A decline in the abundance of harbor porpoise, *Phocoena phocoena*, in nearshore waters off California, 1986–93

Karin A. Forney
Southwest Fisheries Science Center
National Marine Fisheries Service, NOAA
P.O. Box 271, La Jolla, California 92038

Harbor porpoise, *Phocoena phocoena*, have been caught incidentally in set gill nets off the central California coast since at least 1958 (Norris and Prescott, 1961). The annual mortality of harbor porpoise caught in gill nets in this region peaked in the mid-1980's and then gradually declined (Barlow and Forney, 1994) as fishing effort decreased following the implementation of restrictions and area closures in order to protect marine mammals, sea birds, and sport fisheries (Barlow et al., 1994). In 1986, a series of aerial line-transect surveys was initiated jointly by the California Department of Fish and Game and the National Marine Fisheries Service to monitor trends in abundance of the central California harbor porpoise population. Harbor porpoise in this region are managed separately from animals found off northern California and Oregon, because movement of animals along the U.S. West Coast appears limited, and fishery-induced mortality is restricted to central California (Barlow and Hanan, in press). An analysis of covariance model applied to the first five annual surveys (1986–90) failed to detect a significant trend in abundance (Forney et al., 1991); however, simulations revealed that statistical power to detect trends, given the level of variability observed in the time series, was low with only five survey years. A minimum of ten survey years was estimated as necessary to provide sufficient power.

Additional surveys utilizing the same methodology were conducted in 1991 and 1993, completing an eight-year time series. In updating the analysis of trends in central California harbor porpoise abundance for the period 1986–93, I anticipated either that 1) no significant trend would be identified because of low power, or 2) an increase in abundance might be detected because the population was expected to be recovering after the reduction in fishery-induced mortality. However, a declining trend in central California harbor porpoise abundance was identified for the period 1986–93. Because of the surprising nature of this result and because of the management implications, this report presents the updated 1986–93 analysis and includes additional data from the 1989–1993 aerial surveys in northern California for the first time.

Methods

A complete description of both field and analytical methodology can be found in Forney et al. (1991), and only a brief summary of the methods used is provided here.

Field methods

Aerial line-transect surveys were conducted from late summer to early fall (15 August through 15 November) of the years 1986–91, and 1993. In each survey year, a set of 26 transects between Point Conception and the Russian River (Fig. 1A) was replicated as often as weather permitted (generally 4–8 times) to monitor the central California harbor porpoise population. Beginning in 1989, a set of 17 additional transects between the Russian River and the California-Oregon border (Fig. 1B) was surveyed 1–3 times per field season to monitor the northern California population. The transects followed a zigzag pattern designed to survey systematically between the coast and the 92-m (50-fathom) isobath, which is the depth range in which the majority of harbor porpoise are expected to be found in this region (Barlow, 1988). The only deviation from this design occurred outside San Francisco Bay, where the 92-m (50-fathom) contour is located too far offshore for safe operation of the survey aircraft; in this region, the transect lines extended only to the 55-m (30-fathom) contour. Total transect length was 916 km, and under good weather conditions all transects could be surveyed in two days. The survey platform was a high-wing, twin-engine Partenavia P-68 aircraft outfitted with two bubble windows for lateral viewing and with a belly port for downward viewing. The survey team consisted of three observers (situated left, right, and belly) and one data recorder. Line-transect methods were followed with sighting distances calculated from the angle of declination to the sighting (obtained with a hand-held clinometer) and from the aircraft's altitude. Surveys were flown at about 167–185 km/hr (90–100 knots) airspeed and 213 m

Manuscript accepted 8 June 1995.
Fishery Bulletin: 741–748 (1995).

