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SEASONAL VARIATION IN RECEPTION OF FIN WHALE CALLS AT FIVE GEOGRAPHIC AREAS IN THE NORTH PACIFIC

In late August 1991 scientists at the National Oceanic and Atmospheric Administration's (NOAA) National Marine Mammal Laboratory (NMML) and Pacific Marine Environmental Laboratory (PMEL) began a pilot study to investigate the capability of hydrophones from the U.S. Navy's fixed array system to detect large whales in the North Pacific by passive reception of their calls. PMEL had previously established a direct data link from five bottom-mounted arrays of the Navy SOSUS (SOund SUrveillance System), *via* the Naval Oceanographic Processing Facility (NOPF) at Whidbey Island, Washington, to study low-level seafloor seismicity (Fox *et al.* 1994). PMEL subsequently provided NMML tapes of SOSUS hydrophone data from which whale calls were analyzed. As in an analogous study conducted in the North Atlantic (Nishimura and Conlon 1994, Clark 1995, Mellinger and Clark 1995), calls attributable to whales were received at each SOSUS site at rates that varied seasonally (Anonymous 1996).

Pulsed signals, similar to those recorded from fin whales (*Balaenoptera physalus*), were the most distinctive of the whale calls received during the pilot study. In addition to other sounds, fin whales produce characteristic, loud, short calls termed "20-Hz pulses" (Watkins 1981). These signals are roughly 1 sec long, with energy concentrated near 20 Hz and source levels of ~160–186 dB re 1μPa-m (reviewed in Thomson and Richardson 1995). Such pulses are produced in: (1) long stereotyped bouts, composed of repeated series of either single or "doublet" pulses with regular interpulse intervals, and (2) comparatively short series with irregular interpulse intervals. The long bouts (<1–32.5 h) of stereotyped calling by individual whales are thought to be reproductive displays (Watkins *et al.* 1987, Thompson *et al.* 1992), while the shorter irregular pulse sequences (≤5 min) are produced in series by a number of different whales and have been associated with feeding, socializing, and transiting animals (Watkins 1981, McDonald *et al.* 1995). Calls attributed to fin whales during the pilot study had peak energy centered near 20 Hz and

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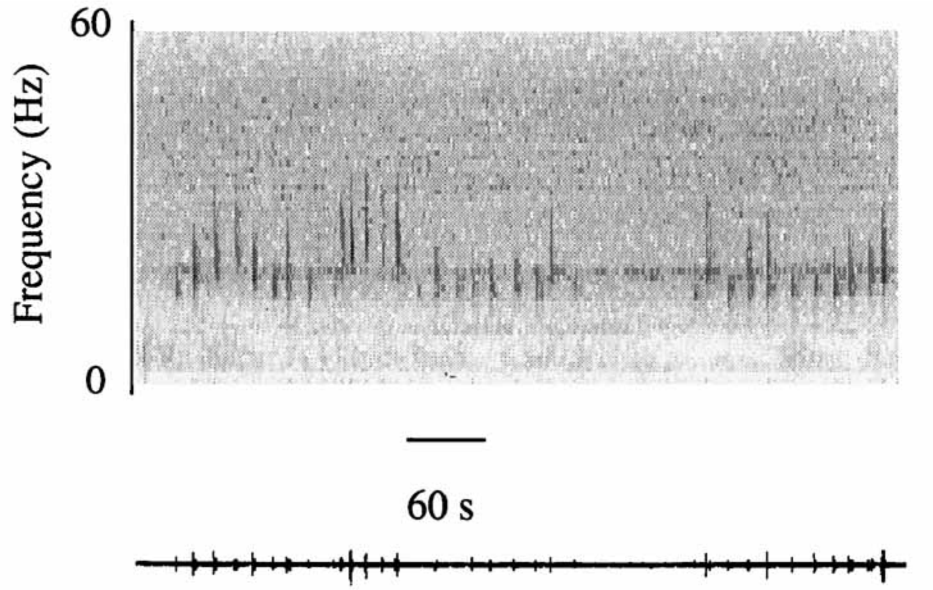

Figure 1. Example spectrogram of fin whale pulses recorded *via* SOSUS in the North Pacific.

irregular repetition intervals (Fig. 1), similar to fin whale calls recorded from bottom-mounted hydrophones north of Oahu, Hawaii (Thompson and Friedl 1982, fig. 3b) and seafloor seismometers deployed roughly 500 km west of Oregon (McDonald *et al.* 1995, fig. 8).

