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National Oceanic and Atmospheric Administration
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Population abundance and trend estimates for beaked whales and sperm whales in the California Current from ship-based visual line-transect survey data, 1991 – 2014

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ABSTRACT

For several species – fin whale, sperm whale, and beaked whales – Bayesian trend models were previously fit to data from six visual line-transect surveys conducted in the California Current between 1991 – 2008. In 2014, the NOAA Southwest Fisheries Science Center conducted another, seventh, comparable line-transect survey: the California Current Cetacean and Ecosystem Assessment Survey (CalCurCEAS). Updated trend estimates incorporating the new survey data have been published for fin whales but not yet for beaked whales or sperm whales. Here, new trend model estimates (of population trend and abundance) are presented for beaked whales and sperm whales. There is little evidence of trends in overall sperm whale abundance, but the new analysis supports prior evidence for an increasing number of sperm whales that occur in small groups (presumed to be adult or near-adult males). Cuvier's beaked whales appear to have decreased in abundance from high values in 1991-93, but that decline now appears to have leveled off. There is some weak evidence of an increasing trend in Baird's beaked whales. *Mesoplodon* beaked whales showed markedly higher abundance in 2014, reversing a declining trend from 1991-2008 that had been noted in a previous analysis. The increase may have be driven by an influx of tropical species of *Mesoplodon* during the unusually warm ocean conditions in 2014.

INTRODUCTION

Marine mammal stock assessment reports (SARs), conducted by NOAA pursuant to the Marine Mammal Protection Act, require minimum estimates of population size and estimates of population trend for all U.S. marine mammal stocks (NMFS 2016).

Visual data from six ship-based line transect surveys in California Current waters off the U.S. West Coast (conducted between 1991 and 2008) were used to estimate population abundance for all encountered cetacean stocks (Barlow 2010) and population trend for several species: fin whale, *Balaenoptera physalus* (Moore and Barlow 2011), beaked whales (family Ziphiidae) (Moore and Barlow 2013) and sperm whale, *Physeter macrocephalus* (Moore and Barlow 2014).

In 2014, the NOAA Southwest Fisheries Science Center conducted a seventh such survey, referred to as the California Current Cetacean and Ecosystem Assessment Survey (or, CalCurCEAS 2014). Following CalCurCEAS 2014, updated population abundance estimates for

all stocks were provided by Barlow (2016) and the trend model for fin whale was updated (Nadeem et al. 2016).

Here we provide new trend model estimates of beaked whale and sperm whale abundance in the California Current survey area. The models generate estimates of population trend but also population abundance, which are considered generally preferable to the Barlow 2016 estimates because they make greater use of encounter rate data from previous surveys and are thus considered better informed and are more precise and stable through time (less prone to sampling errors in individual years).

METHODS

Survey

CalCurCEAS 2014 was conducted aboard the 52-m R/V *Ocean Starr*, chartered by the NOAA Southwest Fisheries Science Center, from 5 August to 9 December 2014. This vessel was previously the NOAA ship *David Starr Jordan*, from which many prior marine mammal surveys were conducted; thus methods used for collecting data from this ship were fully consistent with prior surveys. Survey methods follow those described previously (e.g., Barlow and Forney 2007). Any details specific to this survey are described by Barlow (2016).

Analysis and Inference

Sperm whale analysis

Statistical analysis for sperm whale was conducted as described by Moore and Barlow (2014); it is merely updated here by including the new survey data.

Beaked whale analysis

For beaked whales, statistical methods closely followed those described by Moore and Barlow (2013), but with some differences. Here we estimate the mean population growth rate parameter r using a Markov process model, whereas Moore and Barlow (2013) only fit a log-linear regression trend model. Let N_{j0} be the initial population abundance (in the year prior to the first survey) for species j and N_{jt} be population abundance in year t for $t = 1991$ to 2014 (redefined in the model as $t = 1$ to 24); and let r_j be the rate of population change. The regression model is

