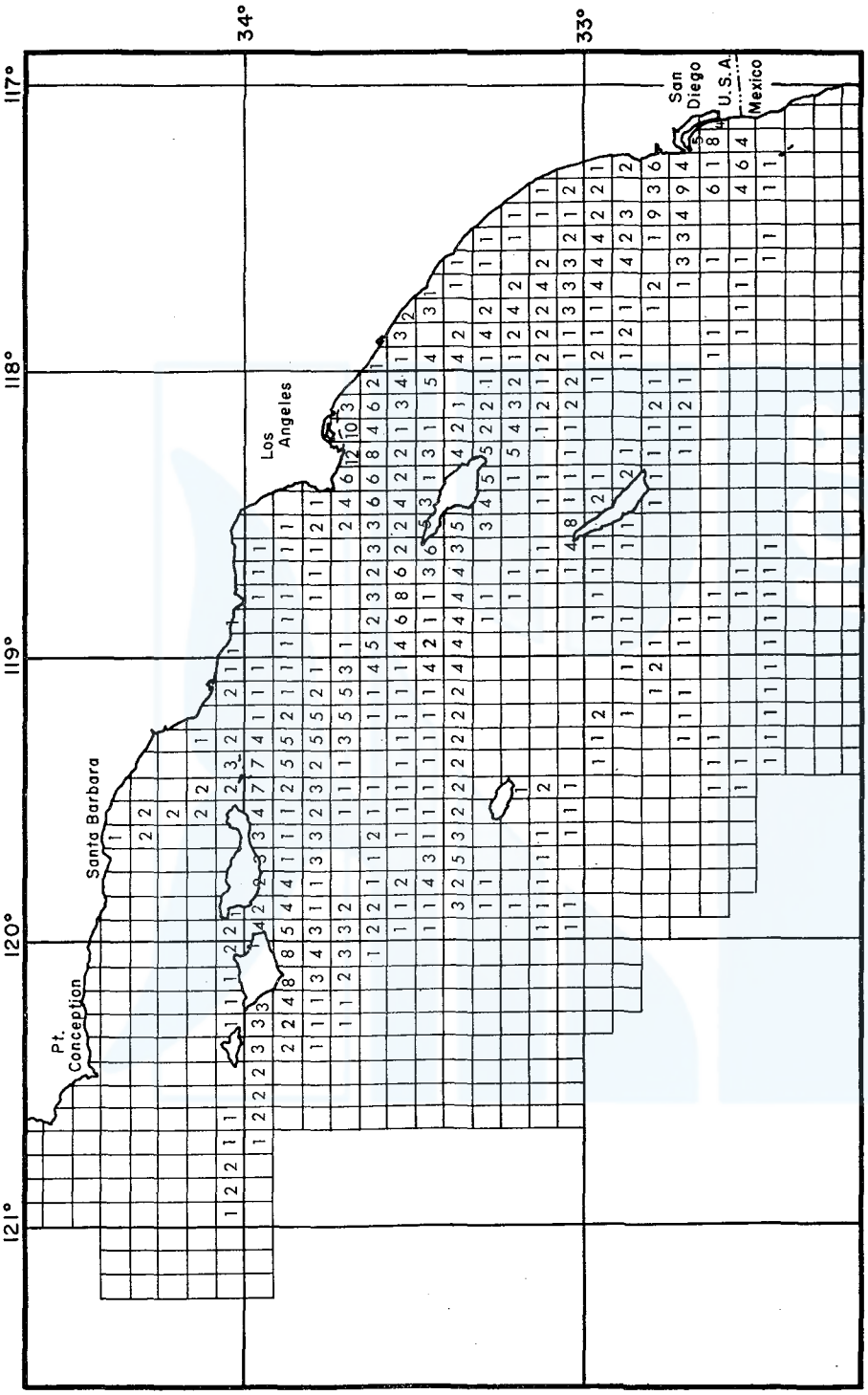

Fig. 6. Ship survey effort by University of California, Santa Cruz (UCSC), April 1975 to March 1976. Numbers in 5-degree blocks denote number of times that area was surveyed by ship during the study period (Dohl *et al.*, 1980).

Naval Ocean Systems Center (NOSC)

Aerial surveys were conducted regularly by the Naval Undersea Center (now NOSC) from January 1968 through April 1976 over the California continental shelf, principally between latitudes 32°N and 34°N (Table 1; Fig. 4). The methods employed in these surveys were described in detail by Leatherwood (1974), Evans (1975), Leatherwood and Walker (1979), and Leatherwood *et al.* (1980). Sightings were critically evaluated using the review procedures of the SWFC system referred to above, and unverifiable sightings were discarded. Effort was given as plots of transect lines (Fig. 4) and estimates of nautical miles (nm) flown.

University of California, Santa Cruz (UCSC)

Shipboard and aerial surveys sponsored by the U.S. Department of the Interior, Bureau of Land Management (BLM), were conducted in the Southern California Bight during 1975 and 1976 by the Coastal Marine Laboratory, University of California, Santa Cruz (Dohl *et al.*, 1980) (Table 1). Transects were designed to provide uniform coverage of the entire study area throughout the year. Methods of quality control on sightings data were not reported. Therefore, because original data entries were unavailable to us for review, we have simply accepted sightings on the assumption that they were subjected to adequate quality control by the program's internal review process. Effort was characterized as the number of times each 5-minute block was surveyed (Figs 5 and 6) and as the number of nautical miles covered (Table 4). Note the substantial overlap in aerial coverage between NOSC and UCSC surveys (Figs 4, 5, 6).

Other Sources

In addition to the unpublished sources of data, we examined scientific publications and extracted sighting records from them. For all these records, we collected, as available, date, location, number of animals, and information source. We assembled a total of 1300 reliable records, 1104 unpublished accounts from various programs and 196 previously published. Except for obvious misidentifications or obscure references with irreconcilable disparities, we assumed published records reflected correct identification. Sightings published twice or more were only entered in the data base once. Each known at-sea collection for which date, location, and number of animals was available was also considered to represent a sighting of a herd. For each map and analysis we used all appropriate sightings. For those sightings in which herd size was recorded as a range (e.g., 45–50 animals), we used the midpoint rounded to the lowest integer (e.g., 47).

Data were grouped by various combinations of quarter, 1- and 5-degree latitude belts, and depth zones (inside or outside the approximately 1,000 fm isobath). Maps, histograms, descriptive statistics, and frequency distributions were prepared, and grouped or paired samples were compared to detect patterns of occurrence (Table 2). For numbers of herds and numbers of animals, we determined sample sizes (N), sum, mean (x), standard deviation (s), standard error (s_x) and range (Table 3).