The pilot SOSUS study marked the first attempt to acoustically monitor widely spaced areas in the North Pacific Ocean for fin whale calls over a one-year period. While 20-Hz pulses have proven a reliable means to passively detect and track fin whales at sea (*e.g.*, Watkins 1981, Watkins *et al.* 1987, Thompson and Friedl 1982, McDonald *et al.* 1995), previous studies have been restricted to one locality. While it is generally accepted that passive acoustic methods can complement conventional cetacean survey techniques, long-term application of bioacoustics to the study of whales is still in its infancy. In this report, seasonal variation in reception of calls attributed to fin whales at five areas in the North Pacific are collated with available sighting data and seasonal patterns of productivity for provisional assessment of the utility of such passive acoustic monitoring to the investigation of cetacean ecology.

The Navy's SOSUS consists of a series of bottom-mounted hydrophone arrays that transmit signals to shore-based facilities for signal processing (Wit 1981, Nishimura and Conlon 1994, Richelson 1998). Because SOSUS is still an operational U.S. Navy facility, actual array locations and hydrophone depths are not available. However, a provisional map of SOSUS sites developed by the Navy for use by the Acoustic Thermometry Ocean Climate (ATOC) project (ATOC 1995), is modified here to portray approximate areas monitored for

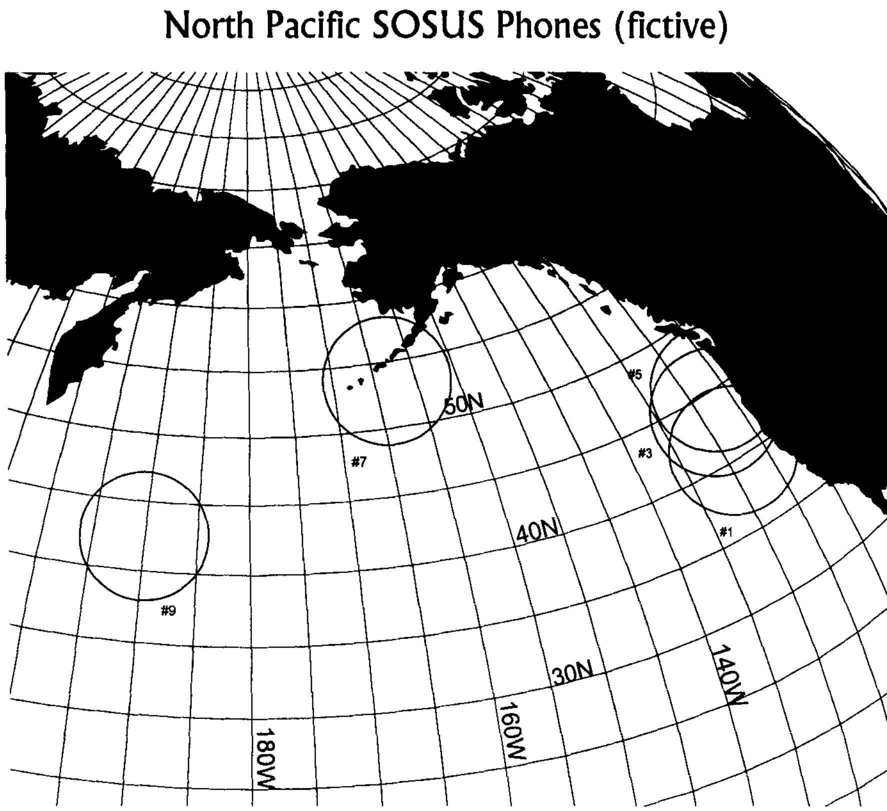

Figure 2. Map of the eastern North Pacific depicting approximate areas monitored by the five SOSUS sites.

whale calls during the pilot study (Fig. 2). In general, the five areas include waters ~500 km west of the U.S. west coast (sites #1, #3, and #5), south of the Alaskan Peninsula (site #7), and toward the Emperor Seamounts (site #9) in the western North Pacific. Sites offshore the U.S. west coast are roughly 185–370 km apart and so monitor overlapping areas.