$$N_{jt} = N_{j0}\exp(r_j t + \varepsilon_{jt}), \tag{1a}$$

whereas the Markov model is

$$N_{jt} = N_{j,t-1}\exp(r_j + \varepsilon_{jt}), \tag{1b}$$

and where ε_{jt} for either model is normally distributed process error on the log scale. Animal density $D_{jt} = N_{jt}/A$, where A is the study area (km^2). For the observation model, following Moore and Barlow (2013, 2014), the expected numbers of groups detected are:

$$\mu_{jt} = \frac{D_{jt}}{s_j} * 2L_t * \frac{\sum_{b=1}^{5} \frac{L_{tb}*g(0)_{jb}}{f(0)_{jb}}}{\sum_{b=1}^{5} L_{tb}}, \tag{2}$$

where s_j is mean group size, L_t is the total length of transect surveyed (km) each year, L_{tb} is like L_t but broken down by Beaufort class within t, $g(0)$ is the probability of detection for animals on the transect line, and $1/f(0)_{jb}$ is the effective strip half-width in Beaufort class b, estimated using distance sampling formulae as in Moore and Barlow (2013, 2014). Group size data are used to estimate s_j, and detection-distance data are used estimate parameters of the model for $f(0)_{jb}$.

A minor difference between the current analysis and that of Moore and Barlow (2013) is that here, observed group sizes were assumed to come from negative binomial distributions (Poisson × gamma formulation) rather generalized Poisson distributions. That is, if x_{ji} are the individual group sizes for species j, then $x_{ji} \sim$ Poisson($s_j \times \rho_i$), where $\rho_i \sim$ gamma(α, α) has a mean of 1 and variance determined by α, which must be positive. Smaller values of α imply greater variance. We used time-constant (null) models for group size given small within-year sample sizes and lack of obvious indication that mean group size was trending or varying much across surveys for any of the species.

The detection function model (for estimating $f(0)$ parameters) was the same as described by Moore and Barlow (2013). Detection-distance data were pooled across species to estimate model parameters, and the detection function was modeled to vary with Beaufort state and group size, the latter being used as proxy for a species effect, since Baird's beaked whales occur in larger groups than Cuvier's or *Mesoplodon* whales. Truncation distance was 4 km perpendicular from the survey vessel (more distant sightings were excluded from the analysis).

A more important difference in the current model vs. Moore and Barlow (2013) is how we handled detections of "unidentified ziphiid whale". Moore and Barlow (2013) modeled unidentified ziphiids as a separate population and then allocated the yearly estimated abundances to Cuvier's and *Mesoplodon* whales in proportion to the estimated relative abundances for those species. Here we modeled these detections as part of the observation process for the three identifiable species groups (Cuviers', Baird's and *Mesoplodon* beaked whales); thus, there was no separate population process model for unidentified ziphiids. If μ_{jt} (equation 2) are the number of beaked whale groups expected to be *detected*, then let $\omega_{jt} = \mu_{jt}\varphi_{jt}$ (for j = 1, 2, 3) be the number of groups expected to be actually *identified* as one of the three taxa, where φ_{jt} represents the probability of doing so. The expected number of groups assigned to the unidentified ziphiid group, denoted in our analysis by j = 4, is $\omega_{4t} = \sum_{j=1}^{3} \mu_{jt}(1 - \varphi_{jt})$. We assume all φ_{jt} = 1 for Baird's beaked whale (j = 2), so this species does not contribute to ω_{4t}, and we assume that φ_{jt} are equal for Cuvier's (j = 1) and *Mesoplodon* whales (j = 3) such that $\varphi_{1t} = \varphi_{3t} = \varphi_t$. For these two groups, we estimate φ_t using an ad hoc temporal trend model, i.e., logit(φ_t) = $\gamma + \beta t$. We base this model on the observation that both the total number and proportion of beaked whale detections recorded as "unidentified ziphiid" increased over the time series while detections of the other two species groups generally trended downward (Table 3). We speculate that this may reflect a tendency for observers to have become more conservative through time in assigning animals to the species/genus level. A bootstrapping routine (Moore and Barlow 2014; see their Supplement 1) indicated that encounter rate variance for beaked whales did not differ markedly from Poisson (variance to mean ratio varied from 1 to 1.4 across

the four modeled groups), therefore we used a Poisson likelihood to model the number of groups encountered: $n_{jt} \sim Poisson(\omega_{jt})$ for $J = 4$ ziphiid groups including the "unidentified" group.