TABLE 2. THE VARIOUS COMBINATIONS IN WHICH AVAILABLE SIGHTINGS DATA WERE EXAMINED

	Overall			Quarterly					Depth zone by 5° belt and quarter	
				1° belt			5° belt			
No. Herds	M	D	H	M	D	H	D	H	D	H
No. Individuals	M	D	H	M	D	H	D	H	D	H
Herd size	F	D			—		—		—	

M=maps
H=histograms
D=descriptive statistics
F=frequency distribution

TABLE 3. NUMBER OF HERDS, TOTAL NUMBER OF ANIMALS, AND HERD SIZES FOR PACIFIC WHITE-SIDED DOLPHINS, BY QUARTER AND 5° LATITUDE BELT, FROM LATITUDE 20°N TO 60°N

Latitude belt	Quarter	No. Herds	Total no. animals	Mean herd size	St. dev.	St. error	Min. herd size	Max. herd size
20-25	I	23	6,196	269.39	682.28	142.27	1	3,000
20-25	II	7	210	30	44.99	17.00	1	125
20-25	III	3	105	35	35	—	10	75
20-25	IV	4	46	11.50	9.95	4.98	1	20
25-30	I	99	9,096	91.88	466.24	46.86	1	3,500
25-30	II	85	5,544	65.22	250.72	27.19	1	2,000
25-30	III	105	30,665	292.05	936.48	91.39	1	6,000
25-30	IV	55	6,570	119.45	321.03	43.29	1	1,750
30-35	I	87	8,722	100.25	217.41	13.31	1	1,000
30-35	II	49	4,324	88.24	209.02	29.86	1	1,000
30-35	III	38	5,425	142.76	417.03	67.65	1	2,500
30-35	IV	66	3,217	48.67	115.84	14.26	1	750
35-40	I	154	3,565	23.15	59.57	4.80	1	500
35-40	II	119	2,444	20.54	64.20	5.89	1	500
35-40	III	38	851	22.39	49.31	8.00	1	300
35-40	IV	16	996	62.25	125.10	31.28	1	450
40-45	I	8	522	65.25	112.68	39.84	2	300
40-45	II	28	1,731	61.82	160.69	30.37	1	725
40-45	III	56	2,220	39.64	61.58	8.23	1	275
40-45	IV	8	71	8.88	14.67	5.19	2	45
45-50	I	17	184	10.82	10.31	2.50	1	30
45-50	II	47	3,914	83.28	210.74	30.74	1	1,000
45-50	III	39	2,658	68.15	163.68	26.21	1	900
45-50	IV	6	484	80.67	94.09	38.41	2	250
50-55	I	9	535	59.44	43.41	14.47	5	250
50-55	II	8	1,399	174.88	337.83	119.44	3	100
50-55	III	15	204	13.60	15.32	3.96	1	1,000
50-55	IV	11	748	68	107	32.26	1	50
55-60	I	—	—	—	—	—	—	—
55-60	II	12	2,215	184.58	572.17	165.17	2	2,000
55-60	III	15	2,057	137.13	258.15	66.65	1	1,000
55-60	IV	3	529	176.33	280.31	161.84	12	500

For analysis of latitudinal effects, only groupings by 5-degree latitude belt resulted in adequate sample sizes. One-degree belts were retained for mapping. Maps were produced showing number of herds (Figs 7 and 8) and number of animals (Figs 9 and 10), by one-degree blocks for all samples combined. Charts were made on a DEC-PDP 11/34 using the AMPS Mapping Package (Analytical Software, Inc.). Densities for each block on the sighting charts were calculated by summing the number of herds and number of animals sighted in each block each quarter. For example, all the animals sighted from longitudes 117°00′W to 117°59′W and from latitudes 32°00′N to 32°59′N were counted as being in the block 32°N by 117°W.

The following problems with data ruled out the use of significance tests on any of the data sets: (a) sightings were not collected at random; (b) sightings could not be assumed to be independent of one another, because of the animals' tendency to aggregate and variability among observers in defining and scoring groups as

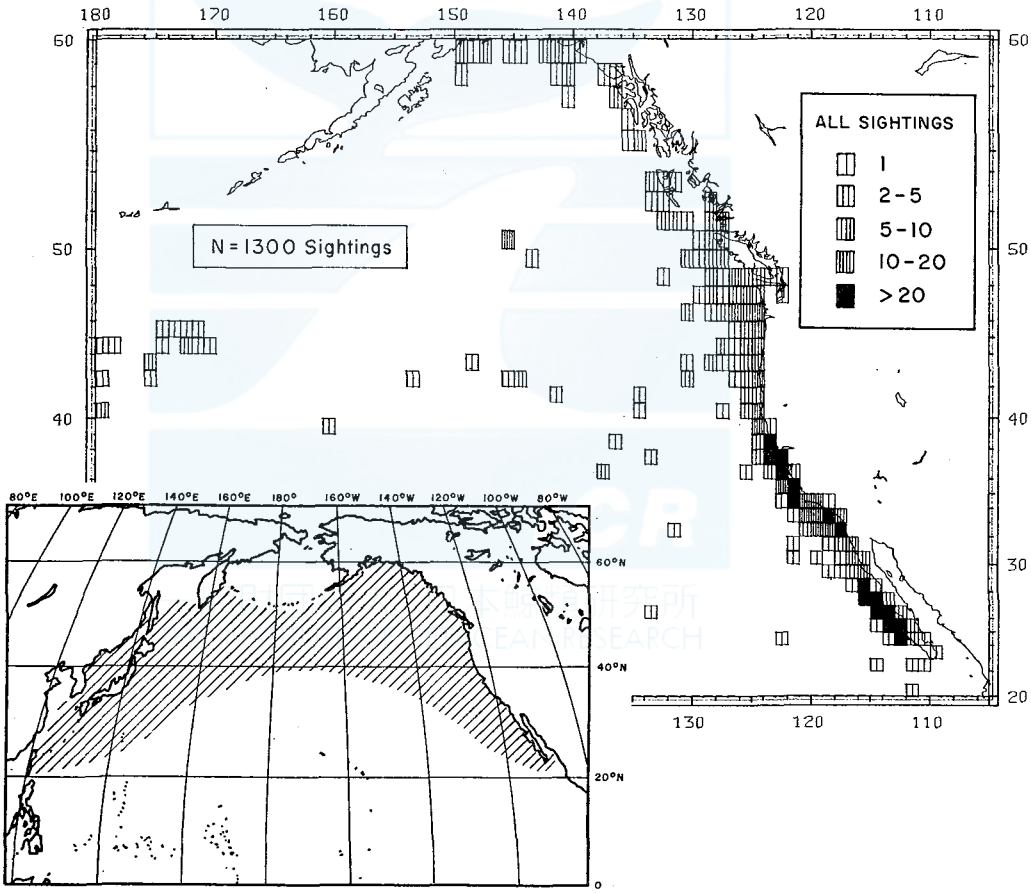

Fig. 7. Number of sightings (herds) of Pacific white-sided dolphins by 1-degree block from all seasons and all sources, 1949 to 1979. The inset illustrates the species' probable range.