During the pilot study, digital data up to 50 Hz were recorded from a single hydrophone at each SOSUS site and sent to NMML for analysis of whale calls. Because signals were received at high rates, a pseudo-random sampling strategy was adopted to extract portions of tape for analysis. The basic sampling unit was a 10-min segment. Each segment of the 24-h day was sampled once during a 2-wk period. Three of six segments for each hour of the day were randomly drawn from the first week and the remaining three from the second week. Over the course of the pilot study 3,744 segments (*i.e.*, 144 segments/2-wk period × 26 periods) were sampled at each of the five SOSUS sites. Therefore, total call counts for each site represent a 624-h sample, composed of 26 24-h samples, scored bi-weekly over the one-year period.

To process samples, NMML developed file conversion programs in Turbo

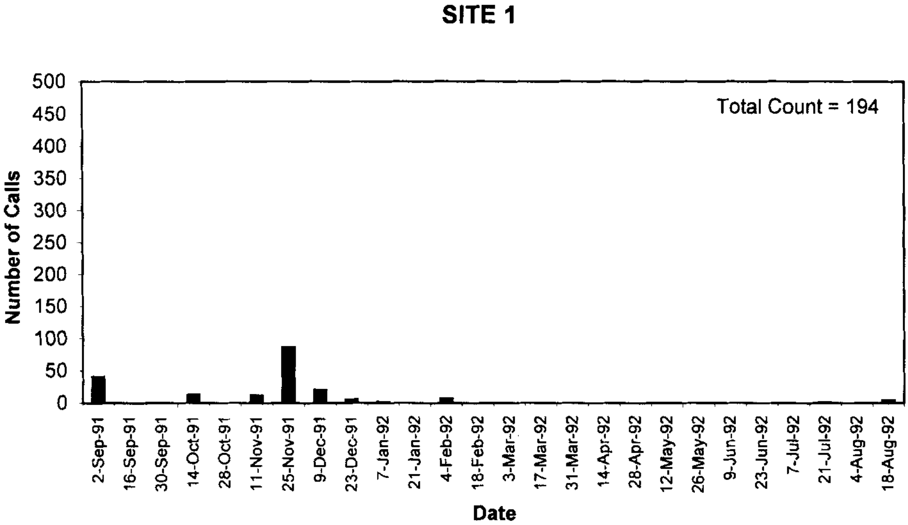

Figure 3. Histograms of fin whale call reception at five SOSUS sites in the North Pacific, September 1991–August 1992. Call counts represent a 60-min sample drawn over a 2-wk period; date reflects midpoint of sampling period.

Pascal (Borland) and Microsoft QuickC for use with SIGNAL (Engineering Design), an acoustic analysis software package. Signals with characteristics that could be identified by eye after spectral analysis were classified by temporal and frequency parameters. The distinctive 1-sec, 20-Hz calls attributed to fin whales were classified as "Pulse 20" (P20) signals. P20 signals were counted automatically by a SIGNAL-based analysis algorithm trained to recognize a pulse series as a signal event. Post-analysis, P20 signals were randomly checked to verify proper classification. The verification procedure indicated that the algorithm correctly identified P20 signals 93% of the time. Error was attributed to 7% of the overall sample when the algorithm was triggered by a single pulse, not likely of biological origin.

A total of 4,274 P20 signals were tallied during the pilot study, with the greatest number of calls at SOSUS site 3 (n = 1,625, 38%), the fewest at site 1 (n = 194, 4%), and about the same number at sites 5, 7 and 9 (n = ~800, ~20%). Histograms of counts per 2-wk period at each SOSUS site depict seasonal variation of call reception (Fig. 3). At site 1, calls were received only between August and February, with a small peak in number in November. Call reception at site 3 was bimodal over the first six months of the study, with the largest peaks in September and October, secondary peaks from December to February, and few the rest of the year. At site 5, call reception was relatively uniform from July through September, with small peaks in November, February, and May. Histograms of call counts at sites 7 and 9 were reversed from each other, with call rates at site 7 high from May through August, and site 9 high from September through November, and few calls at either site the rest of the year.