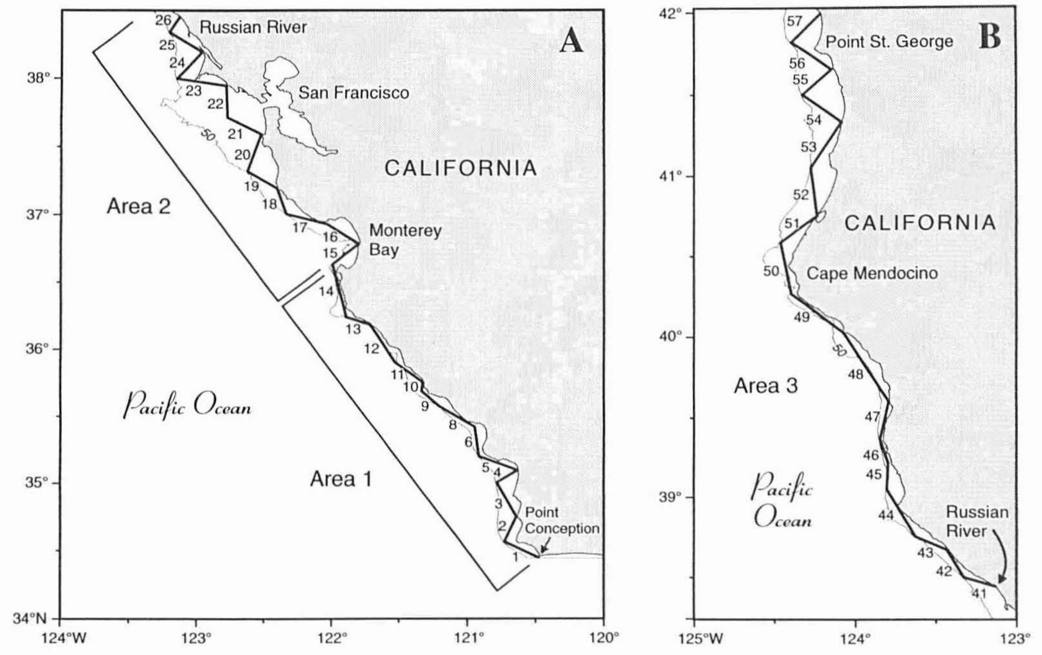

Figure 1

Flight transects and defined areas for aerial surveys for harbor porpoise, *Phocoena phocoena*, in (**A**) central California (transects 1–26; areas 1 and 2) and (**B**) northern California (transects 41–57; area 3). Transect 7 was combined with transect 8 after 1986 and is not shown.

(700 ft) altitude. Flights were conducted only when weather conditions were good (Beaufort sea states 0–3, mostly with clear or partly cloudy skies). Sighting information and environmental conditions were recorded and updated throughout the survey by using a laptop computer connected to the aircraft's LORAN navigation system.

Analytical methods

The number of porpoise observed per kilometer of search effort was used as a measure of relative abundance. These data were stratified by Beaufort sea state (0–1, 2, and 3), area (transects 1–14 and 15–26 in central California, and 41–57 in northern California; see Fig. 1), and percent cloud cover (<25%; ≥25%). After log-transformation, a stepwise selection procedure was used to construct an analysis of covariance model of the form:

$$P = \mu + \alpha_1 + \alpha_2 + \ldots + \delta(y - \bar{y}) + \varepsilon, \tag{1}$$

where P is the log-transformed value of the number of porpoise seen per kilometer + 0.001; μ is the mean value of P; the α's are factors influencing apparent porpoise abundance (such as sea state); δ is the coefficient for the covariate year (y); $\bar{y}$ is the mean year; and ε is a random error term. This additive model for the log-transformed data is equivalent to a multiplicative model for the actual data (stratification variables such as sea state are expected to change the fraction of animals observed, and thus have a multiplicative effect). Variability caused by unequal survey coverage in each combination of sea state, percent cloud cover, and geographic area was included in the model by weighting by the number of kilometers flown. The analysis was done separately for central California alone (transects 1–26) and for both central and northern California (transects 1–26 and 41–57). Previous simulations (Forney et al., 1991) indicated that power would still be low with this eight-year time series; therefore, the critical value for type-I error was set at $\alpha = 0.10$. This was expected to provide a power of approximately 60% to detect a large change in abundance of ±10% per year but would still have low power (approximately 25%) to detect trends on the order of ±5% per year.

Results

A summary of survey coverage (total kilometers surveyed, percent surveyed under good conditions) and

Table 1

Summary of harbor porpoise, *Phocoena phocoena*, aerial survey data collected 1986–1993 in central and northern California. Areas 1, 2, and 3 correspond to transects 1–14, 15–26, and 41–57, respectively (see Fig. 1). "% good conditions" is defined as 100 times the total kilometers surveyed with Beaufort sea states 0–2 and <25% cloud cover, divided by the total number of kilometers flown in all conditions. "—" = no surveys were flown; SD = standard deviation.