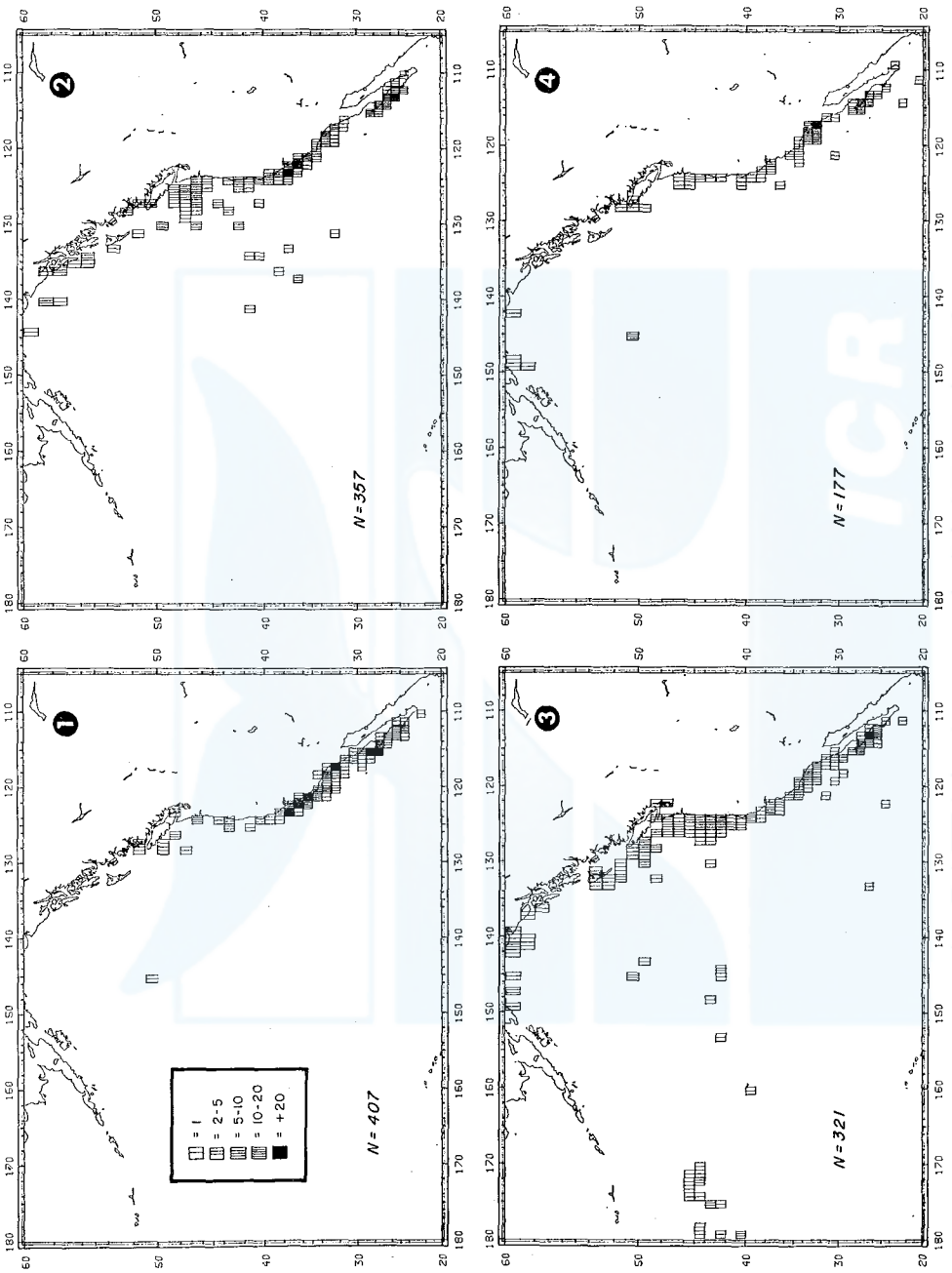

Fig. 8. Number of sightings (herds) of Pacific white-sided dolphins by 1-degree block, by quarter, from all sources, 1949 to 1979.

