Relative abundance of pelagic resources utilized by the California purse-seine fishery: Results of an airborne monitoring program, 1962–90

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Abstract. – During the period 1962–90, an aerial monitoring program conducted in cooperation with aerial spotters searching for pelagic fishes off California and Baja California, Mexico resulted in the development of an index of apparent abundance for six species of fishes: the northern anchovy *Engraulis mordax*, Pacific sardine *Sardinops sagax*, Pacific bonito *Sarda chiliensis*, Chub mackerel *Scomber japonicus*, jack mackerel *Trachurus symmetricus*, and bluefin tuna *Thunnus thynnus*. Northern anchovy was the dominant species observed, accounting for 89.7% of tonnage recorded during 1962–90. Chub mackerel comprised 6.1% of the total tonnage, jack mackerel 2.1%, Pacific sardine 1.0%, Pacific bonito 0.6%, and bluefin tuna 0.5%.

Apparent abundance indices were computed by dividing the tonnage observed by the number of "block areas" (10' lat. × 10" long.) searched, expressed as tons/block area flown (T/BAF). Indices were calculated for the total area and for the core area of distribution and abundance for each species. All species exhibited large fluctuations in apparent abundance over time. The apparent abundance index for Pacific sardine declined to a very low level during 1966–83. A substantial increase in abundance occurred during the mid- to late-1980s, with the 1990 index value 58 times that observed during the early 1960s. The chub mackerel abundance index declined to a very low level during 1966–76, then increased to a record high value in 1978 and has since declined. The northern anchovy abundance index increased in the early 1970s, with high abundance levels recorded during 1972–81, and then declined sharply to very low levels in the 1980s. The Pacific bonito abundance index was high during 1965–67 and 1983–85, with current levels well below the long-term mean. Very high abundance index levels for jack mackerel were recorded during 1975–79, then declining to very low levels in the 1980s. The bluefin tuna abundance index increased during 1972–80, declining to very low index values since. Based on these data, several species appear to be fluctuating unpredictably with respect to species abundance over time.

Aerial indices were compared with available total, spawning, and larval biomass estimates developed for several species. The most significant correlation of the aerial index was between the northern anchovy and Pacific sardine larval indices.

The rapid decline of the Pacific sardine *Sardinops sagax* fishery in the late 1940s resulted in increased research by the State of California Department of Fish and Game (CDF&G), Federal Government, and other institutions to determine the underlying principles that govern the sardine's behavior, availability to the fishery, and total abundance (Clark & Marr 1955, Sette 1969, Radovich 1982). Catch-per-unit-effort (CPUE) studies of the sardine purse-seine fishery off California did not indicate a significant decline in abundance until just prior to the fishery collapse (Fox 1974). Fisheries tend to target their fishing effort in areas of high densities of fishes (Radovich 1982, Squire & Au 1990), hence CPUE may not accurately reflect resource abundance (de La Mare 1984; J.B. Phillips, CDF&G, pers. commun., 1954). Clark & Marr (1955) concluded that, in addition to other information needs, better information is needed on changes in availability of sardine to the fishery. Related to this is the need for better real-time measures of trends in apparent abundance for successful management of pelagic schooling resources.

In the mid-1950s, the use of aircraft in searching and fishing operations of the California purse-seine fleet had become well established, as was the case in many other U.S. fisheries (Squire 1961). Having had experience in conducting commercial aerial fish spotting and several aerial fish-resource surveys, I initiated a pelagic monitoring program in the fall of 1962, with the cooperation of aerial fish-spotter pilots searching for fish for the commercial purse-seine fishery off central and southern California. The purpose of the program was to develop an effective method of measuring apparent abundance and monitoring changes in abundance. In the case of aerial observations, the concentrations of fish observed may or may not be subjected to fishing.

This paper updates the analysis of apparent abundance data collected by the aerial monitoring program from the first full year of data, 1963–90, using different analytical methods than used in earlier papers (Squire 1972, 1983). It also reviews the trends in apparent abundance during the period 1963–90 for six pelagic species by geographical area and compares the relation of the aerial abundance estimates to other independent biomass estimates made for the same species. The term "apparent abundance" (Marr 1951) refers to that portion of total abundance that is available to the fishery.

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Species included in this study are the northern anchovy *Engraulis mordax*, Pacific sardine *Sardinops sagax*, Pacific bonito *Sarda chiliensis*, chub mackerel *Scomber japonicus*, jack mackerel *Trachurus symmetricus*, and bluefin tuna *Thunnus thynnus*. These species, along with market squid *Loligo opalescens*, are the primary targets of the commercial purse-seine fleet based in San Pedro, California. Most are also fished by the southern California sportfishing fleet. The species are members of a complex interacting coastal and oceanic ecosystem that crosses international boundaries (Sette 1969).

Methods

Procedures for collection and tabulation of data

Since the fall of 1962, fish-spotter pilots have been directed to complete a flight logchart at the termination of each spotting flight. These pilots were instructed to draw their flight track on the chart and record the locations of all schools of fish species observed, along with their best estimates of tonnage observed. These data were recorded either as total tonnage of fish in