Finally, compared to Moore and Barlow (2013), we use newer estimates for Beaufort sea state-specific $g(0)$, which represents the probability of detecting a group of animals that resides on the transect line (perpendicular distance from line = 0 km). Moore and Barlow (2013) used some preliminary Beaufort-specific $g(0)$ estimates for Cuvier's beaked whale (*Ziphius cavirostris*) and *Mesoplodon* species, and they did not use Beaufort-specific values for Baird's beaked whale but rather used a constant value of 0.87 (based on a parametric bootstrap of values provided by Barlow 1999), which reflected poor knowledge at the time of Baird's beaked whale long dive times. In the present analysis, Beaufort-specific $g(0)$ estimates for Cuvier's and *Mesoplodon* beaked whales – for sea states 1 to 5 – are based on published values from Barlow (2015) (Table 1). We assume $g(0)$ in sea state 0 is the same as for sea state 1, which differs from Barlow (2015), but we think our assumption is justified based on field experience and the fact that Barlow's models were fit to few data in sea state 0 (so that relative differences for sea state 0 and 1 are most likely extrapolated from his exponential model rather than empirically estimated). Empirical estimates of $g(0)$ for Baird's beaked whale do not exist, but Barlow (2016) used the same $g(0)$ as for *Mesoplodon* (Jay Barlow, pers. comm.). For consistency, we do the same, but only for the calmest sea conditions, i.e., for Beaufort state 0. The rationale for using this $g(0)$ value (0.47, in Beaufort 0) is that while Baird's whales are much easier to see than *Mesoplodon* at the surface, they also have longer dive times and are thus visible less often. However, as a departure from Barlow (2016) we assume that the relative decline in $g(0)$ with sea state for Baird's beaked whale may be more similar to that of other large odontocetes such as Risso's dolphins, pilot whales, or killer whales. Thus, averaged across all Beaufort conditions, our estimates of $g(0)$ are considerably higher for Baird's beaked whales than *Mesoplodon*. Compared to the analysis of Moore and Barlow (2013), the newer $g(0)$ values will result in lower abundance estimates for Cuvier's beaked whales and higher estimates for Baird's beaked whale. Ultimately, empirical information on $g(0)$ is needed to improve population size estimates for Baird's beaked whales.

Table 1. Estimates of $g(0)$ in different sea states for beaked whales (CVs in parentheses). Values for Cuvier's beaked whale and *Mesoplodon* are based on Barlow (2015). CVs for the first Beaufort class are from Barlow (1999). Values for Baird's beaked whale are assumed, based on species with similar sighting characteristics (see text).

Beaufort class in model (*b*)	Corresponding Beaufort sea state	Cuvier's beaked whale	*Mesoplodon* species	Baird's beaked whale
1	0 and 1	0.40 (0.35)	0.47 (0.23)	0.47 (0.23)
2	2	0.28 (0.39)	0.26 (0.28)	0.39 (0.28)
3	3	0.19 (0.43)	0.15 (0.33)	0.34 (0.32)
4	4	0.13 (0.49)	0.10 (0.40)	0.30 (0.38)
5	5	0.09 (0.55)	0.09 (0.47)	0.26 (0.44)

Parameters in table were approximated as informative priors using a beta distribution for $g(0)_{b=1}$ and then calculating distributions for $b = 2, 3, 4, 5$ as $g(0)_b = g(0)_1 * \exp(\beta b) * \overline{g(0)_0}/\overline{g(0)_1}$, where $\overline{g(0)_0}$ and $\overline{g(0)_1}$ are point estimates for $g(0)_0$ and $g(0)_1$ published by Barlow (2015; see his Table 6). For Cuvier's beaked whale, $g(0)_1 \sim \text{Beta}(4.480, 6.664)$ and $\beta \sim \text{Normal}(-0.38, 0.08)$. For *Mesoplodon*, $g(0)_1 \sim \text{Beta}(9.509, 10.637)$ and $\beta \sim \text{Normal}(-0.55, 0.08)$. For Baird's beaked whale, $g(0)_1 \sim \text{Beta}(9.509, 10.637)$ and $\beta \sim \text{Normal}(-0.15, 0.075)$.