Area		Year						
		1986	1987	1988	1989	1990	1991	1993
1	no. of sightings	36	28	15	22	18	12	9
	no. of porpoise	62	47	20	44	29	20	17
	mean group size ± SD	1.72 ± 0.91	1.68 ± 1.79	1.33 ± 0.49	2.00 ± 1.41	1.61 ± 1.04	1.67 ± 0.65	1.89 ± 0.93
	km surveyed	1,767	1,618	1,834	1,653	1,887	1,066	1,941
	% good conditions	56.4%	66.7%	31.3%	32.4%	60.3%	56.5%	68.7%
2	no. of sightings	63	44	88	60	57	43	69
	no. of porpoise	104	76	154	134	126	76	149
	mean group size ± SD	1.65 ± 1.17	1.73 ± 1.11	1.75 ± 1.18	2.23 ± 1.51	2.21 ± 1.47	1.77 ± 1.11	2.24 ± 1.61
	km surveyed	1,282	1,463	2,086	1,607	1,751	669	1,919
	% good conditions	55.9%	34.3%	36.0%	42.1%	32.0%	58.9%	59.9%
3	no. of sightings	—	—	—	44	173	87	143
	no. of porpoise	—	—	—	76	296	166	246
	mean group size ± SD	—	—	—	1.73 ± 1.21	1.71 ± 1.27	1.91 ± 1.02	1.72 ± 1.40
	km surveyed	—	—	—	804	1,084	612	966
	% good conditions	—	—	—	34.1%	67.3%	77.9%	88.0%

sighting information (number of sightings, number of porpoise, and mean group size) is provided in Table 1 for each year and region. Survey coverage was comparable in most years, but owing to poor weather throughout the 1991 field season, only about half of the usual replication was obtained during this year. Differences also occurred in the proportion of survey effort obtained under good sighting conditions, defined as Beaufort sea states 0–2 and as less than 25% cloud cover. Consistent differences in encounter rates, measured as the number of porpoise observed per kilometer surveyed, are apparent between the three defined areas (Fig. 2). Substantially higher encounter rates occurred in northern California than in central California, and the lowest encounter rates occurred south of Monterey Bay, in the southern end of this population's range.

The best model obtained by the stepwise selection procedure for central California data included area, Beaufort sea state, and cloud cover as categorical variables, and year as the covariate (Table 2). All four factors were significant at $\alpha = 0.10$, with probabilities ranging from 0.0001 to 0.0798 (Table 3). With the exception of the inclusion of the covariate year in the model, these results are qualitatively the same as those for the analysis of the first five years of data (Forney et al., 1991).

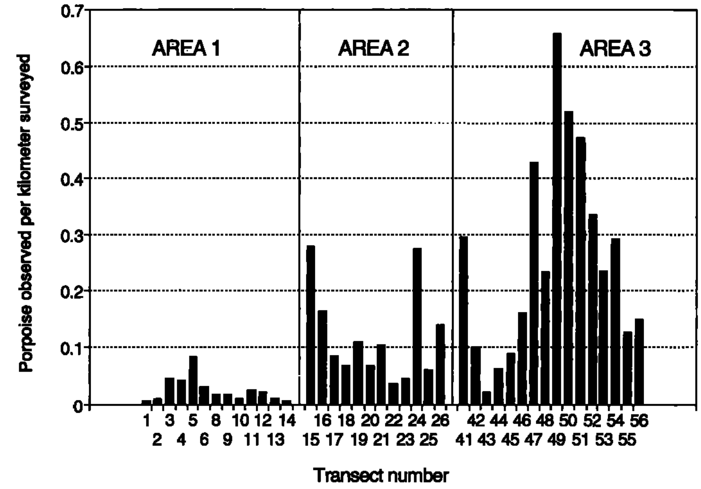

Figure 2

Mean number of harbor porpoise, *Phocoena phocoena*, observed per kilometer on each of the surveyed transects. Only data obtained under good survey conditions (Beaufort sea state 0–2, <25% cloud cover) are included. Transect and area numbers correspond to those shown in Figure 1.