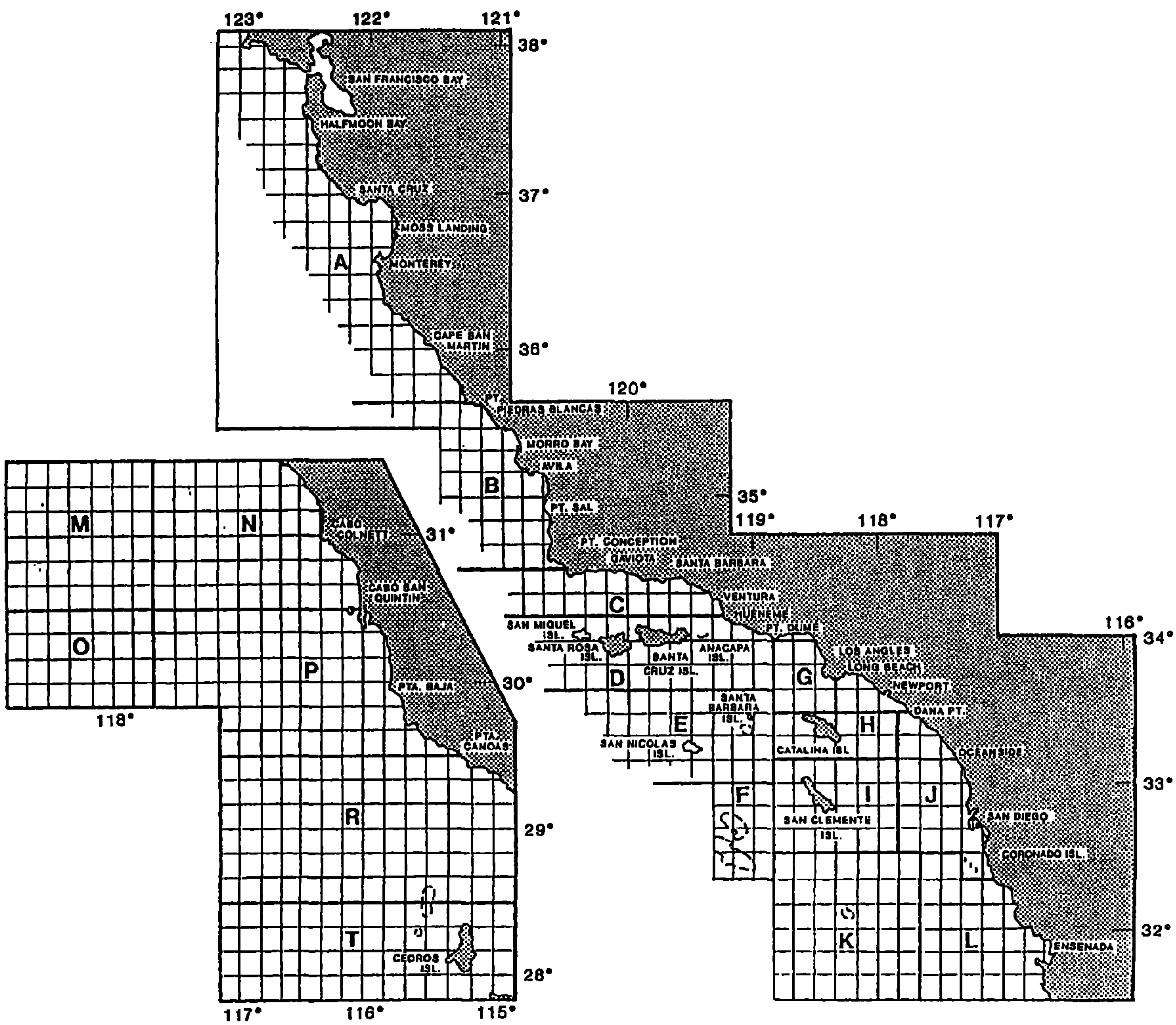

Figure 1

Block areas designated for sampling from off central California to Mexico, grouped in 18 zones, A to T. (Zones Q and S were originally used on flight logs; however, no flights were recorded for these zones.)

the area or numbers of schools with an estimate of the tonnage of each school. Procedures for recording species observations and survey effort have not changed since 1962. Other information such as time of flight (day or night) and flight duration also are recorded on the flight log. Flight logs are submitted quarterly and data from each log are entered into the computer after editing.

Spotter pilots' income is derived from the commercial fishery at a current rate of ~6% of the vessel's gross income. Spotter pilots are paid a nominal fee by the National Marine Fisheries Service (NMFS) to maintain a flight log record of their observations. Pilots in the program averaged ~600h flight time/yr and, with 4–6 pilots, the total number of hours flown was ~3000/yr.

From 1963, the first full year of operation, to 1990, annual indices of abundance for each species were calculated for the total area (from northern Baja California, Mexico to San Francisco, California) and for selected groups of 10" lat. × 10" long. block areas, similar to the "block area" statistical system used by CDF&G (Anon. 1935). These groups of block areas are referred to in this paper as "zones" and were designed to encompass important commercial fishing areas (Fig. 1).

Flight effort for the total area and each zone was determined by counting the number of times the aerial spotter's flight track entered a block area, termed a "block area flight" (BAF). Species abundance was recorded as the tonnage estimate (and hence approximates biomass) for the area observed. Also recorded on the flight log was time of the observation (day or night), pilot, and, since 1988, the target species of the commercial operation.

The procedure to measure effort has not changed from previous studies; however, the computation of species abundance has been modified. In previous analyses (Squire 1972, 1983), abundance was estimated as a rank index according to discrete incremental values of tonnage (tonnage range values). For example, for the northern anchovy, an observation within a block area estimated to be 0–100t was recorded as 1, 100–200t was recorded as 2, etc. Each species had different tonnage range values, since the amount of tonnage observed varied greatly between species. Therefore, the abundance index values for each species are not directly comparable. For this analysis, actual tonnage values as recorded by the spotter pilot and a modification of the index used by Squire (1972) are used, which allows for direct comparison of abundance index values between species.

The apparent abundance index is T/BAF, where T = tonnage estimate, and BAF = total number of block area flights (day plus night, all zones).

Results and discussion

Observation effort and sightings

During the period 1963–90, a total of 24 aerial fish-spotter pilots participated in the program and reported flight operations totaling over 67,000h, searching a total of 376,446 block areas. Table 1 gives the annual search effort (BAF/yr), day and night, during the period 1962–90. From 1963 to 1990, a total of 253,239 BAF were made during day operations (67%) and 123,207 BAF during the night. Pilots have searched an average of 13,444 BAF/yr; however, the variation in annual spotting effort is considerable. There was reduced effort in early 1970. Abundance data for 1970

Table 1
Search effort in block area flights (BAF), day and night, 1963–90, from off Baja California, Mexico to central California. Asterisk indicates <1/2 yr of operation.