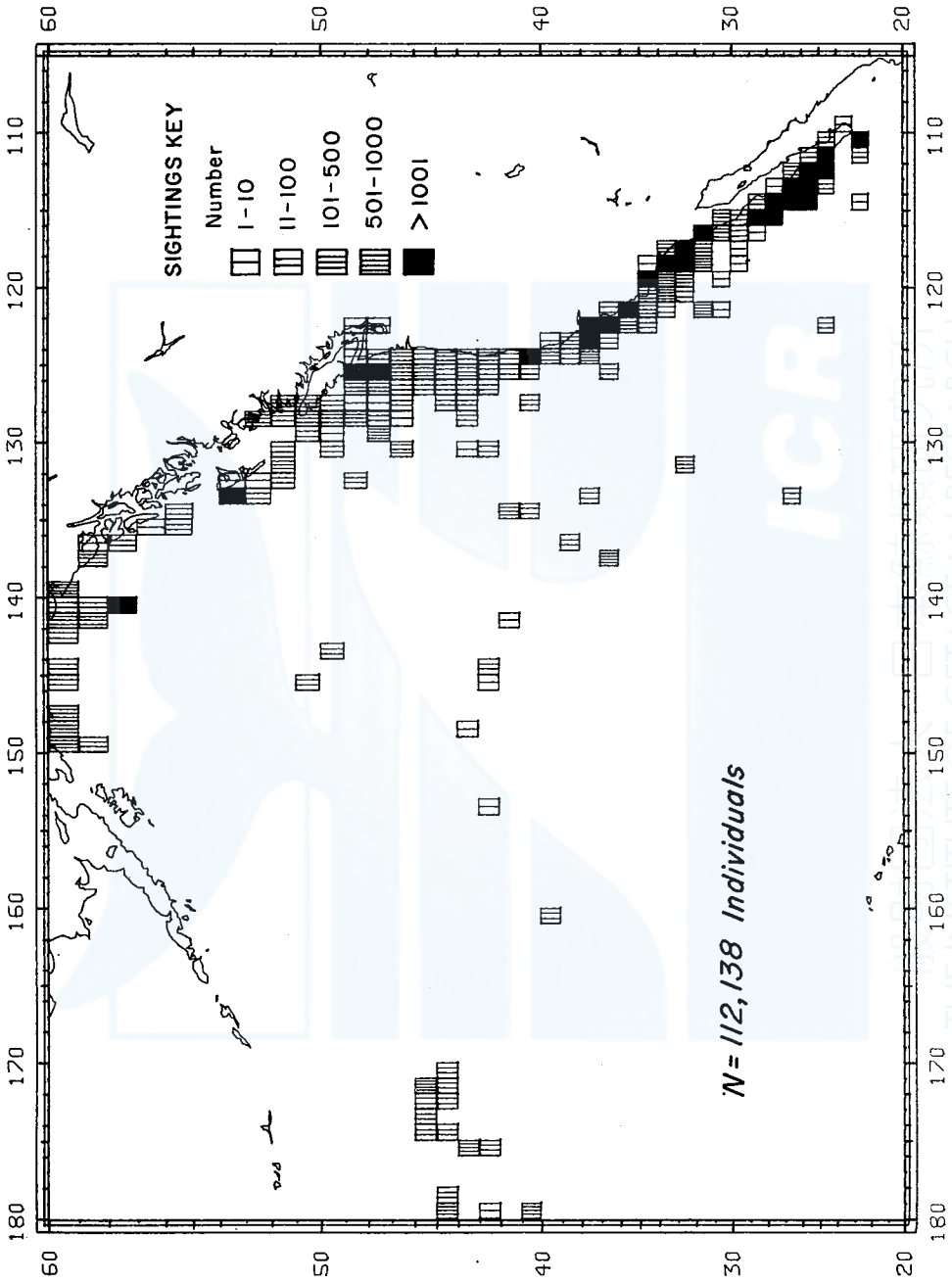

Fig. 9. Total number of Pacific white-sided dolphins observed by 1-degree block, from all sources, 1949 to 1979.

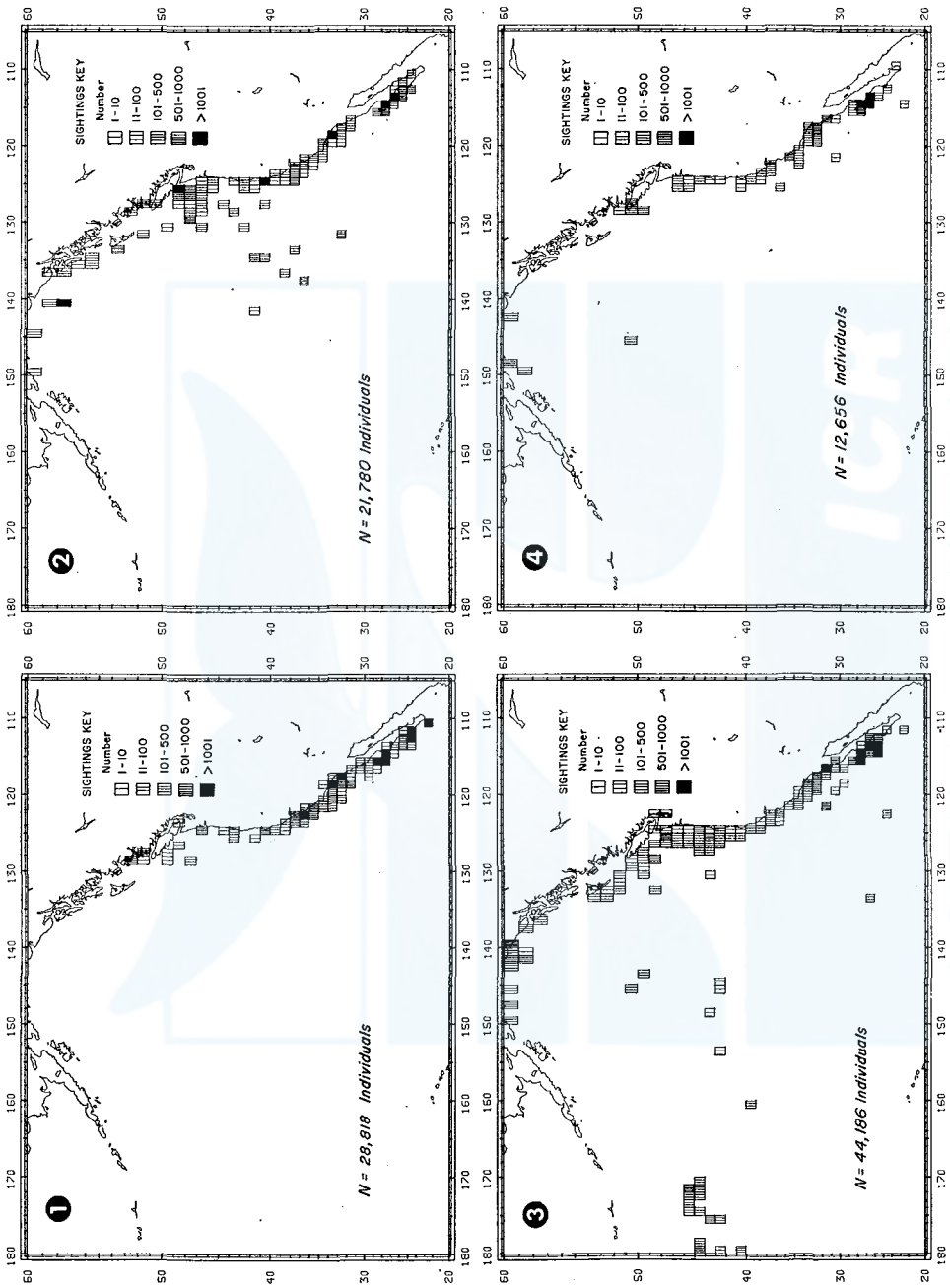

Fig. 10. Total number of Pacific white-sided dolphins observed by 1-degree block, by quarter, from all sources, 1949 to 1979.

separate small herds or "superherds"; and (c) pooled effort was impossible to quantify. We feel that even if statistical significance were demonstrated, it would not be possible to ascribe any biological significance to the results. Therefore, to define patterns for the area overall, we depended solely on direct examination of graphic presentations of the data.