Statistical inference

Model parameters were estimated using Bayesian MCMC approaches in OpenBUGS (called through R) as per all previous trend analyses we have conducted for these marine mammal stocks. Inference is based on posterior probability distributions for model parameters. MCMC specifications for sperm whales and beaked whales are as in Moore and Barlow (2013, 2014).

The interpretation of *r* is different for regression and Markov models. For the regression model, *r* is related to the mean rate of population change that *has actually occurred* during the survey time frame. For the Markov model, *r* is the mean annual growth rate for a *long-term underlying population process*. Consider a long-term (e.g., 500 years) population trajectory simulated from a stochastic population model with the parameter *r* set to be $0.03 \pm$ error. The population thus grows over the long-run at an average rate of 3% per year, but for a particular 20-year time period during which this hypothetical population is surveyed, the population may have declined at an average rate of 2% per year. Survey data from this time period may provide high certainty about the 20-year population decline that occurred (as inferred from a precise regression estimate of *r*) but we may nonetheless be uncertain about the long-term population process, i.e., what the population will have done over the course of 500 years (as inferred from wide confidence limits for the Markov estimate of *r*).

Still another statistic for inferring population trend over the survey period (for estimating what the population *actually did* during that period) is to calculate the geometric mean of the *T* annual growth rate estimates, i.e., $\bar{\lambda} = \left[\prod \frac{N_{t+1}}{N_t} \right]^{1/T}$, where *T* is the number of annual time periods. Uncertainty in the estimates for N_t are propagated through the MCMC process to generate Bayesian credible intervals for growth parameters *r* and $\bar{\lambda}$.

The percentages of the posterior distributions that correspond to negative population growth (i.e., $r < 0$, $\bar{\lambda} < 1$) are interpreted as the probability that population *is declining in the long run* and *declined during the survey period*, respectively.

RESULTS AND DISCUSSION

Data summaries

Study effort (transect length in km), tabulated by Beaufort state and Year, is summarized in Table 2. Less effort was accomplished in 2014 than in most years. For species analyzed for this report, the numbers of groups sighted while on effort are in Table 3. See Barlow (2016) for additional data summaries, such as effort, sightings and observed mean group sizes by geographic strata, and maps of survey transects and sighting locations.

Table 2. Visual line-transect survey effort (km)						
	Beaufort state					
	0 & 1	2	3	4	5	TOTALS
1991	799	1498	2103	4149	1466	10035
1993	361	1032	1852	1764	1230	6239
1996	785	1304	3544	5147	3894	14674
2001	265	968	1543	4490	2271	9537
2005	253	1327	2247	4414	2603	10844
2008	474	1368	1647	4177	3897	11561
2014	297	1246	1937	3065	2778	9323
TOTALS	3234	8743	14873	27225	18139	72,213

Table 3. Number of on-effort groups sighted by year. For sperm whales, these are the number of sightings with 5.5 km (perpendicular distance) of the survey vessel. For the beaked whales, the truncation distance was 4 km.

	Sperm whale (small + large)†	Cuvier's beaked whale	*Mesoplodon* species	Baird's beaked whale	Unidentified beaked whale
1991	4 + 9 = 13	18	6	2	0
1993	1 + 12 = 13	12	7	3	3
1996	5 + 8 = 13	9	14	5	3
2001	5 + 6 = 11	5	0	2	2
2005	12 + 9 = 21	3	3	3	4
2008	10 + 3 = 13	10	1	5	4
2014	9 + 4 = 13	6	7	4	8
TOTALS	46 + 51 = 97	63	38	24	22

† Small groups are 1 or 2 animals; large groups are ≥ 3 (see Moore and Barlow 2014 for explanation)