Year	Block area flights: Day	Night	Total
1962*	362	512	874
1963	3,541	3,279	6,820
1964	5,245	3,415	8,660
1965	5,086	4,367	9,453
1966	7,708	3,781	11,489
1967	7,632	3,495	11,127
1968	7,823	3,835	11,658
1969	9,745	5,896	15,641
1970	4,646	1,853	6,499
1971	12,308	5,181	17,489
1972	7,402	4,448	11,850
1973	12,450	5,031	17,481
1974	8,356	3,887	12,243
1975	7,923	3,398	11,321
1976	14,782	3,781	18,563
1977	7,795	7,788	15,583
1978	6,517	4,415	10,932
1979	10,727	4,767	15,494
1980	3,624	3,403	7,027
1981	9,237	3,781	13,018
1982	9,597	5,754	15,351
1983	13,904	4,571	18,475
1984	9,144	1,063	10,207
1985	15,243	4,031	19,274
1986	12,300	5,684	17,984
1987	8,474	6,348	14,822
1988	7,185	3,335	10,520
1989	8,744	4,116	12,860
1990	16,101	8,504	24,605
Total 1963–90	253,239 = 67%	123,207 = 33%	376,446

Avg. = 13,444 BAF/yr, 1963–90

Table 2

Sighting estimates of total tonnage by species and percentage and by zones, for the period 1962–90.

Zone	Northern anchovy	Pacific sardine	Pacific bonito	Chub mackerel	Jack mackerel	Bluefin tuna
A	25,147,498	19,157	674	108,345	56,158	0
B	865,308	2,739	4,690	216,873	98,035	0
C	11,633,297	*614,595*	*233,330*	*1,386,548*	104,949	333
D	5,126,158	345,360	86,860	639,099	268,823	1,938
E	467,400	22,454	3,688	203,190	45,937	2,934
F	358,614	50,130	250	701,416	*789,877*	22,773
G	*28,519,793*	99,587	37,176	521,732	361,180	3,154
H	5,292,980	183,500	26,363	1,145,839	222,005	1,785
I	1,578,398	33,165	26,231	1,292,866	256,731	27,938
J	10,453,074	68,243	205,553	130,471	30,855	26,494
K	242,164	1,200	2,045	525	910	79,846
L	1,215,269	0	28,418	1,365	50	86,521
M	500	0	0	0	0	9,603
N	2,495,734	4,200	13,881	24,650	0	*143,625*
O	0	0	0	0	0	0
P	123,305	0	2,313	400	0	64,423
R	1,110	0	0	0	0	8,652
T	0	0	0	0	0	0
	93,520,602	1,444,321	671,472	6,373,169	2,235,510	480,019
%	89.7	1.0	0.6	6.1	2.1	0.5

Table 3

Day/night sighting estimates for northern anchovy, Pacific sardine, Pacific bonito, Pacific mackerel, jack mackerel and bluefin tuna, 1962–90.

	Day	Night
Northern anchovy *Engraulis mordax*		
Tonnage	30,140,974	63,379,618
% day/night	32.3	67.7
Pacific sardine *Sardinops sagax*		
Tonnage	361,548	1,082,498
% day/night	25.1	74.9
Pacific bonito *Sarda chiliensis*		
Tonnage	521,302	151,169
% day/night	77.5	22.5
Pacific mackerel *Scomber japonicus*		
Tonnage	2,534,780	3,837,366
% day/night	39.8	60.2
Jack mackerel *Trachurus symmetricus*		
Tonnage	746,827	1,488,683
% day/night	33.5	66.5
Bluefin tuna *Thunnus thynnus*		
Tonnage	462,262	17,756
% day/night	96.3	3.7

are thus not directly comparable to other years, although most search effort was during a period of high abundance levels. Through the years, the center of search effort was off southern California, with search activity off northwestern Baja California, Mexico during the summer for bluefin tuna. There was considerable search effort north of Point Conception into the Monterey Bay area for chub mackerel and Pacific sardine during the early years of the program and less so since the decline in those species' abundances in the mid-1960s.

Estimates of total tonnage sighted by species by zone are given in Table 2. The tonnage estimated for northern anchovy far exceeds that of all other species, totaling 89.7%. The greatest tonnage of northern anchovy was observed in zone G; Pacific sardine, Pacific bonito, and chub mackerel in zone C; jack mackerel in zone F; and bluefin tuna in zone N.

Most spotting effort was carried out during summer to fall, with 49% of BAFs accounted for during the months of July, August, and September (1980–90). During any one year, the amount of effort expended in any one month was highly variable due to fluctuations in abundance, weather, and fleet operations. In summer months, a substantial portion of the increase in spotting effort is related to searching for bluefin tuna, or other species such as albacore *Thunnus alalunga* and yellowfin tuna *Thunnus albacares*.

Differences in tonnage sighted between day and night (Table 3) are similar to that reported by Squire (1972). Northern anchovy, Pacific sardine, chub mackerel, and jack mackerel were more commonly observed at night, while Pacific bonito and bluefin tuna were more commonly observed during the day.

Table 4
Total area index values in T/BAF, day plus night. Dash indicates an abundance level <0.01 T/BAF.

Year	Total area	Year	Total area
Northern anchovy *Engraulis mordax*			
1962	0.66	1977	713.80
1963	141.38	1978	340.19
1964	80.66	1979	382.83
1965	153.45	1980	322.01
1966	83.26	1981	89.87
1967	163.63	1982	42.78
1968	72.20	1983	4.17
1969	195.82	1984	4.54
1970	608.43	1985	27.24
1971	195.63	1986	7.55
1972	81.05	1987	20.67
1973	745.98	1988	42.90
1974	354.25	1989	16.05
1975	819.93	1990	11.96
1976	293.77		
Pacific sardine *Sardinops sagax*			
1962	—	1977	—
1963	0.77	1978	—
1964	0.90	1979	—
1965	0.04	1980	—
1966	0.02	1981	0.01
1967	—	1982	0.12
1968	—	1983	0.15
1969	—	1984	1.88
1970	—	1985	34.37
1971	—	1986	19.87
1972	—	1987	11.76
1973	—	1988	77.11
1974	—	1989	6.23
1975	—	1990	11.83
1976	—		
Pacific bonito *Sarda chiliensis*			
1962	1.18	1977	0.14
1963	6.28	1978	4.35
1964	2.32	1979	0.31
1965	3.47	1980	0.33
1966	10.16	1981	1.73
1967	5.34	1982	0.38
1968	3.06	1983	0.96
1969	1.50	1984	8.17
1970	0.87	1985	3.22
1971	2.93	1986	0.22
1972	2.28	1987	1.55
1973	2.98	1988	1.55
1974	1.40	1989	0.98
1975	0.48	1990	0.76
1976	0.43		
Pacific mackerel *Scomber japonicus*			
1962	2.74	1977	72.30
1963	6.62	1978	142.26
1964	1.06	1979	63.75
1965	0.41	1980	39.10
1966	0.23	1981	31.59
1967	—	1982	26.71
1968	—	1983	8.89
Pacific mackerel *Scomber japonicus* (continued)			
1969	0.03	1984	72.44
1970	0.83	1985	88.73
1971	0.13	1986	41.77
1972	0.03	1987	17.38
1973	0.18	1988	21.66
1974	—	1989	3.53
1975	0.02	1990	3.18
1976	0.47		
Jack mackerel *Trachurus symmetricus*			
1962	5.04	1977	60.40
1963	13.73	1978	82.54
1964	11.56	1979	19.13
1965	9.97	1980	9.23
1966	2.70	1981	4.42
1967	6.61	1982	6.15
1968	11.41	1983	1.56
1969	3.55	1984	1.82
1970	1.87	1985	1.61
1971	5.91	1986	1.44
1972	6.27	1987	1.01
1973	0.21	1988	0.47
1974	1.88	1989	1.37
1975	5.69	1990	0.23
1976	3.89		
Bluefin tuna *Thunnus thynnus*			
1962	4.40	1977	7.12
1963	6.81	1978	30.07
1964	6.81	1979	12.32
1965	0.90	1980	0.69
1966	9.46	1981	0.80
1967	3.42	1982	0.80
1968	6.03	1983	0.20
1969	0.39	1984	0.66
1970	0.02	1985	2.57
1971	0.42	1986	3.03
1972	2.75	1987	0.55
1973	16.45	1988	0.56
1974	17.28	1989	0.48
1975	2.54	1990	0.35
1976	13.20		