Table 2

Stepwise model building procedure for the 1986–93 central California aerial survey data. Parameters marked in bold indicate variables that were included in the model at each step. P=ln(porpoise/km + 0.001); μ = mean value of P; BF = Beaufort sea state; AR = area; CL = cloud cover, and YR = year. Interaction effects are represented with an asterisk between the variables.

	Step number and base model				
	1	2	3	4	5
	$P = \mu$	$P = \mu + AR$	$P = \mu + AR + BF$	$P = \mu + AR + BF + CL$	$P = \mu + AR + BF + CL + YR$
Probability value for tested additional variables	BF: 0.0183	**BF: 0.0009**	**CL: 0.0003**	**YR: 0.0798**	BF*AR: 0.7823
	AR: 0.0001	CL: 0.0013	YR: 0.5508	BF*AR: 0.8043	BF*CL: 0.9131
	CL: 0.0379	YR: 0.3514	BF*AR: 0.7567	BF*CL: 0.8981	CL*AR: 0.1640
	YR: 0.4606			CL*AR: 0.1344	YR*AR: 0.2783
					YR*BF: 0.7010
					YR*CL: 0.7943

Table 3

Results of analysis of covariance for central California and combined central and northern California aerial survey data. The complete model simultaneously includes all variables marked in bold in Table 2. SE = standard error.

	Central California			Central and northern California		
Source	df	F	P	df	F	P
Model	5	15.70	0.0001	6	22.64	0.0001
Area	1	52.75	0.0001	2	48.30	0.0001
Beaufort sea state	2	8.71	0.0004	2	11.26	0.0001
Cloud cover	1	17.18	0.0001	1	18.91	0.0001
Year	1	3.16	0.0798	1	3.04	0.0850
Error	73			85		
r^2		0.5182			0.6151	
Year coefficient (SE)		−0.098 (0.055)			−0.087 (0.050)	
Annual rate of change		9.3%			8.3%	

The important difference is that the five-year time series did not reveal a trend in abundance, whereas the analysis including the new (1991 and 1993) data indicated a decline in harbor porpoise abundance in central California during the eight-year period 1986–93. To investigate the possibility that animals may have moved northward into northern California, the analysis was repeated with northern California as a third area stratum. The results were essentially the same: the year effect was slightly less pronounced but still significant at $\alpha = 0.10$ (Table 3). Figure 3 shows a plot of relative abundance (porpoise observed per kilometer) in each of the three defined areas for the period 1986–93, adjusted for the effects of sea state and cloud cover (based on the parameters of the best-fitting model). The combined relative abundance for all of central California, calculated as an average of the values of porpoise per kilometer for areas 1 and 2, weighted by the proportion of the total study area encompassed by each (33.6% for area 1; 66.4% for area 2), is indicated by a dashed line in Figure 3.

Discussion

The indication of a declining trend in abundance is somewhat surprising, given that the central California population of harbor porpoise was expected to be recovering from impacts of heavy fishery-related mortality prior to about 1987 (Barlow and Forney, 1994). The point estimate for the decline corresponds to a 9.3% per year decrease (coefficient of variation, CV=0.56) in harbor porpoise abundance for central California (or 8.3%, CV=0.56, if northern California surveys are included in the analysis); however, the confidence in this value is low because of the low power of the test. There are a number of possible explanations for the observed decline, including 1) statistical error, 2) movement of animals out of the study area, 3) effects of fishery-related mortality, and 4) change in natural mortality and net reproduction. Each of these possibilities will be discussed separately below.

Statistical error

It is possible that the results of the test are incorrect, that is, an α-error (detecting a trend although

