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Acoustic pingers eliminate beaked whale bycatch in a gill net fishery

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Bycatch of beaked whales in gill net fisheries has been documented worldwide (Nicholson 1954, Di Natale 1994, Read 1994, Siliciliano 1994, Julian and Beeson 1998, Waring *et al.* 2006). Acoustic pingers have been successfully used to reduce bycatch of harbor porpoises (*Phocoena phocoena*) (Kraus *et al.* 1997, Trippel *et al.* 1999, Gearin *et al.* 2000) and common dolphins (*Delphinus delphis*) (Barlow and Cameron 2003), but pinger efficacy in reducing beaked whale bycatch has never been evaluated due to the rarity of beaked whale entanglements in fisheries. We report that bycatch of beaked whales in a California drift gill net fishery dropped to zero when acoustic pingers were added to reduce cetacean bycatch and that this effect is much greater than bycatch reductions for other cetacean taxa.

Our study is based on 17 yr of fishery observer data collected by biologists at sea aboard drift gill net vessels fishing for swordfish and sharks in the California Current (Julian and Beeson 1998, Carretta *et al.* 2005). In the first 6 yr of the fishery observer program (1990–1995), biologists observed 33 beaked whales entangled in 3,303 fishing sets: 21 Cuvier's beaked whales (*Ziphius cavirostris*), 5 Hubb's beaked whales (*Mesoplodon carlhubbsi*), 1 Stejneger's beaked whale (*M. stejnegeri*), 1 Baird's beaked whale (*Berardius bairdii*), 2 unidentified *Mesoplodon* species, and three "unidentified ziphiids" (Fig. 1). All entanglements were single animals. Since pinger use began in 1996, there have been *no* beaked whale entanglements in 4,381 observed sets through 2006 (Fig. 2). In contrast, 260 cetaceans representing 12 species were observed entangled during this same 11-yr period.

The sound characteristics of pingers used in this fishery are specified in regulations (source level ~135 dB RMS, re: 1 μPa @ 1 m, frequency 10–12 kHz, pulse duration = 300 ms, pulse interval = 4 s). A simple spherical propagation model indicates that these sounds should be audible at 15 dB over ambient noise at 100 m. Pinger frequencies (10–12 kHz) are within the range of sounds (5–80 kHz) that Cook *et al.* (2006) reported to be detectable by beaked whales, but are lower than