Indices of apparent abundance

Abundance index levels in tons/block area flight (T/BAF) were calculated for the total area by species for day plus night observations for the years 1962–90 (Table 4). From the total area index, the general trend of species abundance can be obtained. However, an index designed to better represent abundance change of each species is needed; therefore, a second set of abundance index values was calculated using only data from a core area of abundance as determined for each species by day or night, depending upon which period best represented the abundance of the species (Squire 1972). With the exception of data from one aerial spotter pilot (computer file 26), all data collected during 1962–90 was used in this analysis.

Data reflecting number of sightings and tonnage observed and its geographical distribution were used to define the geographical limits of the core area for each species. The core area for each species was determined to include all or portions of the following zones: northern anchovy, zones C,D,G,H; Pacific sardine, zones C,D,G,H; Pacific bonito, zones C,D,G,J; chub mackerel, zones C,D,G,H,I; jack mackerel, zones D,F,G,H,I; bluefin tuna, zones I,K,L,N,P (Fig. 1). For each species, the number of block areas in each zone comprising its core area and the total number of block areas in its core area are given in Table 5.

The core-area index is the mean of the T/BAF weighted to account for differences in size of core area within the zone to obtain a stratified mean (Cochran 1966). For each zone, the weight factor was the ratio of the total number of block areas having high species density in the zone to the total number of block areas

Table 5
Areas of high density determining core-area abundance, by species.

Core area determined for	Zone	Block areas
Northern anchovy	Zone G =	10 block areas
Engraulis mordax	D =	11 " "
	C =	10 " "
	H =	6 " "
		37 block areas comprising the anchovy core area
Pacific sardine	Zone C =	6 block areas
Sardinops sagax	D =	5 " "
	G =	5 " "
	H =	4 " "
		20 block areas comprising the Pacific bonito core area
Pacific bonito	Zone C =	6 block areas
Sarda chiliensis	D =	8 " "
	G =	8 " "
	J =	7 " "
		29 block areas comprising the Pacific bonito area
Chub mackerel	Zone G =	6 block areas
Scomber japonicus	H =	3 " "
	I =	3 " "
	D =	5 " "
	C =	4
		21 block areas comprising the Pacific mackerel core area
Jack mackerel	Zone D =	8 block areas
Trachurus symmetricus	G =	7 " "
	H =	3 " "
	I =	3 " "
	F =	4 " "
		25 block areas comprising the jack mackerel core area
Bluefin tuna	Zone I =	20 block areas
Thunnus thynnus	L =	20 " "
	K =	15 " "
	N =	18 " "
	P =	8 " "
		81 block areas comprising the bluefin tuna core area

with high density comprising the entire core area. Core-area abundance (weighted T/BAF) is

$$\sum w_i \, (t/BAF)_i,$$

where W_i – weight for zone i = a/b
a = blocks in core area from zone i
b = total blocks in core area, all zones
$(T/BAF)_i$ = T/BAF for zone i.

Abundance trends by species

Core-area index values in Figs. 2–7 are presented as a weighted mean index and as a running average of three to better illustrate trends in abundance. Core-area abundance index values are given in Table 6.

Table 6

Core-area index values in T/BAF, day or night in T/BAF. Dash indicates an abundance level <0.01 T/BAF.