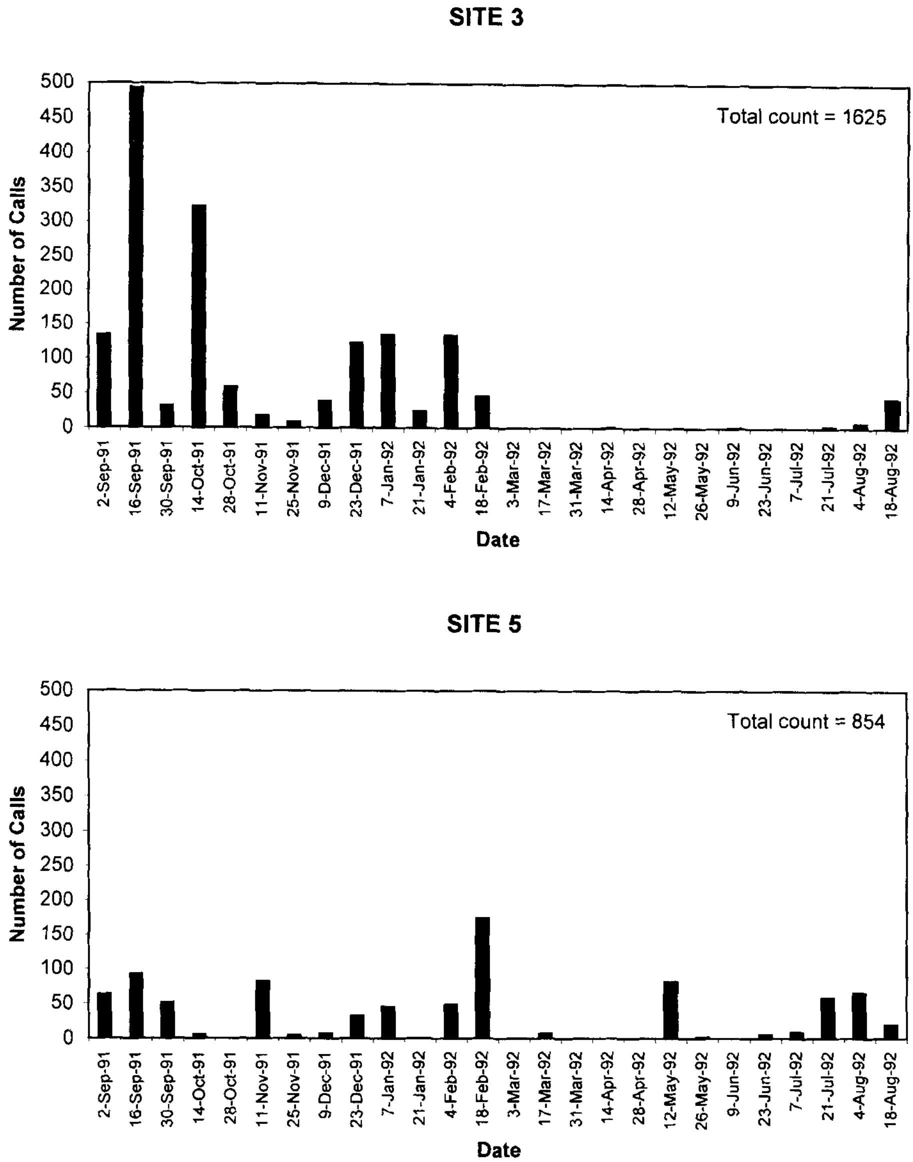

Figure 3. Continued.

Although limited to a 48-h/mo sample at each site, the reception of calls at the five SOSUS sites can be correlated with fin whale behavioral ecology. Generally, mysticete migrations are presumed to be a means for whales to find and forage upon seasonal dense patches of prey (Nemoto 1970, Katona and Whitehead 1988). Fin whales feed on zooplankton and schooling fish and aggregate where prey densities are high (Piatt and Methven 1992, Piatt *et al.* 1989). Concentrations of zooplankton and fishes generally occur in areas of