Data from the Southern California Bight were examined in somewhat greater detail. For the NOSC aerial surveys, we calculated number of herds per hundred nautical miles and number of dolphins per nautical mile flown (Table 5, I_1 and I_2,

TABLE 4. SUMMARY OF EFFORT AND SIGHTINGS OF PACIFIC WHITE-SIDED DOLPHINS BETWEEN LATITUDES 32°N AND 35°N AND A CALCULATED INDEX OF DENSITY FROM UCSC AERIAL SURVEYS, MAY 1975–MARCH 1976

Period	Nautical miles flown	Number of animals seen	I_2 Number of dolphins per n.m.
May	954	2,024	2.120
July	2,080	2,540	1.220
August	1,383	70	0.050
September	765	100	0.140
October	1,935	292	0.150
November	2,034	1,892	0.930
December	934	0	0.000
January	3,255	12	0.003
February	2,520	7	0.003
March	1,800	768	0.043

TABLE 5. INDICES OF DENSITY OF PACIFIC WHITE-SIDED DOLPHINS (*L.o.*) IN THE SOUTHERN CALIFORNIA BIGHT (32°N TO 34°N), 1968–1976, FROM NOSC AERIAL SURVEYS. THE TOTAL NUMBER OF HERDS SEEN IS FOLLOWED IN PARENTHESES BY THE NUMBER OF HERDS FOR WHICH ESTIMATES OF NUMBERS WERE AVAILABLE. ALSO SHOWN ARE INDICES OF DENSITY FOR NORTHERN RIGHT WHALE DOLPHINS (*L.b.*) FOR THE SAME AREA (FROM LEATHERWOOD AND WALKER, 1979)

Month	Effort flown in n.m.	Total no. of herds *L.o.*	I_1-Herds per 100 n.m.		Total no. of indiv. *L.o.*	I_2-Dolphins per n.m.
			L.o.	*L.b.*		*L.o.*
January	1,890	16 (15)	0.85	3.30	2,687	1.42
February	2,005	12 (18)	0.60	11.48	1,626	0.81
March	2,645	7	0.26	1.38	766	0.29
April	4,475	23 (15)	0.51	2.04	3,626	0.81
May	2,150	3	0.14	0.39	90	0.04
June	1,390	1	0.07	0	50	0.04
July	2,120	4	0.19	0	268	0.13
August	2,267	1	0.04	0	6	<0.01
September	1,470	3	0.20	0	68	0.05
October	1,795	3 (2)	0.17	0.36	296	0.16
November	550	3 (2)	0.55	0.54	159	0.29
December	2,025	19 (13)	0.94	1.77	2,123	1.05
Totals	24,762	95 (72)	0.384	—	11,766	0.48

respectively). Because herd size was not estimated for each sighting, in calculating the I_2 values we: (a) found that no significant variability in herd sizes among months could be demonstrated and (b) assumed that those for which herd size estimates were available (72) were representative of all 95 herds. Therefore, in estimating number of animals seen per month, each empty cell was filled with the overall

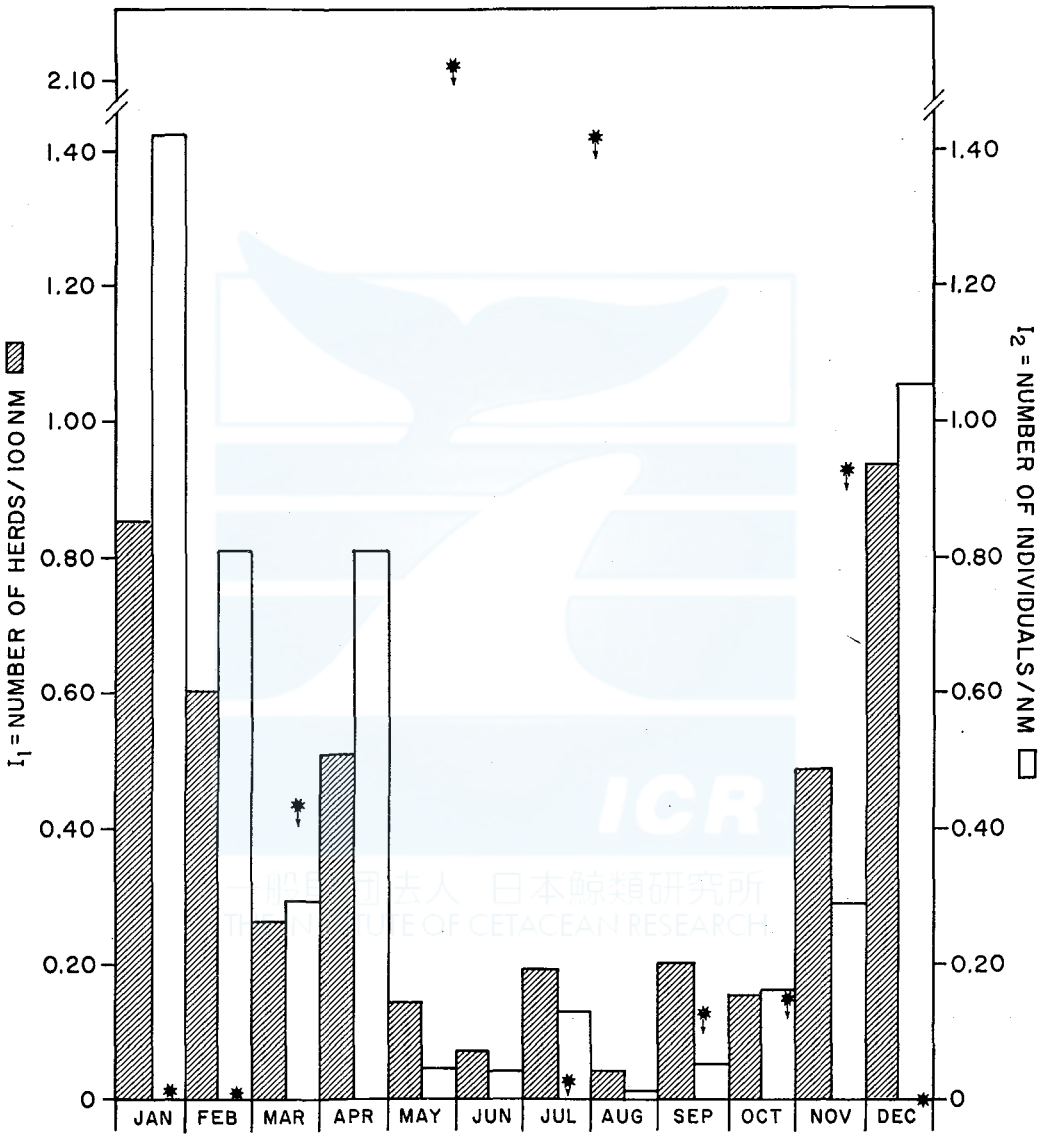

Fig. 11. Indices of abundance of Pacific white-sided dolphins off Southern California 1968 through 1976, based on NOSC aerial surveys. The * indicates I_2 values calculated from Dohl *et al.*, 1980, Table III-93, for aerial surveys of the same area, May 1975 to March 1976.

mean (x=145.7, s=271.2).