Year	Core area	Year	Core area
Northern anchovy *Engraulis mordax*			
1962	0.09	1977	858.73
1963	250.98	1978	263.89
1964	160.55	1979	624.80
1965	253.85	1980	578.68
1966	116.92	1981	236.71
1967	225.70	1982	67.86
1968	173.41	1983	7.72
1969	309.84	1984	6.76
1970	629.03	1985	47.88
1971	362.59	1986	13.39
1972	54.55	1987	33.28
1973	1143.55	1988	69.20
1974	494.29	1989	7.24
1975	1010.70	1990	31.45
1976	456.10		
Pacific sardine *Sardinops sagax*			
1962	—	1977	—
1963	1.38	1978	—
1964	1.31	1979	—
1965	0.02	1980	—
1966	0.03	1981	—
1967	225.70	1982	0.24
1968	0.01	1983	0.33
1969	—	1984	2.77
1970	—	1985	97.36
1971	—	1986	32.35
1972	—	1987	20.12
1973	—	1988	145.75
1974	—	1989	34.84
1975	—	1990	39.03
1976	—		
Pacific bonito *Sarda chiliensis*			
1962	2.20	1977	0.23
1963	2.29	1978	0.96
Pacific bonito *Sarda chiliensis* (continued)			
1964	3.39	1979	0.38
1965	5.88	1980	0.38
1966	14.84	1981	1.78
1967	7.20	1982	0.56
1968	3.35	1983	1.31
1969	1.58	1984	9.93
1970	—	1985	3.98
1971	3.47	1986	0.30
1972	2.83	1987	1.05
1973	3.34	1988	2.42
1974	1.76	1989	1.23
1975	0.74	1990	1.15
1976	0.59		
Chub mackerel *Scomber japonicus*			
1962	4.04	1977	104.80
1963	3.36	1978	198.72
1964	1.63	1979	85.27
1965	0.80	1980	58.78
1966	0.51	1981	41.74
1967	0.01	1982	29.24
1968	0.01	1983	19.00
1969	0.07	1984	59.91
1970	2.95	1985	148.18
1971	0.33	1986	85.48
1972	0.10	1987	36.06
1973	0.48	1988	43.55
1974	—	1989	7.83
1975	—	1990	3.19
1976	0.05		
Jack mackerel *Trachurus symmetricus*			
1962	5.28	1977	91.41
1963	23.10	1978	74.90
1964	14.69	1979	20.13
1965	14.58	1980	12.25
1966	4.49	1981	7.77
1967	15.26	1982	10.14
1968	24.21	1983	2.20
1969	5.68	1984	7.47
1970	2.91	1985	6.23
1971	12.55	1986	2.63
1972	11.65	1987	1.69
1973	0.39	1988	1.03
1974	3.41	1989	2.86
1975	13.17	1990	0.81
1976	11.59		
Bluefin tuna *Thunnus thynnus*			
1962	6.57	1977	8.71
1963	6.97	1978	34.52
1964	6.97	1979	12.87
1965	1.28	1980	0.89
1966	13.03	1981	0.95
1967	4.51	1982	1.37
1968	9.45	1983	0.05
1969	0.59	1984	0.62
1970	—	1985	2.32
1971	0.87	1986	1.98
1972	6.94	1987	0.77
1973	17.38	1988	1.23
1974	18.32	1989	1.02
1975	2.60	1990	0.73
1976	13.73		

Northern anchovy (Fig. 2) The core area index (night index) was near 180 T/BAF in the mid- to late-1960s. The index increased in the early 1970s, and during 1972–80 remained in the range of 450–700 T/BAF. The index began to decline in 1980 and reached a low level of abundance by 1983 (<50 T/BAF), a level considerably below that observed in the mid-1960s.

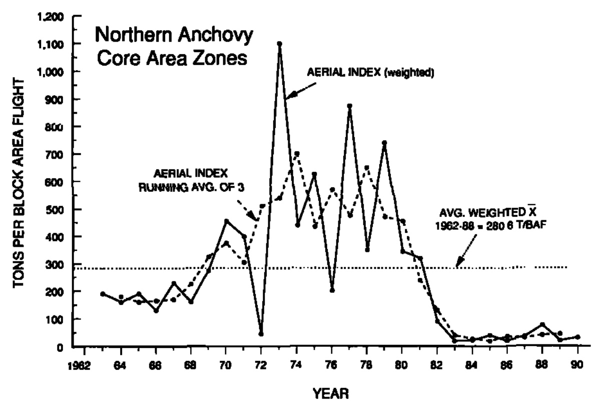

Figure 2
Abundance index levels in T/BAF for northern anchovy *Engraulis mordax* core area, night index, weighted $\bar{x}$, and running average (×3).

Pacific sardine (Fig. 3) The Pacific sardine resource was in a state of decline at the time the aerial spotter program was started. Average tonnage calculated for the 1963–66 period for the core-area index was 1.03 T/BAF. Very low abundance indices were recorded from 1967 until the early 1980s with some years reporting zero sightings of sardine schools. The core-area running mean index (night index) increased to 60 T/BAF by 1988.

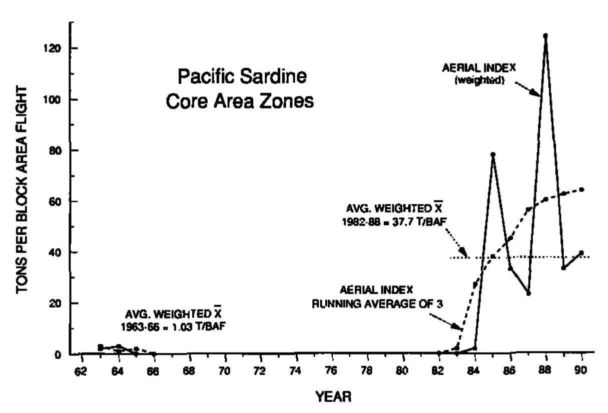

Figure 3
Abundance index levels in T/BAF for Pacific sardine *Sardinops sagax* core area, night index, weighted $\bar{x}$, and running average (×3).

Pacific bonito (Fig. 4) Abundance levels for Pacific bonito show considerable fluctuation. Bonito were rarely taken off southern California prior to the strong El Niño of 1957–58 (Radovich 1960). They were common in southern California waters after this event and were intensively fished starting in about 1963. The increase in fishing effort redirected to this species was the result of decreased abundance of Pacific sardine and chub mackerel.

The core-area index value (day index) reached a high in 1966 of 10.5 T/BAF. This is the highest index value recorded for bonitó during 1962–90. The index then declined, increased slightly in 1972 to 3.2 T/BAF, and substantially increased in 1984 to 5.5 T/BAF.

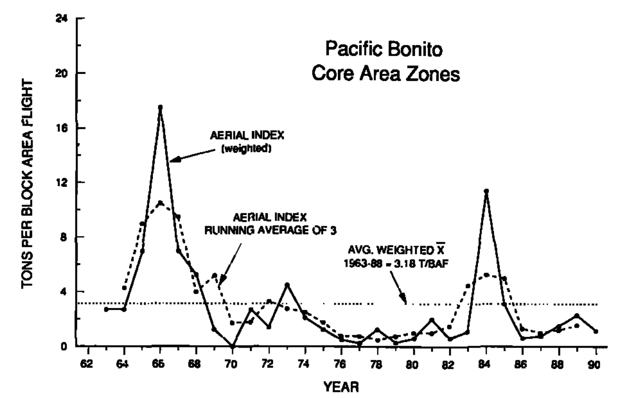

Figure 4
Abundance index levels in T/BAF for Pacific bonito *Sarda chiliensis* core area, day index, weighted $\bar{x}$, and running average (×3).