Sperm whale

Sperm whale abundance estimates for the study area during survey years are summarized in Table 4 and shown in Figure 1. These estimates are from the Markov process model. The growth rate parameter r from this model had a posterior median and mean of +0.01 (SD = 0.06) with a broad 95% credible interval (CRI) ranging from -0.11 to +0.13 and a 60% chance of being positive, indicating high uncertainty in the long-term population growth rate for sperm whales. The growth rate estimate r from the regression model had a posterior mean of +0.01 with 95% CRI ranging from −0.06 to +0.07 (62% chance that growth has been positive), indicating that even for just the 1991 – 2014 study period, we cannot conclusively determine whether the population has changed or in which direction.

As reported by Moore and Barlow (2014), the trend for animals traveling in small groups of 1 or 2 (assumed to be adult males) continues to show evidence of being positive, with the growth rate from 1991 to 2014 having averaged $r = +0.04$ (95% CRI: 0 to 0.10) and there being a 96% chance of being r positive.

Modeled mean group size across all years (for groups with > 2 individuals) was 15, slightly smaller than the value of 16 reported by Moore and Barlow (2014). In 2014, observed mean group size (for four groups with > 2 individuals) was 9.5 (range 5 to 16.5).

| Table 4. Posterior distribution summaries for population size of sperm whales using California Current waters off the U.S. West Coast					
Year	20th perc	Mode	Median	Mean	CV
1991	1050	1215	1637	1895	0.59
1993	1135	1370	1726	1991	0.57
1996	1154	1307	1690	1900	0.50
2001	1279	1499	1849	2074	0.50
2005	1451	1686	2108	2383	0.50
2008	1291	1499	1890	2117	0.50
2014	1270	1499	1997	2281	0.57
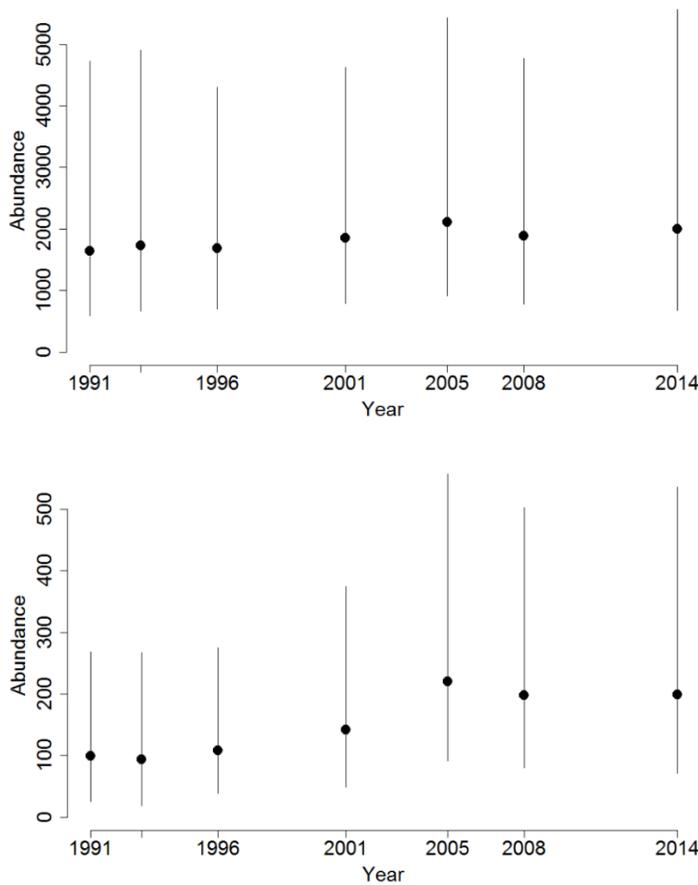
Figure 1. Sperm whale population size estimates from the Markov process model. Top panel is for the entire number of individuals using the study area; bottom panel is just for individuals occurring in "small groups" (i.e, adult males traveling in groups of 1 or 2). The points represent medians from the Bayesian posterior summaries; lines are 95% credible intervals.