For comparison, we converted indices of density for northern right whale dolphins in the same area, reported by Leatherwood and Walker (1979) as the number of herds or animals per square nautical mile, to I_1 and I_2 values and presented those in Table 5. For the UCSC aerial survey data (Dohl *et al.*, 1980), we also calculated monthly I_2 values (Table 4).* Trends indicated by the two programs (NOSC and UCSC) were compared graphically (Fig. 11), but no attempt was made at a rigorous analysis of observed patterns.

RESULTS AND DISCUSSION

Overall Pattern of Distribution

Herds of Pacific white-sided dolphins were seen in all 5-degree latitude belts between latitudes 20°N and 60°N in all quarters of the year, except for latitudes 55°–60°N in quarter I, January-March. The 1,300 herds (112,138 individuals) included in the analysis were widely distributed from the continental shelf throughout the pelagic temperate eastern North Pacific, although records were more abundant within the few coastal 1-degree blocks in each latitude belt (Figs 7 through 10). The apparent coastward concentration as well as the areas of higher density observed north to south along the coast probably reflect levels and centers of observational effort (Fig. 12), with sightings clustered near Seattle, near the Monterey / Santa Cruz area, and within the 35° to 30°N and 30°N to 25°N latitude belts.

The steady decreases in number of sighting records throughout the year, from 407 herds in the first quarter to 177 herds in the fourth quarter, also probably reflect effort. In fact, for all the data combined, there were no detected trends in distribution of herds which could not be explained readily on the basis of the survey effort alone. It is only when records are examined regionally, with emphasis on the three programs permitting quantitative analysis, that any patterns can be discerned which might be considered biologically meaningful.

The probable North Pacific range of white-sided dolphins, inferred from records presented herein and published records from the western North Pacific, is shown in the inset to Fig. 7. Available data suggest a continuous range across the North Pacific. In the area covered by this paper, sightings decrease in the area west of longitude 135°W and south of latitude 45°N, but there has been insufficient observational effort in pelagic areas to confirm the existence of a hiatus between eastern and western North Pacific " populations ".

Distribution North of Latitude 40°N

Sample sizes are small and effort unquantifiable north of latitude 40°N. Sightings do occur there throughout the year, although almost all the more north-

* Estimates of density and indices of density from previous programs are presented in the units reported. Original data were unavailable to us; so, we were unable to translate to common units.

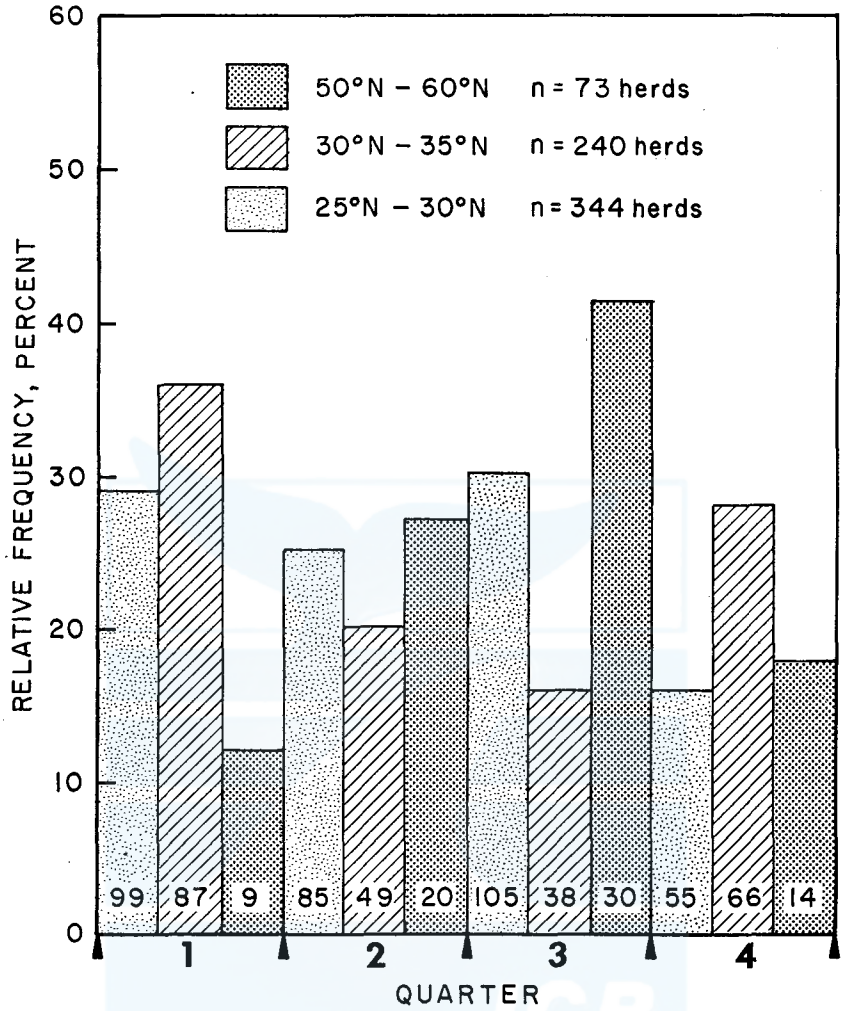

Fig. 12. Relative distribution of sightings by quarter within the three areas of greatest interest. The number of herds comprising each class interval is shown.

ern records refer to quarters II and III (spring through fall), and almost all the sightings for quarters IV and I are in coastal regions. In the Gulf of Alaska, the seasons when Pacific white-sided dolphins are reported most frequently and widely are also the periods of most intensive fishing and research activity. We have no way of determining whether this apparent seasonal pattern in dolphin distribution is real or an artifact of observational effort. Based on opportunistic sightings of 3, 8, 50, and 15 herds in quarters I through IV, respectively, Consiglieri and Braham (1982) concluded that this species, indeed, occurs seasonally in the Gulf of Alaska. They further concluded, based on the same set of sightings, that in southeastern and southern Alaskan waters Pacific white-sided dolphins occur principally on the continental shelf. Further evidence that Pacific white-sided dolphins are present

seasonally off southern Alaska is provided by Hall and Tillman (1977) and Hall (1979), who reported that despite extensive year-round aerial and ship surveys in Prince William Sound and immediately adjacent to its entrances, Pacific white-sided dolphins were observed only once—in October just outside Montague Strait. Currently available data are opportunistic in nature or limited in region, and therefore inconclusive. The question of seasonality of occurrence of Pacific white-sided dolphins in the Gulf of Alaska and North Pacific north of latitude 40°N, particularly in pelagic regions, cannot be resolved without systematic seasonal sampling over a broader area than has been surveyed to date (1982).