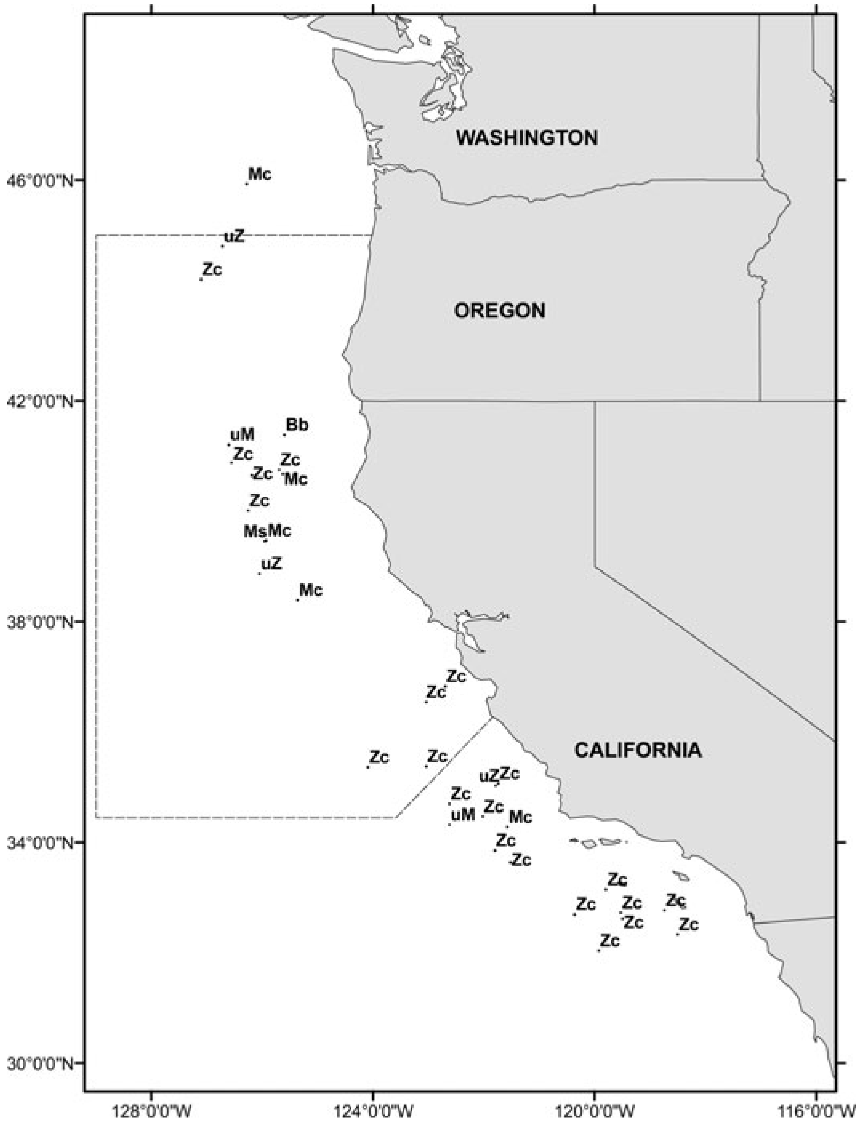

Figure 1. Locations of observed beaked whale entanglements in the swordfish drift gill net fishery. Species key: Bb = *Berardius bairdii*, Mc = *Mesoplodon carlhubbsi*, Ms = *Mesoplodon stejnegeri*, Zc = *Ziphius cavirostris*, uM = unidentified *Mesoplodon* species, uZ = unidentified ziphiid. Bounded region has been closed to gill netting from 15 August to 15 November annually since 2001.

peak frequencies recorded from *Z. cavirostris* and *M. densirostris* (Johnson *et al.* 2004, Zimmer *et al.* 2005). Pinger frequencies do overlap with sounds recorded from *M. densirostris* near Hawaii (Rankin and Barlow 2007) and *B. bairdii* off the U.S. west coast (Dawson *et al.* 1998). Nets in this fishery are approximately 1,800 m long

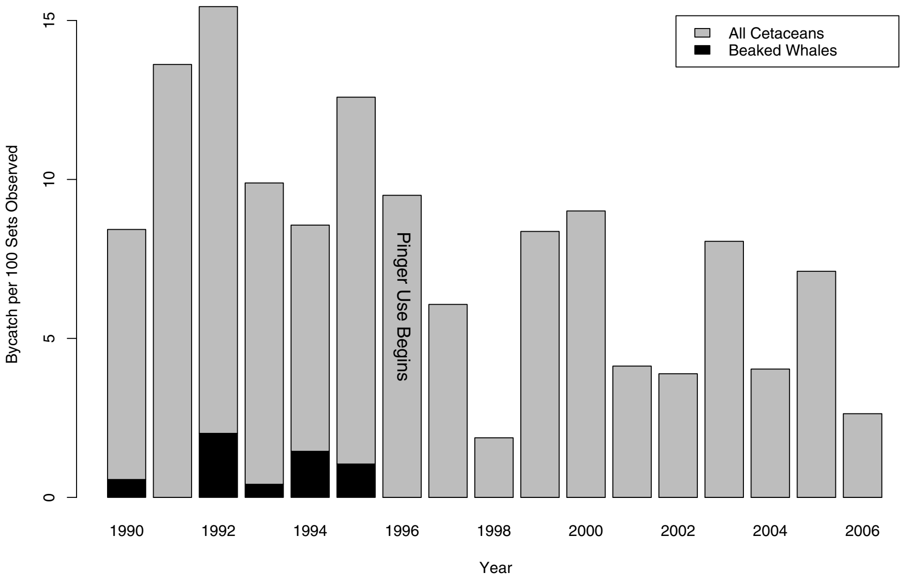

Figure 2. Bycatch rates (of individuals) of all cetaceans and beaked whales per 100 observed sets, 1990–2006.

and 65 m deep, with mesh sizes ranging from 35 to 60 cm. Nets are fished from dusk until dawn and are suspended from floats so that the tops of the nets are at 11–22 m depth and the bottoms are at 75–90 m depth. Regulations require that acoustic pingers be attached every 91 m and within 9 m of the floatline, and every 91 m and within 11 m of the leadline. Thus, the average net contains approximately 40 pingers.

Three significant regulatory changes have occurred in this fishery since 1996: the introduction of acoustic pingers, a mandatory increase in minimum fishing depth to 11 m, and a seasonal area closure implemented in 2001 that shifted fishing effort to the south (Fig. 3). Of these changes, the introduction of pingers is the most likely factor in the reduction of beaked whale bycatch. Minimum fishing depth requirements are not a likely factor, as most sets (63%) were already fished 11 m or deeper before regulations took effect. Also, the proportion of sets fished at <11 m (37%) and the proportion of total beaked whale bycatch (36%) observed in these "shallow" sets were nearly identical. The area closure is not a likely factor, as beaked whale entanglements had already dropped to zero in 2,670 observed sets with pingers for five consecutive years preceding the closure. Also, the rate of beaked whale entanglements inside the closure area (17 whales in 1,410 sets) and outside the closure area (16 whales in 1,893 sets) did not differ significantly from 1990 to 1995 ($P = 0.34$, two-tailed randomization test).