Beaked whales

See Moore and Barlow (2013) for inferences about detection function parameters and group sizes, for which current results are largely unchanged. We note, however, that given different values of $g(0)$ in the current analysis, the Beaufort-specific detection probabilities differ in the new analysis. We define detection probability as the probability of detecting a group that is present within the truncation distance W of the survey trackline, i.e., $p = \frac{g(0)}{Wf(0)}$. For Cuvier's beaked whale, average detection probability point estimates ranged across years from 0.18 to 0.24. For Baird's beaked whale, values ranged from 0.30 to 0.37. For *Mesoplodon* whales, values ranged from 0.15 to 0.20. These are the marginal values, i.e., integrated across Beaufort survey conditions in each year.

Beaked whale abundance estimates for the study area during survey years are summarized in Tables 5 – 7 and shown in Figure 2. These estimates are from the Markov process model. Estimates of r and λ reported in the following paragraphs are posterior means.

For Cuvier's beaked whale, the growth rate parameter r from the Markov model had a posterior median and mean of −0.03 (SD = 0.06) with a broad 95% credible interval (CRI) ranging from −0.17 to +0.09 and a 70% chance of being negative. The growth rate estimate r from the regression model was −0.03 (SD = 0.03) with 95% CRI ranging from −0.10 to +0.03 (85% chance that change has been negative), and the geometric mean λ was 0.98 (SD = 0.02) with 95% CRI ranging from 0.94 to 1.02 (83% chance of negative growth). These metrics continue to provide some evidence that Cuvier's beaked whale abundance in the study area declined from 1991 to 2014. Specifically, it appears that numbers decreased between the 1993 and 1996 survey but have remained stable at this lower level since then. As noted above, because different $g(0)$ estimates were used in the current analysis, population size estimates are *lower* than reported by Moore and Barlow (2013).

For Baird's beaked whale, estimates of long-term and short-term population change are uncertain and our best inference is that the population has remained stable or increased slightly over the study period. The Markov model estimate of r was 0.01 (SD = 0.08), ranging from −0.14 to +0.15, which is rather uninformative. But the geometric mean λ was 1.02 (SD = 0.03) with 95% CRI ranging from 0.96 to 1.08 and a 72% chance of being positive. As noted above, because different $g(0)$ estimates were used in the current analysis, population size estimates are *higher* than reported by Moore and Barlow (2013).

For *Mesoplodon* whales, population abundance estimates were up in 2014 compared to previous years (Figure 2). As a result, the long-term growth rate estimate from the Markov model was $r = 0.03$ (SD = 0.07), with 95% CRI ranging from −0.10 to +0.18, implying high uncertainty in long-term dynamics. The geometric mean λ was 1.03 (SD = 0.02) with 95% CRI ranging from 0.98 to 1.07, corresponding to an 87% chance that *Mesoplodon* abundance in 2014 was higher than in 1991. These results suggest a reversal of the trend documented from 1991 – 2008 by Moore and Barlow (2013).

Interpreting results for *Mesoplodon* is difficult because this is a multi-species group that includes warm- and cold-water species, so temporal trends for one species can mask trends of another. We hypothesize that the 2014 abundance increase may reflect an influx of warm-water

animals into the study area. During the 2014 survey, California Current water temperatures were anomalously high (e.g., Bond et al. 2015) and many warm-water species from diverse taxonomic groups (birds, mammals, fishes) were documented in uncharacteristically northern areas during the CalCurCEAS cruise and by various other studies. In contrast with the widespread distribution of *Mesoplodon* sightings over the course of our previous California Current cruises (Moore and Barlow 2013), six out of seven sightings in 2014 were made off Central and Southern California (Barlow 2016) where we would expect to see increased occurrence of more warm-water and subtropical species such as Blainville's (*M. densirostris*) and Pygmy beaked whales (*M. peruvianus*). One of those 2014 sightings was confirmed to be Blainville's beaked whales, the first confirmed sighting of that species in the 1991-2014 survey time series.