From available data, we are unable to verify the reported occurrence of Pacific white-sided dolphins in the Bering Sea (Clark, 1945). The various programs of NMML (see Table 1), the sources of incidental sightings used by Consiglieri and Braham (1982), and 8 one-hundred hour aerial surveys of the eastern Bering Sea conducted between March 1982 and April 1983 (Leatherwood, 1983) likely provided adequate coverage of the waters north of the Aleutians to judge whether these dolphins occur regularly in the Bering Sea. The absence of records is taken to mean that they do not.

Distribution South of Latitude 23°N

Similarly, we regard the evidence that Pacific white-sided dolphins do not occur regularly south of about latitude 23°N to be convincing (see Figs 7 and 9). Coverage of the waters south of Baja California has been extensive in both area and season.

Although observational effort in the NMFS dolphin-tuna program generally decreased from quarter I to quarter IV according to the fishing schedule of the tuna fleet, there was some effort in a broad area south of latitude 30°N year-round (Figs 2 and 3). In addition to the shipboard observations, three extensive aerial surveys of the eastern tropical Pacific tuna grounds have been conducted by NMFS (Smith, 1975; Barham, Evans and Coe, 1975; Barham and Powers, 1977; Powers and Barham, 1977; Holt and Powers, 1982). Therefore, we consider the low number of sightings there—five confirmed south of latitude 23°N, the southernmost at 20°N—to be biologically meaningful. If appreciable numbers of Pacific white-sided dolphins had been present, there undoubtedly would be more records.

Depth Preferences

Northern and southern limits of the species' range are more readily defined than are its inshore-offshore limits. There have been a few sightings in water as shallow as 20 fathoms (Consiglieri and Braham, 1982; NOSC unpublished records; Leatherwood, personal observations) though these appear exceptional excursions into shallow water. Otherwise, these dolphins are encountered widely in continental shelf, continental slope, and offshore zones. Because of uncertainty in position records, we cannot report the maximum depth of water where Pacific white-sided dolphins have been seen. However, the westernmost records in the study area were plotted at locations in which surrounding water for a radius of at

least 100 nm was more than 3000 fms deep.

Little can be said about the relative frequency of occurrence of Pacific white-sided dolphins in waters of different depth. The fact that, overall, most sightings were made inshore of the approximately 1000 fm isobath probably reflects effort patterns rather than an aspect of dolphin distribution.

There does appear, however, to be a tendency for Pacific white-sided dolphins to occur nearer to the coast south of about latitude 30°N. The effort in pelagic waters between latitudes 20°N and 30°N was appreciable and the encounters with Pacific white-sided dolphins few.

Seasonal Trends in Distribution

The only two portions of the study area in which observed distribution patterns are not likely an artifact of sampling effort are the waters off Baja California and in the Southern California Bight. Off Baja California, the effort is tied to fishing and research activities of the tuna fishery, essentially declining steadily throughout the calendar year with a slight increase in the fourth quarter associated with research cruises and early departures from San Diego by fishing vessels bound for the eastern tropical Pacific (Fig. 3). Despite this declining trend in effort, the number of sightings and number of animals per quarter off Baja California did not decline consistently through the calendar year (Figs 8 and 10, Table 6). In fact, for the area between latitudes 25°N and 30°N, the number of sightings and total number of animals observed in the third quarter were substantially greater than the number observed during the previous two quarters (Table 3). This sharp increase in numbers during a period of relatively low sampling effort is of interest. It suggests an influx of animals to this area during late summer and early fall. There is no reason to believe such an influx would consist of animals moving inshore from the west. Rather, judging by published accounts about the seasonal movements of Pacific white-sided dolphins south of Point Conception (e.g. Brown and Norris, 1956; Leatherwood and Reeves, 1978; Leatherwood *et al.*, 1982), it seems most reasonable to us that these are dolphins moving southward from the area off Southern California between latitudes 30°N and 35°N.

The monthly indices of density from the NOSC aerial surveys indicate that Pacific white-sided dolphins are at their peak density and peak number off Southern California from November through April, and are less common from late spring

TABLE 6. DETAILS OF EFFORT AND SIGHTINGS OF PACIFIC WHITE-SIDED DOLPHINS, 25°N AND 30°N, FROM NMFS DOLPHIN-TUNA PROGRAM, 1974 THROUGH 1979. I_1 AND I_2 VALUES ARE NUMBER OF HERDS AND NUMBER OF INDIVIDUALS PER SURVEY HOUR, RESPECTIVELY.

Quarter	Approximate number of survey hours	Number of sightings	I_1	Number of animals	I_2	Mean herd size $\bar{H}$
I	>375	99	<0.27	9,096	<24.26	92
II	565	85	0.15	5,544	9.83	65
III	250	105	0.44	30,665	3,738.66	292
IV	190	55	0.29	6,570	34.58	119

through late fall (Fig. 11, Table 5). This seasonal pattern is consistent with that reported for the area by previous investigators, based on subjective impressions (e.g., Norris and Prescott, 1961; Leatherwood *et al.*, 1972) or on preliminary analysis of the NOSC data (Leatherwood and Reeves, 1978; Leatherwood *et al.*, 1982). It is also very similar to the seasonal pattern reported by Leatherwood and Walker (1979) for the northern right whale dolphin, a sympatric species with which Pacific white-sided dolphins have a strong affinity in coastal waters (Table 5). From these data, Pacific white-sided dolphins appear to reach their lowest densities off Southern California during the periods discussed above, when they are apparently at their highest densities off Baja California. We emphasize that the argument for a relationship between these two phenomena is only circumstantial; there is no direct evidence of a coast-wise migration. The origin of the apparent "immigrants" to Baja California waters in quarter III and the destination of the "emigrants" from Southern California in quarters II and III remain unknown. The peak density off Southern California is 1.42 individuals per nm (Fig. 11); off Baja California it is reported to be 0.06 individuals per nm^2 (Fox, 1977).