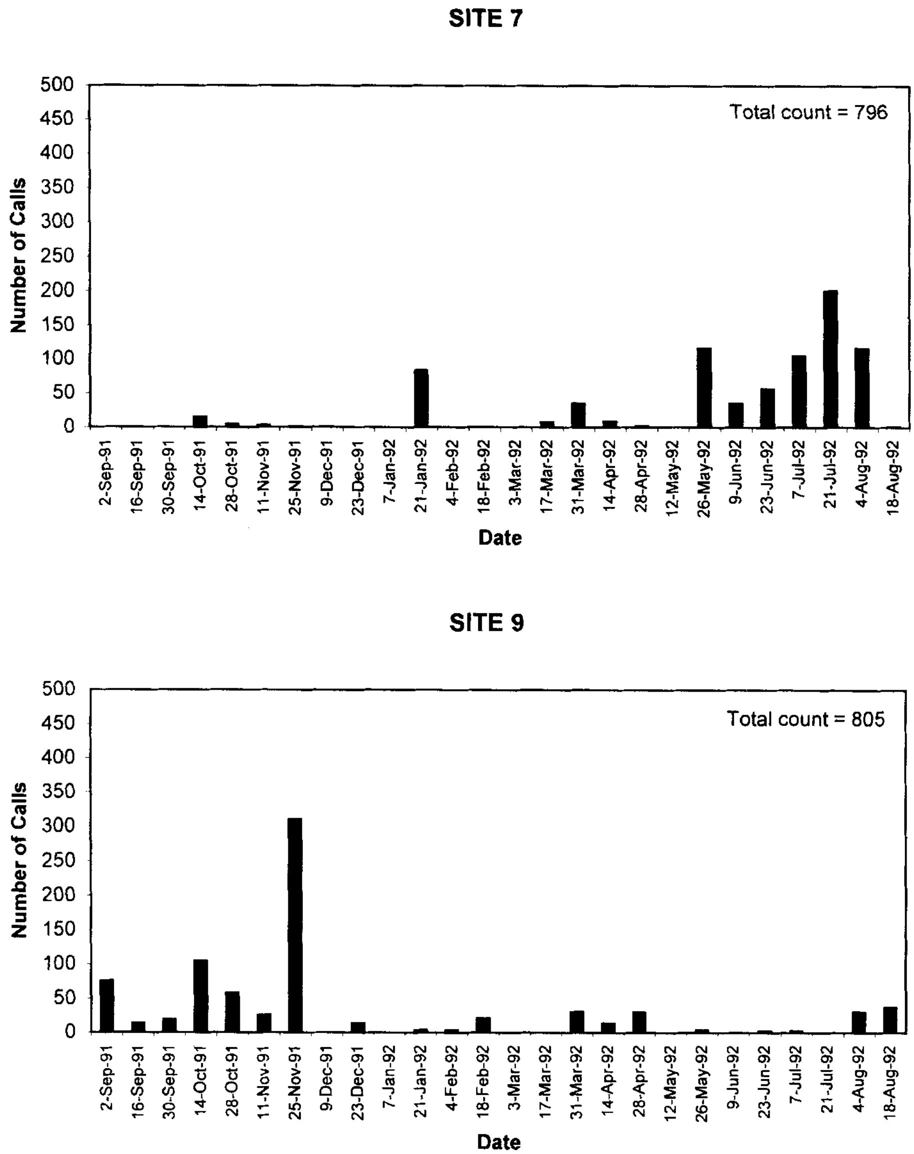

Figure 3. Continued.

high productivity and along oceanic fronts, which are often associated with bathymetric features such as the continental shelf and slope, submarine canyons, and seamounts (Steele 1974, Boehlert and Genin 1987, Dower *et al.* 1992). Each SOSUS site monitored waters associated with distinctive bathymetric features. Sites 1, 3, and 5 received calls of fin whales occupying continental shelf and slope waters offshore of the U.S. west coast, as well as whales associated with nearby seamounts farther west (*e.g.*, Cobb, Thompson, Brown

Bear, *etc.*). SOSUS sites 7 and 9 monitored waters of the Aleutian Trench and toward the Emperor Seamounts, respectively. Further, these areas lie within dynamic oceanographic domains: sites 1, 3, and 5 in the California Current, site 7 in the Alaskan Counter Current, and site 9 in the North Pacific Current.

From vessel and aerial survey sighting data, Barlow (1995) estimated the fin whale population offshore California in summer/fall 1991 to number 935 whales (CV = 0.635), with an estimate of only 49 whales (CV = 1.012) for the winter/spring period (Forney *et al.* 1995). Sites 1, 3, and 5 monitored broad areas offshore of the U.S. west coast for fin whale calls, including part of the range of the California population. All three of these SOSUS sites exhibited increased call reception from summer through winter, with peaks during fall and winter months. However, because acoustic monitoring is not limited by visibility, weather, or presence of observers, each hydrophone indicated differences in seasonal call pattern not apparent from sighting data. Of note, call counts at site 1 increased to their highest level in November coincident with a lull in call reception at site 3. Call counts at site 5 exhibited peaks in February (18 February) and May (12 May), when P20 signals were essentially absent at sites 1 and 3. In addition, the period of consistent, relatively high call counts at site 5 (21 July–30 September) preceded that at site 3 by roughly one month (18 August–28 October).