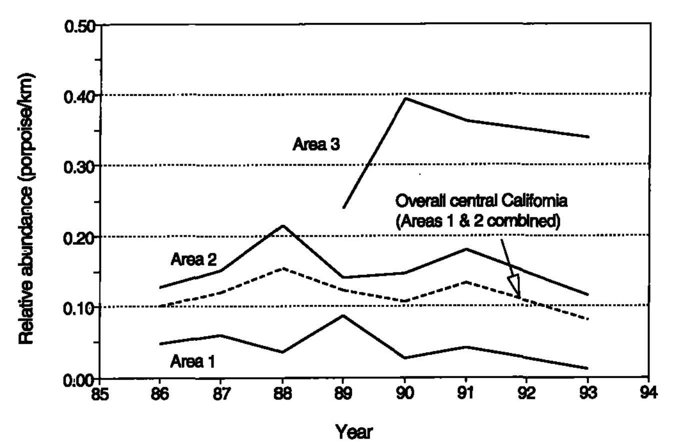

Figure 3

Relative abundance of harbor porpoise, *Phocoena phocoena,* for the period 1986–93. Relative abundance is defined as the number of porpoise observed per kilometer surveyed, adjusted for the effects of sea state and cloud cover on sighting rates. Areas correspond to those shown in Figure 1. The combined relative abundance for all central California was calculated as an average of the adjusted values of porpoise per kilometer for areas 1 and 2, weighted by the proportion of the total study area encompassed by each (33.6% of the total study area was in Area 1; 66.4% was in area 2).

in fact the population is stable) or γ-error (detecting a decline when the population is in fact increasing; Forney et al., 1991) has occurred. The latter is expected to be virtually zero for this eight-year time series (Forney et al., 1991). The former was set at 0.10 a priori in order to increase power. Assuming symmetry, this should have resulted in a 5% probability of detecting a decline if the population were in fact stable.

Movement of animals out of the study area

In recent years, an increasing body of evidence indicates that long-term changes have occurred in the California Current during the last few decades, including an increase in surface water temperature and sea level height (Roemmich, 1992), a decrease in zooplankton abundance (Roemmich and McGowan, 1995), and changes in the size of seabird populations (Ainley et al., 1994). There has also been a dramatic increase in the abundance of short-beaked common dolphins, *Delphinus delphis,* off California (Barlow, 1995; Forney et al., 1995), possibly due to a northward shift in the distribution of this tropical and warm-temperate species (Anganuzzi and Buckland, 1994). A northward range extension into central California has also been documented for another tropical and warm-temperate species, the bottlenose dolphin, *Tursiops truncatus,* following the El Niño event of 1982–83 (Wells et al., 1990). This species now is seen regularly in nearshore waters off central California, within the range of the harbor porpoise.

Similarly, harbor porpoise in central California may have shifted their distribution out of the study area (either to the north or farther offshore) in response to environmental changes, causing an apparent decline in abundance in the nearshore region. Unfortunately, no detailed data on harbor porpoise distributions and oceanographic conditions are available to test this hypothesis. However, it is noteworthy that the relative abundance of harbor porpoise in central California (dashed line in Fig. 3) exhibits a significant negative correlation (α=0.05, Pearson correlation coefficient r=–0.79, P=0.035) with 1986–93 September sea-surface temperature anomalies off Monterey Bay,[1] despite the coarse nature of these two measurements. Thus, in years when sea-surface temperatures were warmer, the relative abundance of harbor porpoise (a temperate species) was lower, and vice versa. This may be indicative of movement of harbor porpoise in relation to changes in sea-surface temperature (or to other environmental factors that are correlated with sea-surface temperature), but it is not known whether harbor porpoise move northward or offshore in response to such environmental changes.

Studies of pollutant ratios in animals along the U.S. West Coast suggest that harbor porpoise do not move frequently between central and northern California (Calambokidis and Barlow, 1991). Consistent with these observations, a shift of animals from central to northern California is not indicated in the analysis of this aerial survey series because the declining trend is still significant when northern California data are included. However, power to detect trends reliably in the northern portion of the study area is probably low, given only four surveys in this region. Additional surveys will improve the ability to detect a northward shift within California, if one is present. It is important to note, however, that harbor porpoise off northern California show a continu-

---

[1] The sea-surface temperature anomaly is defined as the deviation of the mean monthly sea-surface temperature in a given year from the long-term mean for that month. Thus positive anomalies indicate warmer than average months and vice versa. Oceanographic Monthly Summary, U.S. Dep. Commer., NOAA, National Ocean Service, available from NOAA/NOS, Ocean Products Branch, 5200 Auth Road, Room 100, Camp Springs, MD 20746.

ous distribution into waters off Oregon (Barlow, 1988; Barlow et al., 1988), where they are managed separately because of jurisdictional boundaries. Without simultaneous surveys in Oregon, a more widespread shift in distribution cannot be ruled out.