Chub mackerel (Fig. 5) Declining abundance levels noted in the early to mid-1960s matched the collapse of the fishery, with extremely low index levels (>5 T/BAF) noted for the core-area index (night index) in 1967–75. After 1976, the abundance index rose rapidly to a peak of 170 T/BAF in 1978, then declined to a range of 15–55 T/BAF in 1981–89.

Jack mackerel (Fig. 6) Abundance was high during the mid 1970s. The core-area index (night index) increased to 234 T/BAF in 1976 and declined to <10 T/BAF after 1979.

Bluefin tuna (Fig. 7) For the core area, there were three peaks in the index (day index) of abundance: 1967, 1973, and 1978. The index for recent years is well below the 1963–88 average of 10.8 T/BAF.

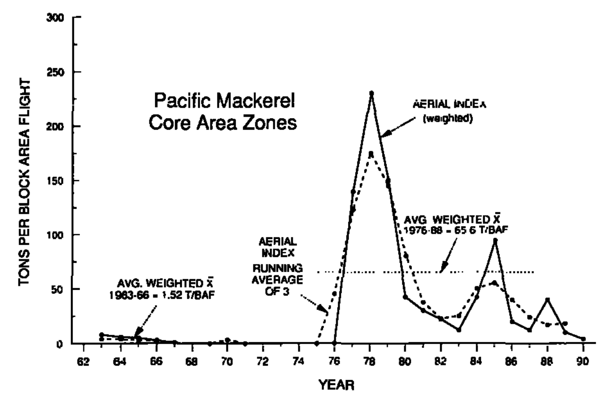

Figure 5

Abundance index levels in T/BAF for chub mackerel *Scomber japonicus* core area, night index, weighted $\bar{x}$, and running average (<3).

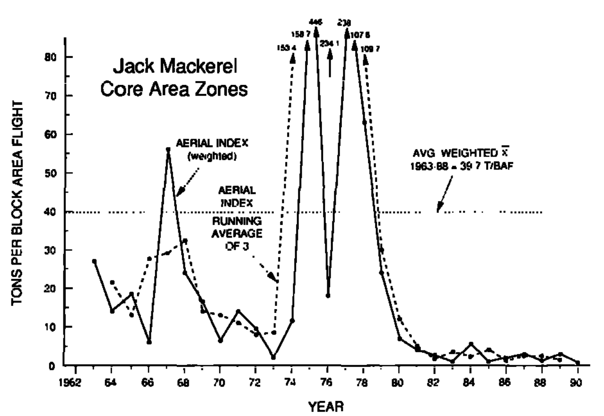

Figure 6

Abundance index levels in T/BAF for jack mackerel *Trachurus symmetricus* core area, night index, weighted $\bar{x}$, and running average (<3).

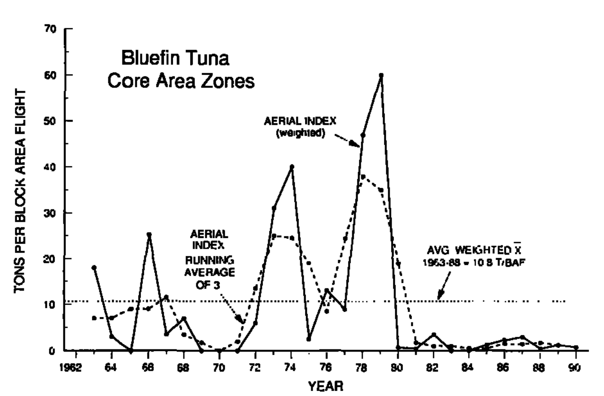

Figure 7

Abundance index levels in T/BAF for bluefish tuna *Thunnus thynnus* core area, night index, weighted $\bar{x}$, and running average (<3).

Interaction between species

To compare periods of high and low abundance of the six species, the logarithm of the moving weighted averages of core-area abundance indices (day or night, dependent upon which time the species was observed more frequently and in greater quantity) were plotted (Fig. 8). The dominant feature of Fig. 8 is the abundance index for the northern anchovy. High index levels of 200–500 T/BAF were recorded during 1962–82, a 21 yr period. The index declined sharply in 1983 and 1984, increasing since. The northern anchovy is the more stable species in terms of less annual percentage change in abundance than any of the other five species. During 1966 and 1967, jack mackerel, bluefin tuna, and Pacific bonito were at higher levels of abundance than those observed in the early 1970s. The Pacific sardine and chub mackerel resources were low in abundance by 1965, and declined to extremely low levels by 1970. The northern anchovy, jack mackerel, chub mackerel, and bluefin tuna increased in abundance in 1974–79. Exceptions were the Pacific bonito and sardine.

The very strong El Niño condition of 1982–83 (Quinn et al. 1987) had a significant effect on the distribution of coastal pelagic species (Fluharty 1984, Squire 1987). This period saw declines in abundance for all species, except Pacific bonito and chub mackerel. These two species showed significant declines in 1986–87. A rapid increase in Pacific sardine abundance was evident in 1984, immediately following the El Niño event and continuing into the late 1980s.

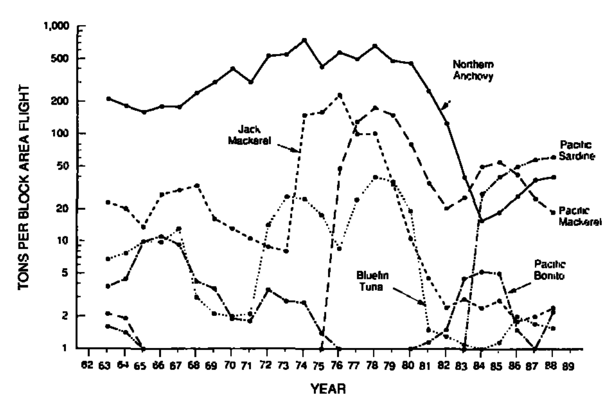

Figure 8

Comparison of core-area fluctuations in apparent abundance index levels for northern anchovy *Engraulis mordax*, Pacific sardine *Sardinops sagax*, chub mackerel *Scomber japonicus*, Pacific bonito *Sarda chiliensis*, jack mackerel *Trachurus symmetricus*, and bluefin tuna *Thunnus thynnus*. Data plotted on a semi-logarithmic scale, in weighted $\bar{x}$, T/BAF, by moving average (<3).