The recent stranding record also supports a predominance of warmer-water species in the study area. One confirmed and one probable Blainville's beaked whale stranded near Neah Bay, Washington (2016) and at Vandenberg Airforce Base (north of Santa Barbara, California, 2013), respectively. This species had not stranded along the U.S. West Coast since 1985, and the Washington stranding was the northernmost on record for this species. One Pygmy beaked whale, last observed in the stranding record in 2001, stranded in Humboldt County, California, in 2012, also a northernmost record. One Perrin's beaked whale (*M. perrini*), not observed since 1997 (a strong El Niño year), stranded near Los Angeles, California, in 2013. In contrast, Hubbs' beaked whale (*M. carlhubbsi*), a cooler-temperate species that stranded relatively often in California in the 1980s and 1990s, has only been observed in the stranding record once since 1996 (in Washington in 2010; see Moore and Barlow 2013). Two Stejneger's beaked whales (*M. stejnegeri*) have stranded along the U.S. West Coast since 2010 (one in Oregon, one in Washington, both in May 2015). In short, since 2010 (the most recent year of data summarized by Moore and Barlow 2013), the stranding record for *Mesoplodon* of the U.S. West Coast has consisted mostly of warmer-water species, in sharp contrast to what Moore and Barlow (2013) summarized for the decades prior. A deeper investigation is warranted to better evaluate the hypothesis that *Mesoplodon* increases in the California Current are driven by an increase warm-water species, but this appears to be the case based on the limited information we have.

Table 5. Posterior distribution summaries for population size of **Cuvier's beaked whales** using California Current waters off the U.S. West Coast

Year	20th perc	Mode	Median	Mean	CV
1991	3347	3700	4860	5692	0.59
1993	3226	4088	4812	5657	0.60
1996	1763	2014	2680	3157	0.62
2001	1546	1655	2422	2892	0.66
2005	1427	1645	2246	2679	0.66
2008	2172	2750	3314	3917	0.63
2014	2059	2259	3274	3928	0.67

Table 6. Posterior distribution summaries for population size of **Baird's beaked whales** using California Current waters off the U.S. West Coast

Year	20th perc	Mode	Median	Mean	CV
1991	1118	1369	1800	2084	0.60
1993	1304	1515	2025	2331	0.58
1996	1316	1462	2007	2264	0.53
2001	1132	1212	1801	2077	0.59
2005	1303	1398	2026	2302	0.56
2008	1634	1938	2496	2848	0.55
2014	1633	1766	2697	3115	0.60

Table 7. Posterior distribution summaries for population size of *Mesoplodon* **beaked whales** using California Current waters off the U.S. West Coast