A decline in beaked whale entanglements might be expected from an overall decline in beaked whale abundance in the California Current. The combined abundance of *Ziphius*, *Mesoplodon* sp. (most sightings of *Mesoplodon* could only be identified

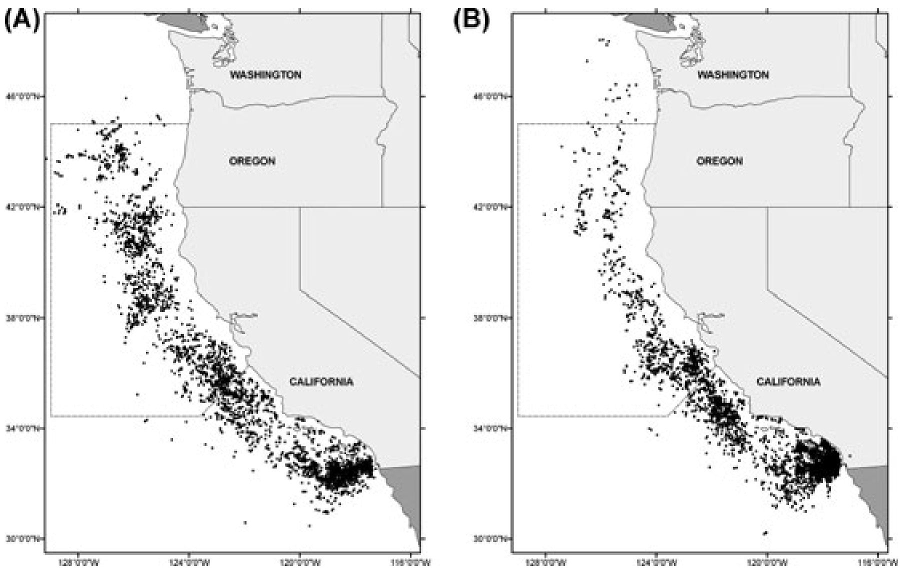

Figure 3. Location of observed fishing sets in the swordfish drift gill net fishery during 1990–1995 (A) and 1996–2006 (B). Bounded region has been closed to gill netting from 15 August to 15 November annually since 2001.

to genus), and *Berardius* in the California Current has been estimated at approximately 7,000 whales for the period 1991–2005, which exceeds combined estimates of blue, fin, and humpback whale abundance in the same region (Barlow and Forney 2007). Survey-specific estimates of beaked whale abundance declined by 62% over this period, but some of that apparent decline is attributed to rougher weather during later surveys. Taylor *et al.* (2007) showed that the probability of detecting a precipitous decline in beaked whale abundance is quite low, given the low precision of survey estimates (CVs >0.60) and intervals between surveys (4 yr). Given the relative rarity of beaked whale sightings, we are unable to determine if the observed decline is statistically significant. Another measure of relative beaked whale abundance is the number of stranded animals. Thirty beaked whale strandings were reported to the California Marine Mammal Stranding Network between 1990 and 2006 and the mean number of annual strandings increased slightly following pinger use (1.66 in years without pingers and 1.82 with pingers).

To evaluate whether the observed absence of beaked whale entanglements during the last 11 yr could have resulted by chance, we examined the probability of observing zero entanglements in 4,381 sets with a simple Poisson model, using the observed entanglement rate prior to pinger use (33 entanglements/3,303 sets = 0.00999 entanglements per set). Given this entanglement rate, the expected number of observed entanglements in 4,381 sets is 43.77 and the Poisson probability of observing zero entanglements is $<10^{-19}$. The likelihood of observing zero entanglements remains low even if the beaked whale population and expected number of entanglements have decreased by 62% ($P = 10^{-7}$) or even by 90% ($P = 0.013$). The likelihood that beaked whale abundance has declined in this region by more than 90% seems remote, given recent abundance estimates and stranding records. The difference in beaked whale entanglement rates with and without pingers is so large that it cannot be explained as a sampling artifact. In contrast, bycatch rates of all cetaceans (mostly dolphins) decreased by only 50% over the same period. Continued bycatch of other cetacean species in the absence of beaked whale bycatch suggests that beaked whales may be among the most sensitive of the cetacean taxa to sounds within the frequency range produced by pingers. These results contribute to our understanding of beaked whale sensitivity to anthropogenic sound and highlight recent concerns about potential threats that some sound sources may pose to beaked whales (Simmonds and Lopez-Jurando 1991, Frantzis 1998, Balcomb and Claridge 2001, Jepson *et al.* 2003, Aguilar de Soto *et al.* 2006, Barlow and Gisiner 2006, Cox *et al.* 2006).

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