Alternatively, harbor porpoise may have changed their distribution in relation to distance from shore or water depth. The surveys extended only to approximately the 92-m (50-fathom) depth contour. Although the majority of harbor porpoise are expected to be found inshore of this depth (Barlow, 1988), an increase in the proportion of animals found in deeper waters could cause an apparent decline within the 0–92 m (0–50 fathom) study area. This hypothesis cannot presently be tested because detailed surveys for harbor porpoise in waters deeper than 92 m have not been conducted off California, and inferences for offshore areas cannot readily be drawn on the basis of distribution patterns inshore of 92 m depth.

Effects of fishery-related mortality

If the detected decline in harbor porpoise abundance along the California coast is a real phenomenon, then one possible cause for the decline may be incidental mortality of this species in California set gillnet fisheries. Although annual mortality is thought to have gradually declined from about 200–300 animals per year in 1980–87 to about 30–50 animals annually in the last few years (Barlow and Forney, 1994), there was no observer program to monitor mortality in set gillnet fisheries from April 1987 to June 1990. Total mortality estimates for these unmonitored years are based on kill rates for the 1990–91 fishing season and on estimated 1987–90 fishing effort (Perkins et al.[2]). These estimates are accurate only if the mortality observed in the 1990–91 fishing season is representative of 1987–90 rates. If fishery-related mortality of harbor porpoise was in fact higher during 1987–90, this may have contributed to a decline in abundance greater than is apparent from the mortality estimates (see Perkins et al.[2]).

Absolute abundance estimates for central California harbor porpoise have recently been updated on the basis of pooled data from the 1988–93 aerial surveys, yielding an estimate of 4,120 (CV=0.22) harbor porpoise (Barlow and Forney, 1994). Assuming an otherwise stable population, 9.3% of the population, or roughly 350–450 animals, would have had to be removed during each year of the study period in order to cause the decline indicated by the analysis for central California. The fishery-related mortality estimates range from 12 animals in 1993 to 197 animals in 1986 and have large standard errors, but the upper 95% lognormal confidence limits of the mortality estimates are lower than 9.3% of the population estimate in all years since 1984 (derived from data in Perkins et al.[2]; Hanan et al.[3,4]; Konno[5]; Julian[6,7]). Although these mortality estimates assumed fishing effort was known without bias, when in fact it may have been underestimated (Julian[7]), fishery-related mortality alone does not appear to be responsible for the decline in harbor porpoise abundance within the central California study area. However, potential effects of age or sex bias in harbor porpose mortality and potential time lags in the impact of such takes are unknown.

Change in natural mortality and net reproduction

An increase in natural mortality (e.g. due to increased predation, disease, or a reduced food supply) could contribute to a decline in abundance. Natural mortality rates for harbor porpoise are not known. The small size of harbor porpoise may make them vulnerable to shark and killer whale predation, but there is no evidence (i.e. from strandings) to suggest that predation rates may have been higher during the past eight years than in prior time periods. Harbor porpoise appear to be opportunistic feeders: market squid, *Loligo opalescens*, spotted cusk eel, *Chilara taylori*, and northern anchovy, *Engraulis mordax*, are known to be prominent components of their diet in the Monterey Bay region (Sekiguchi, 1987; Dorfman, 1990); however, both studies indicate that the northern anchovy is the most important of these prey

---

[2] Perkins, P., J. Barlow, and M. Beeson. 1994. Report on pinniped and cetacean mortality in California gillnet fisheries: 1988–90. Admin. Rep. LJ-94-11. Southwest Fisheries Science Center, Natl. Mar. Fish. Serv., P.O. Box 271, La Jolla, CA 92038.

[3] Hanan, D. A., S. L. Diamond, and J. P. Scholl. 1986. An estimate of harbor porpoise mortality in California set net fisheries April 1, 1984 through March 31, 1985. Admin Rep. SWR-86-16, 38 p. Available from Southwest Region, 300 S. Ferry St., Terminal Island, CA 90731.

[4] Hanan, D. A., S. L. Diamond, and J. P. Scholl. 1987. An estimate of harbor porpoise mortality in California set net fisheries April 1, 1985 through March 31, 1986. Final rep. to National Marine Fisheries Service, Southwest Region, 300 S. Ferry St., Terminal Island, CA 90731.