From inspection of core-area fluctuations (Fig. 8), it is difficult to draw any conclusions regarding interaction among most of the species included in this study. The annual abundance values that appear to be more closely related are those of the northern anchovy and bluefin tuna which were significantly correlated (y=0.76, $P<0.1$).

Pilot estimation of tonnage

Differences between pilots' ability to estimate school or group size are difficult to evaluate using the type of data recorded in flight logs. Computer recording of flight track and species tonnage observed did not include details of what portion of the block was searched, or where the species were sighted. Aerial spotters entering the block area (an 8×10 nm area) may have observed fish schools of the same species in two geographically different locations. Only the sum of the school sizes was coded.

The time of observation is probably the most critical factor in comparisons of pilot sightings because near-surface fish abundance may be highly variable over a short period of time. Therefore, unless pilots are searching the same area at the same time, different levels of abundance are likely to be observed.

Williams (1981) in surveys of pelagic fish resources off southeast Australia indicated that the professional fish spotters were extremely accurate in tonnage estimates of individual schools. In tests conducted by NMFS and CDF&G to determine northern anchovy school size using acoustic gear, a purse seiner and aerial spotter were used. The aerial spotter had a more accurate estimate of school tonnage than obtained from acoustic gear (P. Mardesich, Flying Fishermen, Inc., pers. commun. 1978).

MacCall (1975), using the NMFS computer database, investigated variation in anchovy abundance estimates (comparison of data collected during the same 10d period in 1973 and 1975) and found considerable differences among spotters. The differences were consistent for individual pilots for day and night observations. Variability in reported tonnage was large, but it could be reduced by long-term averaging. MacCall (1975) further suggested that corrections for pilots estimating efficiency be incorporated in calculations of the abundance index to avoid biasing the result toward the spotter with the highest tonnage. The accuracy of fish-spotter estimates of tonnage was approached statistically by Lo et al. (In press) using a delta-lognormal model. All aerial spotter data were used in this analysis. However, until spotter-pilot estimating efficiency is measured in field experiments, correction factors are unknown. It is possible that these differences between spotters may be due more to differences in numbers of schools seen than to differences in size estimates.

Comparison of aerial index to other abundance indices

The problem of variability among spotter pilots complicates comparisons; however, pilots are paid relative to the amount of tonnage caught. Therefore, the aerial spotter needs to have a reasonable estimate of school size to compare with the amount of fish caught by the seiner. The aerial spotter is continually obtaining "ground truth" from the purse-seine vessel relative to species composition and size of the school caught.

Since the decline of the Pacific sardine resource in 1984, considerable effort has been expended on surveys, using various techniques to collect apparent abundance data that could be modeled to produce an estimate of biomass. Acoustic, egg and larva, and aerial-spotter surveys have been conducted. Each survey measures a different component of the population and, therefore, comparisons of abundance estimates from different methods and models must be viewed with caution.

The aerial-spotter program measures apparent abundance of adults and subadults of epi-pelagic schooling fishes, and assumes that most adults in the population are available to the spotters at some time during the year. The aerial index is a direct calculation (T/BAF). It is a non-random type survey, but is not time-restricted.

The operational procedures used by aerial spotters affect the results. Although they do work closely with the fleet in locating and sometimes directing the setting of the purse seine, much of their time is spent searching large areas of the ocean for fishable resources. Many times, the aerial spotter will conduct flight operations in a general survey mode for the fleet, but does not work directly with the fleet. Even though aerial monitoring is conducted throughout the year, most observation effort is in the summer and early fall (49% of BAF during July, August, and September) when concentrations of commercial species are more common in the nearshore areas.

Quantitative apparent-abundance data derived from field surveys (egg and larvae, and acoustic) are statistically treated under various biological assumptions to ultimately obtain an estimate of biomass or tonnage: spawning biomass and total biomass in the case of egg and larva surveys (Lo 1985), and schooled biomass in the case of acoustic surveys (Mais 1974). Although some biomass estimates have been made for other species, such as the chub mackerel and Pacific sardine, most biomass studies and modeling for the California region have involved the northern anchovy (Methot 1989).

Over the past 35 yr, studies by fishery biologists have produced a wide range of population estimates for a number of the pelagic species, in particular, the northern anchovy, Pacific sardine, and chub mackerel. The following describes the results of these and others in relation to aerial abundance indices.

Northern anchovy A review of the many abundance estimates for the northern anchovy over the years 1940–66 was given by Messersmith et al. (1969). For the early years of the aerial program, MacCall et al. (1974) compared anchovy biomass estimates from egg and larva surveys with the night aerial index, resulting in a correlation of +0.30 (1962–69). They also compared the aerial night index with the acoustic estimate (1966–72) producing a negative correlation (r=–0.47).

In a review of egg production of the northern anchovy central stock, Lo (1985) presented a correlation between various indices of anchovy spawning biomass. The biomass index from the aerial surveys had a high correlation (r=0.818) with egg production, and there was a similar correlation (r=0.807) between biomass egg production and acoustic surveys.

Correlation plots of normalized data (standard deviates; Snedecor 1959) were used to compare northern anchovy abundance data presented by Lo (1988) with aerial index values. The aerial index (day plus night) for the core area was compared with Lo's (1988) estimate of spawner biomass, determined from a combination of various estimates from the egg production method and the results of the 1969–85 sonar or acoustic surveys (Lo 1988), giving a correlation of r=0.61, df=14, P<0.05%. The aerial index was also compared with the estimate of schooled biomass based on results of acoustic surveys presented by Lo (1988), giving a correlation of r=0.51, df=13, P<0.05%.

MacCall & Prager (1988) presented anchovy larval-abundance indices for 1963–85. These indices, which are a measure of spawning population, were compared with the core-area aerial index for the same set of years. There was statistically significant correlation between the two indices (aerial/larva) (r=0.82, df=13, P<0.1).

Pacific sardine MacCall & Prager (1988) also reviewed the historical trend of sardine larval abundance, 1951–85. A comparison was made between their arithmetic scale of larval abundance (standard index) and the aerial index during the period 1963–85. Indications of a resurgence of the Pacific sardine resource began in 1978, and for the 1963–85 period MacCall & Prager's (1988) estimate of larval abundance correlates well with the aerial index (r=0.98, df=8, P<0.01).