The trends indicated by the UCSC aerial surveys are slightly inconsistent with those indicated by the NOSC program; the latter covered a slightly more coastal area. Densities derived from data collected in the 10-month UCSC program fluctuate considerably, with about 1–2 individuals per nm^2 in May, July, and

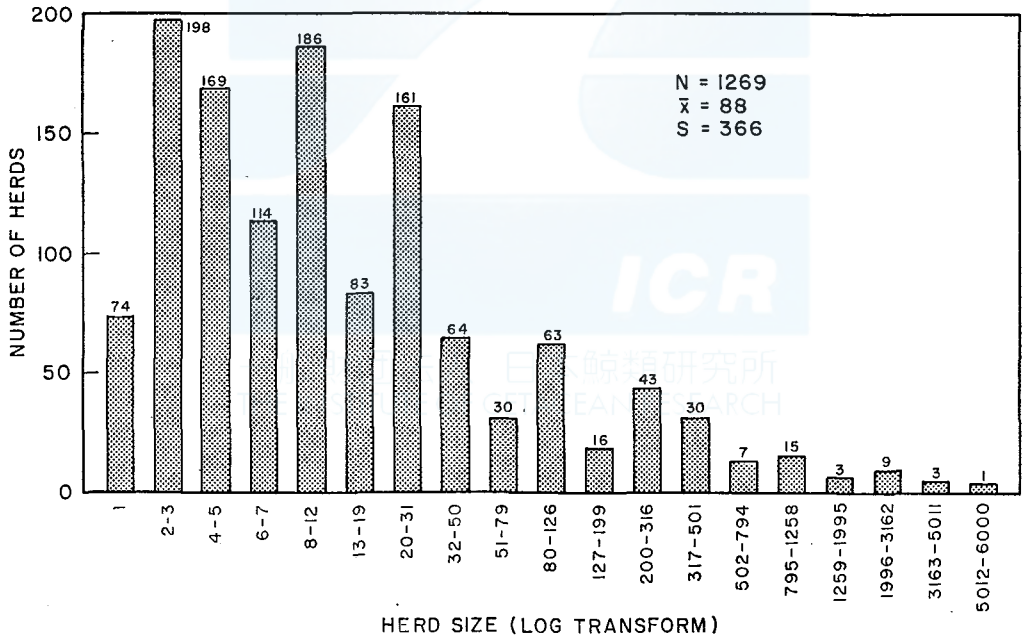

Fig. 13. Log transform of sizes of herds of Pacific white-sided dolphins observed in the eastern North Pacific, 1949 to 1979. Number of herds comprising each class interval is shown. The log transform was performed strictly for presentation. No analysis was conducted on logs of data.

November, and much lower densities in all other months (Table 4). The differences may be due to small sample sizes and the short period of coverage in the UCSC program. However, if they are not, then the results may indicate a shift of the Southern California portion of the population offshore and northwestward in quarters II and III.

Hubbs (1961) described a major transition zone for marine fauna along the outer coast of Baja California at about 24°N latitude, in the vicinity of Magdalena Bay. Au, Perryman and Perrin (1979) noted another water-mass change at the mouth of the Gulf of California, where the fauna tends to change from temperate to tropical. As a temperate-zone species, the Pacific white-sided dolphin probably is influenced by these oceanographic changes. In the areas of most intensive observational effort, between latitudes 20°N and 30°N, it was observed mainly shoreward of the outer margin of the California current (Owen, 1974), suggesting that it is principally an inhabitant of rich upwelling waters.

Trends in Herd Size

The overall distribution of herd sizes is shown in log-transform as Fig. 13.

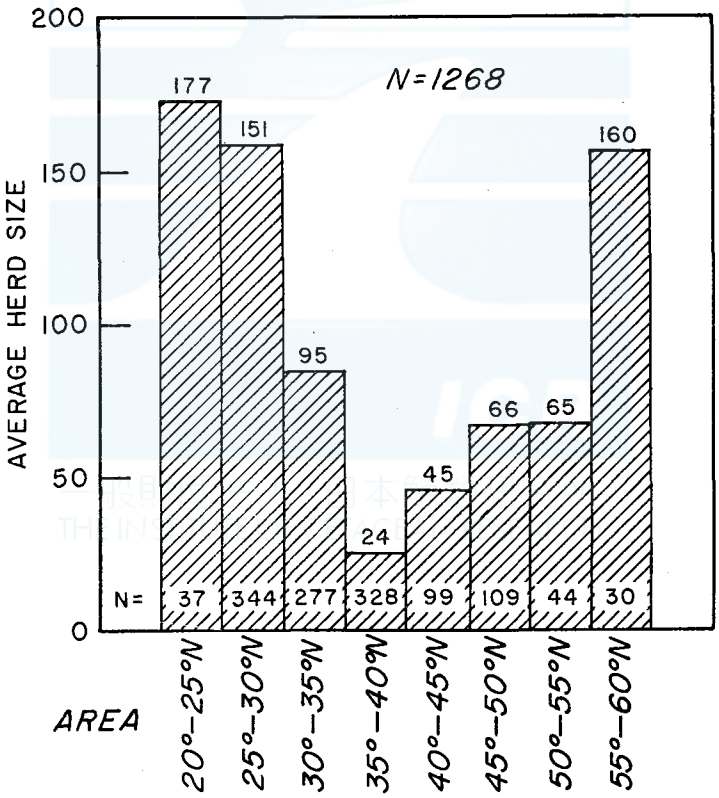

Fig. 14. Mean herd sizes by 5-degree latitude belts, from all sources, 1949 to 1979. Mean values are shown above each class interval. Number of herds comprising each class interval is shown.

The number of animals in the 1,269 sightings for which "group" size estimates were available ranged from 1 to 6,000, about a mean of 88. Above about 20 individuals, the apparent " pulses " in group size are probably spurious, being caused by the tendency of observers to classify estimates into rounded units. Herd sizes varied over the entire geographic range of the sightings (Fig. 14). Those north of latitude 55°N and south of latitude 30°N were significantly larger than those between 30°N and 55°N ($n=1,268$, $F=3.69$, $p<0.01$). In the northernmost area (north of 55°N), where sea-surface conditions are consistently inhospitable to cetacean surveys, it is possible that bad weather and observer bias resulted in a tendency to see and record only large herds. In the other two areas (south of 30°N and between 30°N and 55°N), we assume that observers could detect herds of various sizes and that most participants were able to estimate herd size in a relatively accurate and consistent manner. Therefore, we do not believe the observed differences are artifactual. It is unclear why herds would be larger off Baja California than elsewhere. Perhaps there are inherent differences in herd-size estimation from aircraft (the principal platform used for observations between latitudes 30°N and 35°N) and ships (the platform used almost exclusively south of 30°N).

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