[5] Konno, E. S. 1990. Estimates of sea lion, harbor seal and harbor porpoise mortalities in California set net fisheries for the 1987–88 fishing year. Draft rep. available from California Department of Fish and Game, P.O. Box 271, La Jolla, CA 92038.

[6] Julian, F. 1993. Pinniped and cetacean mortality in California gillnet fisheries: preliminary estimates for 1992. Int. Whaling Comm. Working Paper SC/45/O22, 29 p.

[7] Julian, F. 1994. Pinniped and cetacean mortality in California gillnet fisheries: preliminary estimates for 1993. Int. Whaling Comm. Working Paper SC/46/O11, 28 p.

items. In recent years, California Cooperative Oceanic Fisheries Investigations (CalCOFI) surveys have revealed a decline in California anchovy populations (Jacobsen et al., 1994), and the occurrence of this species in the diet of California sea lions, *Zalophus californianus,* off southern California has decreased markedly since 1991.[8] Based on these considerations, an alternate hypothesis for the observed decline in harbor porpoise abundance is that the population has been affected by a decline in a major food source, the northern anchovy. However, too few stranded or incidentally caught harbor porpoise have been available recently for examination of food habits (Peltier et al., 1993, 1994; Lennert et al., 1994;), and data are presently insufficient to test the possibility of such a relationship.

Conclusions

Despite a reduction in fishery-related mortality, the harbor porpoise population in nearshore waters off central California appears to have declined between 1986 and 1993. Potential causes of this decline are poorly understood, and further studies are imperative. Recent restrictions on coastal gillnet fisheries have substantially reduced harbor porposie mortality in central California. If the decline was caused primarily by fishery-related mortality, then the population should exhibit a stable or increasing trend over the next several years. Continuation of the aerial-survey time series will provide a means of detecting such a trend. Additional research should also address possible relationships between the density and distribution of harbor porpoise and environmental conditions (such as water temperature and prey availability).

Acknowledgments

Financial support and personnel were provided by the National Marine Fisheries Service (Southwest Regional Office and Southwest Fisheries Science Center) and the California Department of Fish and Game (CDFG). The observers and data recorders were J. Barlow, M. Beeson, J. Carretta, D. DeMaster, S. Diamond, T. Farley, D. Fink, T. Gallegos, D. Hanan, A. Hudoff, L. Jones, E. Konno, S. Kruse, M. Larson, J. Lecky, T. Lee, M. Lowry, R. Pitman, J. Scholl, J. Sisson, and B. Taylor (and K.A.F). Aircraft were chartered from Aspen Helicopters, Inc. and contracted from CDFG. Pilots were B. Cheney, B. Cole, J. Drust, B. Hansen, D. Hansen, L. Heitz, K. Lankard, E. Schutze, J. Turner, R. Riediger, R. Throckmorton, and R. Van Benthuysen. The computer data acquisition software was written by J. Cubbage and modified by J. Barlow. Aerial surveys were conducted under Marine Mammal Protection Act Permit 748 and NOAA Sanctuary permits GFNMS/MBNMS-03-93 and MBNMS-11-93. Drafts of this manuscript were reviewed by J. Barlow, S. Benson, R. Brownell, J. Carretta, P. Dayton, D. DeMaster, J. Enright, T. Gerrodette, F. Julian, R. Neal, and two anonymous reviewers. I thank all for their useful comments and constructive criticism.

Literature cited

Ainley, D. G., W. J. Sydeman, S. A. Hatch, and U. W. Wilson.
1994. Seabird population trends along the west coast of North America: causes and the extent of regional concordance. Stud. Avian Biology 15:119–133.

Anganuzzi, A., and S. Buckland.
1994. Relative abundance of dolphins associated with tuna in the eastern Pacific Ocean: analysis of 1992 data. Rep. Int. Whaling Comm. 44:361–366.

Barlow, J.
1988. Harbor porpoise, *Phocoena phocoena*, abundance estimation for California, Oregon and Washington: I. Ship surveys. Fish. Bull. 86:417–432.
1995. The abundance of cetaceans in California waters. Part I: Ship surveys in summer and fall of 1991. Fish. Bull. 93:1–14.