Pacific bonito Pacific bonito, a species whose seasonal abundance off California is more closely associated with environmental conditions (El Niño effects) than the other species (Squire 1987), has not been subjected to detailed assessment. MacCall et al. (1974) used recreational partyboat CPUE data in yearly time-lag periods and compared this with the aerial index. The recreational partyboat fleet generally fishes nearshore and catches younger fish than the offshore commercial purse-seine fleet. The highest correlation (r=0.69) between the recreational fleet CPUE and the aerial index was for a 3 yr lag period (aerial index lags the recreational CPUE). No other independent estimates of Pacific bonito biomass are available for comparison.

Chub mackerel Assessment of the chub mackerel resource has used both standard population-dynamics techniques and methods that utilize egg and larva surveys. For comparison of changes in population over time, Squire (1983) plotted the trend of the aerial index against the spawning biomass index and the larva index of Smith & Richardson (1977). The limited data (1963–67) precluded any long-term comparison; however, all three indices showed a similar decrease. The aerial index was significantly correlated (P<0.05) with both spawning biomass (r=0.99) and the larva index (r=0.94).

The chub mackerel biomass declined to very low levels in the mid-1960s and remained very low until the mid-1970s. A sharp increase in biomass was noted starting in 1976. MacCall & Prager (1988) presented data on chub mackerel larval abundance through 1985. A correlation of the aerial index (core area) with the larva index for 1963–81 was statistically insignificant (r=0.205). A comparison made between the aerial index (core area) and estimated biomass of MacCall et al. (1985) for 1963–84 gave what would appear to be a good fit for the early years, but comparison of later years' estimates was not significant (r=0.26).

Jack mackerel Various indices of abundance for jack mackerel, including the aerial index, show that the resource tends to be highly variable in apparent abundance. Egg and larva surveys have shown the stock to be extremely widespread. Based on tagging data, Knaggs (1973) estimated between 700,000 and 1,500,000 t were available to the fishery in 1973. MacCall et al. (1974) stated that these estimates are in agreement with trends in aerial survey index (Squire

1972). MacCall & Prager (1988) presented graphics on a time-series of abundance indices for jack mackerel larva off southern California. They noted that the index did not correspond well with other larval indices that included samples from central California. An examination of the MacCall & Prager (1988) larva index vs. the aerial index indicated a poor correlation (r=0.16, not significant), particularly for the years 1977–78, a period of marked increase in jack mackerel abundance off southern California.

Bluefin tuna No biomass estimates are available for bluefin tuna in the northeast Pacific, which is part of a Pacific-wide resource. Young year-classes (1–3 yr) are common in the northeast Pacific with some catches of fish up to 6 yr of age (Bayliff 1980). CPUE estimates presented by Calkins (1982) of catch/boat-day (C/BD) for the U.S. purse-seine fishery operating off California and Baja California, Mexico for the years 1963–80 in the area north of 29° N lat. were compared with the aerial core-area mean index. Although both indices (C/BD and T/BAF) show a decline prior to 1980, the correlation was not significant (r=0.033). Calkins (1982) stated that "total catch may be the best indicator of bluefin abundance." Total catch (north of 29° N lat.) as given by Calkins (1982) was compared with the core-area index, and the correlation was again not significant (r=0.147).

Summary and conclusions

The aerial monitoring program has produced information on the trend of apparent abundance for six species of pelagic near-surface schooling species. The program in operation since 1962 utilizes information provided by commercial aerial fish spotters. Spotter pilots operate under strong incentive to estimate tonnage accurately, since their compensation is based on actual tonnage caught. The cost of the program is a small fraction of the cost of other field assessment methods currently used to develop apparent abundance data, such as egg and larva surveys and acoustic surveys.

Data are presented in a relatively simple and understandable index format of tons observed/block area searched (T/BAF). Annual indices (T/BAF) of apparent abundance are calculated for the major species of importance to the commercial purse-seine fleet operating off southern California and northwestern Baja California, Mexico.

All species have shown a fluctuating pattern of apparent abundance over the 29 yr survey period (1962–90). The northern anchovy is the dominant species observed, accounting for 89.7% of all tonnage observed; chub mackerel is second with 6.1%; followed by jack mackerel with 2.1%, and Pacific sardine, Pacific bonito, and bluefin tuna with 2.1%.

From inspection of abundance data, peak periods of higher abundance for four of the six species (chub mackerel, jack mackerel, northern anchovy, and bluefin tuna) occurred in 1977–79. Analysis indicated that species more closely related in abundance over time are the northern anchovy and bluefin tuna, both being at higher levels of abundance during 1972–80. A regression was calculated for 1963–88, giving a significant correlation (r=0.76, P<0.1).

A number of comparisons were made between estimates of biomass (spawning or total biomass) and the aerial abundance indices for the northern anchovy, Pacific sardine, and chub mackerel, and the apparent abundance of bluefin tuna based on CPUE data. There is a significant correlation with the aerial index, the anchovy total biomass estimate, and the historical egg-production index. Also, there was a slightly less but significant correlation with the acoustic survey estimates. The more significant correlations were found in comparing the aerial index with the northern anchovy larva index and the Pacific sardine larva index. For the chub mackerel, a species recognized as having a highly fluctuating record of abundance, the correlations during the early years (1963–66) were very good (aerial index vs. larva index and spawning biomass index); in later years, correlations between the larva index and the estimates of total biomass and the aerial index were not significant. There is a lack of good data relative to the abundance for other species of interest (Pacific bonito, jack mackerel, bluefin tuna) although some comparisons with the aerial data have been made for Pacific bonito, giving a reasonable correlation using a 3 yr lag period. Bluefin tuna C/BD (catch/boat-day) and total catch for the northwest Mexico–southern California fishery were compared with the aerial core index and gave no significant correlation.

Trends of aerial indices indicate that the pelagic resources studied can be described in a state of chaotic fluctuations (Jensen 1987) relative to apparent abundance. The fluctuating record indicates that even short-term predictions of abundance appear not to be feasible. Management must rely on near real-time estimates based on a measurement of a small fraction of the resource, and what is important is the development and use of more than one method or approach in evaluating population status. None of the survey results appear in complete agreement; however, utilizing several approaches to provide "triangles of agreement" (from a method used in navigation) can provide a consensus for management action.

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