Call reception patterns at sites 1, 3, and 5 could indicate one fin whale population moving among feeding areas in the eastern North Pacific, or calls from several subpopulations. In the North Atlantic Ocean at least some fin whales were quite site-tenacious, with 30%–50% of identified individuals returning to a specific feeding area in subsequent years (Seipt *et al.* 1990). Fin whales were seen offshore from Oregon near an area of high bathymetric relief called Newport Valley (near SOSUS site #1) during aerial surveys conducted between May and September in 1989 and 1990, although sighting rates varied by an order of magnitude between years (Brueggeman 1992). In addition, summertime aggregations of fin whales were seen offshore from the Alaskan Peninsula in waters monitored by SOSUS site 7 (Springer *et al.* 1996), and sightings from Japanese whaling vessels collated from 1964 to 1990 indicated relatively high fin whale abundance near the Emperor Seamounts (site 9) from May through September (Miyashita *et al.* 1995).

Patterns of fin whale call reception also generally corresponded to seasonal productivity in the areas monitored. The California Current is a highly dynamic and productive zone, with a strong seasonal presence of cold, nutrient-rich, upwelled water in June and July alternating with a warm, stratified period in September and October (Schwing and Mendelssohn 1997). Indeed, a summer-fall influx of blue whales (*Balaenoptera musculus*) and humpback whales (*Megaptera novaeangliae*), coincident with the stratified period, has been well documented in recent years (Calambokidis *et al.* 1996, Schoenherr, 1991). Similarly, in the central North Pacific many mobile marine organisms, including squids, pomfrets, and blue sharks, migrate to and occupy the Transition Zone (site 9) during the fall-winter and the Subarctic Domain (site 7) in the summer-fall (Murata and Hayase 1993, Pearcy 1991) when secondary productivity is high due to ample light and warmer water. However, in winter the Transition Zone is the preferred foraging area due to its moderate temperature and smaller seasonal fluctuation in productivity (Springer *et al.* 1996, Tanaguchi 1981).

Although patterns of fin whale call reception generally concurred with available sighting data and patterns of seasonal productivity, two important caveats must be kept in mind when interpreting the histograms: (1) variation in call reception could be due to both (a) whale occurrence and behavior and/or (b) sound transmission properties of the water column; and (2) the pilot study call counts depict a compilation of 10-min samples recorded at single hydrophones and therefore represent acoustic "snapshots" of a local area. First, fin whales must have been within acoustic range of a hydrophone for calls to be received. However, the possible effects of behavior on call production and reception are as yet poorly understood. As important, perhaps, are seasonal changes in the physical attributes of the water column that can facilitate or inhibit call reception at the hydrophones by altering sound transmission pathways. Events such as upwelling can affect both whale distribution (*via* increased prey availability), and sound transmission characteristics of the water. Thus, the strong seasonal upwelling cycles evident in the California and Alaskan currents likely play an, as yet, unquantifiable role in the reception of whale calls at SOSUS sites. Therefore, biological and physical factors, as well as the short sample periods, likely caused fin whale calls to be 'missed' during the pilot study. Further, while data from this pilot study extended the scope of acoustic monitoring to five broadly spaced areas across the North Pacific Ocean, the counts from single hydrophones did not reflect the capability of SOSUS to detect whales at far greater ranges *via* beam-formed signal processing.

The SOSUS facility is a unique and important tool for monitoring calling whales in the pelagic environment (Cummings and Thompson 1994, Stafford and Fox 1996). SOSUS allows sampling over spatial and temporal scales previously unavailable to marine mammalogists, but potentially of key importance to investigations of cetacean ecology. Standard visual survey techniques will likely remain largely limited to continental shelf waters by logistic and funding constraints. The use of long-range passive acoustics, available with long-term deployments of deep-water hydrophones in pelagic waters in association with broadscale monitoring of oceanic processes, promises to dramatically increase our knowledge of cetacean ecology and population dynamics.

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