| Year	20th perc	Mode	Median	Mean	CV
1991	1209	1410	1702	1882	0.45
1993	1687	1773	2438	2712	0.48
1996	1867	2119	2657	2925	0.46
2001	652	899	1078	1230	0.60
2005	788	979	1227	1396	0.56
2008	711	860	1148	1307	0.58
2014	1967	1963	3044	3439	0.54
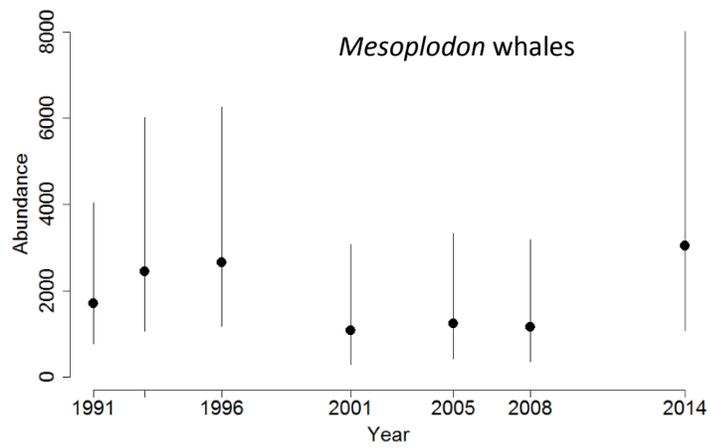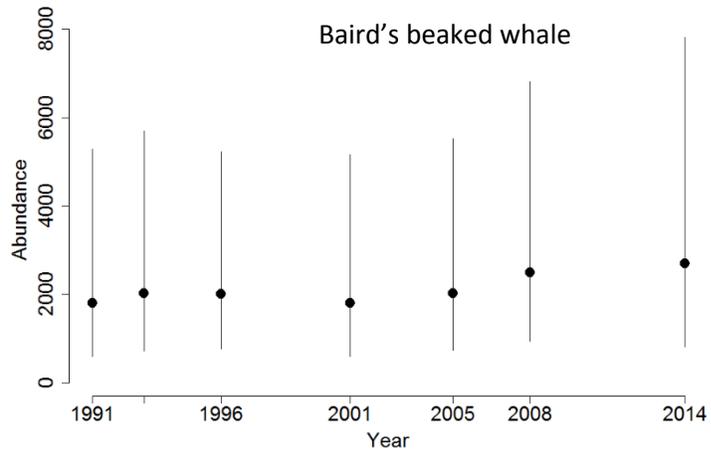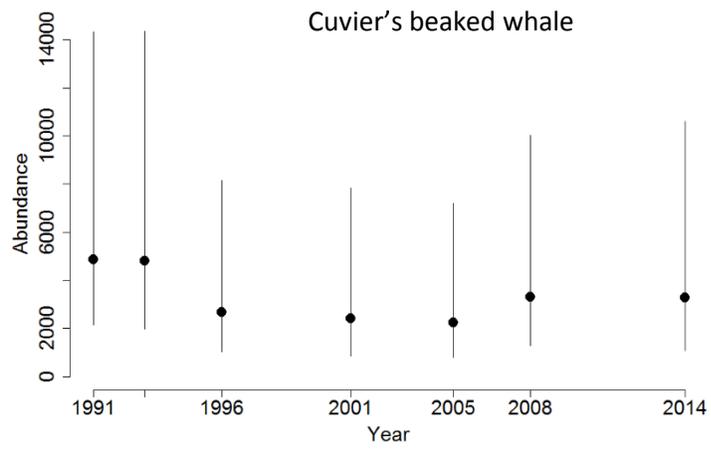
Figure 2. Estimates of population abundance for beaked whales in the California Current study area.

ACKNOWLEDGMENTS

LITERATURE

Barlow, J. 2010 Cetacean abundance in the California Current estimated from a 2008 ship-based line-transect survey. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-456

Barlow, J. 2015. Inferring trackline detection probabilities, g(0), for cetaceans from apparent densities in different survey conditions. Marine Mammal Science 31:923-943

Barlow, J. 2016. Cetacean abundance in the California current estimated from ship-based line-transect surveys in 1991-2014. Southwest Fisheries Science Center, Administrative Report, LJ-2016-01. 63 p.

Barlow, J., Forney, K.A. 2007. Abundance and the population density of cetaceans in the California Current ecosystem. Fishery Bulletin 105:509–526

Bond, N. A., Cronin, M. F., Freeland, H., Mantua, N. 2015. Causes and impacts of the 2014 warm anomaly in the NE Pacific. Geophysical Research Letters 42:3414–3420.

Moore, J. E., Barlow, J. P. 2011. Bayesian state-space model of fin whale abundance trends from a 1991–2008 time series of line-transect surveys in the California Current. Journal of Applied Ecology 48:1195–1205.

Moore, J. E., Barlow, J. P. 2013. Declining Abundance of Beaked Whales (Family Ziphiidae) in the California Current Large Marine Ecosystem. PLoS ONE 8:e52770.

Moore, J. E., Barlow, J. P. 2014. Improved abundance and trend estimates for sperm whales in the eastern North Pacific from Bayesian hierarchical modeling. Endangered Species Research 25:141–150.

National Marine Fisheries Service (NMFS). 2016. Guidelines for Preparing Stock Assessment Reports Pursuant to Section 117 of the Marine Mammal Protection Act. NMFS Instruction 02-204-01, February 22, 2016. Available at: http://www.nmfs.noaa.gov/pr/sars/guidelines.htm (last accessed 2017 January 20).