Barlow J., and K. A. Forney.
1994. An assessment of the 1994 status of harbor porpoise in California. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SWFSC-205, 17 p.

Barlow J., and D. Hanan.
(In press). An assessment of the status of harbor porpoise in central California. Rep. Int. Whaling Comm. Spec. Issue.

Barlow, J., C. W. Oliver, T. D. Jackson, and B. L. Taylor.
1988. Harbor porpoise, *Phocoena phocoena*, abundance estimation for California, Oregon, and Washington: II. Aerial surveys. Fish. Bull. 86:433–444.

Barlow, J., R. W. Baird, J. E. Heyning, K. Wynne, A. M. Manville II, L. F. Lowry, D. Hanan, J. Sease, and V. N. Burkanov.
1994. A review of cetacean and pinniped mortality in coastal fisheries along the west coast of the U.S. and Canada and the east coast of the USSR. Rep. Int. Whaling Comm. Spec. Issue 15:405–426.

Calambokidis, J., and J. Barlow.
1991. Chlorinated hydrocarbon concentrations and their use for describing population discreteness in harbor porpoises from Washington, Oregon and California. *In* J. E. Reynolds III and D. K. Odell (eds.), Marine mammal strandings in the United States, p. 101–110. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 98.

Dorfman, E. J.
1990. Distribution, behavior, and food habits of harbor por-

---

[8] Lowry, M. 1994. Southwest Fisheries Science Center, Natl. Mar. Fish. Serv., P.O. Box 271, La Jolla, CA 92038. Personal commun.

poises (*Phocoena phocoena*) in Monterey Bay. M.S. thesis, San Jose State Univ., San Jose, CA, 57 p.

Forney, K. A., J. Barlow, and J. V. Carretta.
1995. The abundance of cetaceans in California waters. Part II: Aerial surveys in winter and spring of 1991 and 1992. Fish. Bull. 93:15–26.

Forney, K. A., D. Hanan, and J. Barlow.
1991. Detecting trends in harbor porpoise abundance from aerial surveys using analysis of covariance. Fish. Bull. 89:367–377.

Jacobsen, L., N. C. H. Lo, and J. T. Barnes.
1994. A biomass-based assessment model for northern anchovy, *Engraulis mordax*. Fish. Bull. 92:711–724.

Lennert, C., S. Kruse, M. Beeson, and J. Barlow.
1994. Estimates of incidental marine mammal bycatch in California gillnet fisheries for July through December, 1990. Rep. Int. Whaling Comm. Spec. Issue 15:449–463.

Norris K. S., and J. H. Prescott.
1961. Observations on Pacific cetaceans of California and Mexican waters. Univ. California Publ. Zool., Los Angeles, CA, 401 p.

Peltier, K. M., S. J. Chivers, and S. Kruse.
1993. Composition of the 1991 incidental kill of small cetaceans in the eastern tropical Pacific US tuna fishery and two California gillnet fisheries. Rep. Int. Whaling Comm. 43:401–406.

Peltier, K. M., S. J. Chivers, and W. T. Norman.
1994. Composition of the incidental kill of odontocetes in the eastern tropical Pacific US tuna fishery and two California gillnet fisheries for 1992. Rep. Int. Whaling Comm. 44:353–359.

Roemmich, D.
1992. Ocean warming and sea level rise along the southwest U.S. coast. Science (Wash. D.C.) 257:373–375.

Roemmich, D. and McGowan, J.
1995. Climatic warming and the decline of zooplankton in the California Current. Science (Wash. D.C.) 267:1324–1326.

Sekiguchi K.
1987. Occurrence and behavior of harbor porpoises (*Phocoena phocoena*) at Pajaro Dunes, Monterey Bay, California. M.S. thesis, San Jose State Univ., San Jose, CA, 49 p.

Wells, R. S., L. J. Hansen, A. Baldridge, T. P. Dohl, D. L. Kelly, and R. H. Defran.
1990. Northward extension of the range of bottlenose dolphins along the California coast. *In* S. Leatherwood and R. R. Reeves (eds.), The bottlenose dolphin, p. 421–431. Academic Press, Inc., San Diego, CA.