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Marine mammal distribution in Ecuador: surveys aboard a ship of opportunity as a means of monitoring relative abundance

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Abstract. Five marine mammal surveys between 2008 and 2011 were conducted aboard the *Buque de Investigación Orion* (the research vessel for the Oceanographic Institute of the Ecuadorian Navy) within oceanic waters adjacent to mainland Ecuador and the Galápagos Islands. The surveys dedicated extensive time in deep, offshore waters where cetaceans were not densely present. Sightings of 12 species were compared with an earlier survey aboard the *B/I Orion* in 2001 as well as with a subset of published data from three NOAA STAR (*Stenella* Abundance Research) surveys between 1999 and 2003. Additionally, a small boat, near-shore survey, was conducted during June 2010 among and near the Galápagos Islands. Encounter rates ranged annually from 0.012 cetacean/km to 0.027 cetacean/km. The highest encounter rate aboard the *B/I Orion* took place during the April 2009 survey. In order to compare sighting rates between the *B/I Orion* and NOAA platforms, the average effective half-strip widths were used to determine encounter rates per area effectively searched. A zonation within the study region was observed between odontocete and balaenopterid cetaceans as well as between striped (*Stenella coeruleoalba*) and short-beaked common dolphins (*Delphinus delphis*). Several methodological aspects of surveys and geographical features that may influence encounter rates and subsequent abundance estimates are discussed. This study demonstrates that vessels of opportunity provide a valuable means of studying open-ocean and coastal distributions of marine mammals. Possible methodological improvements, such as the use of high-power binoculars, that could increase the absolute number of sightings, the efficiency of these opportunistic surveys, and improve the sighting rates of more evasive species are discussed.

Resumo. Cinco levantamentos de mamíferos marinhos foram realizados entre 2008 e 2011 a bordo do *Navio de Pesquisa Orion* (a embarcação de pesquisa do Instituto Oceanográfico da Marinha Equatoriana) em águas oceânicas adjacentes ao Equador continental e Ilhas Galápagos. Os levantamentos dedicaram extensos períodos a águas profundas de alto mar, onde os cetáceos não apresentam densas populações. Avistagens de 12 espécies foram comparadas a resultados de levantamento anterior realizado a bordo do mesmo *N/P Orion* em 2001, assim como a um subconjunto de dados publicados a partir de três levantamentos NOAA STAR (Pesquisa de Abundância de *Stenella*) conduzidos entre 1999 e 2003. Além disso, um levantamento próximo à costa a bordo de pequena embarcação foi conduzido durante junho de 2010 nas Ilhas Galápagos e proximidades. As taxas de encontro variaram anualmente de 0,02 cetáceo/km a 0,027 cetáceo/km. A maior taxa de encontro registrada a bordo do *B/P Orion* ocorreu durante o levantamento de abril de 2009. A fim de comparar taxas de avistagem obtidas pelo *B/P Orion* e as plataformas NOAA, as larguras médias efetivas de meia banda foram usadas para determinar as taxas de encontro por área efetivamente pesquisada. Uma zonação foi observada dentro da área de estudo entre cetáceos odontocetos e balenopterídeos, assim como entre golfinhos-

listrados (*Stenella coeruleoalba*) e golfinhos-comuns-de-bico-curto (*Delphinus delphis*). Vários aspectos metodológicos dos levantamentos e características geográficas que podem influenciar as taxas de encontro e subsequentes estimativas de abundância são discutidos. Este estudo demonstra que plataformas de oportunidade oferecem um valioso meio para o estudo de distribuição de mamíferos marinhos, costeira e de mar aberto. Discutem-se possíveis melhorias metodológicas, como o uso de binóculos de alta potência que podem aumentar o número absoluto de avistagens e a eficiência desses levantamentos oportunísticos, e aprimorar as taxas de avistagem de espécies mais evasivas.

Introduction

The Eastern Tropical Pacific (ETP) is a biologically productive region of the world's oceans. A small portion of this region stretching westward from the South American continent, the Equatorial Pacific, is responsible for 18-56% of the global ocean new biological production (Chavez and Barber, 1987). Marine mammals, as large and generally apex predators that can consume hundreds of kilograms of marine prey each day, play an important role in this ecosystem and have been impacted for centuries through anthropogenic influences. Regular surveys to assess marine mammal abundance and distribution are vital for furthering our understanding of both the distribution and ecological role of these animals and the impacts of anthropogenic activities. Marine mammal and human interaction within the ETP began in the 18th and 19th centuries with the advent of the region's whaling industry (Townsend, 1935). Whaling expeditions continued through the early 20th century, but scientific observation of cetaceans did not begin until the 1950s and 1960s (*e.g.* Clarke, 1962; Loesh, 1966).

The coastlines within the area now encompassing the Galápagos Marine Reserve (GMR) as well as the Ecuador mainland are biologically productive habitat for marine mammals. Dedicated studies of the sperm whale (*Physeter macrocephalus*) population continued around the Galápagos Islands and Ecuador mainland coast in the 1980s (*e.g.* Whitehead and Waters, 1992; Smith and Whitehead, 2000). From 1988 to 1989 the *R/V Siben* surveyed sperm whales throughout the Galápagos Archipelago, and in 1993-1994 and 2000 the *R/V Odyssey* conducted multiple marine mammal surveys near this same region[1,2]. More recent survey work within the GMR utilized ecotourism vessels as platforms of opportunity and provided detailed information on cetacean species composition within the Reserve (Denkinger *et al.*, 2013). The migratory population of humpback whales (*Megaptera novaeangliae*) can be found within the GMR as well as along the mainland coast from May through September (Félix and Haase, 2001).

A coastal population of common bottlenose dolphins (*Tursiops truncatus*) continues to be well documented along the mainland coast and inside the mouth of the Guayaquil River (*e.g.* Félix, 1997). These coastlines serve as breeding and mating grounds for the humpback whales and bottlenose dolphins (Scheidat *et al.*, 2000; Félix and Haase, 2001; 2005; Alava *et al.*, 2005).

Information on cetacean presence in offshore waters, however, is more difficult to obtain than in coastal and insular waters, but nevertheless it is important to fully understand their distributions and monitor the recovery of species impacted by human activities. For example, results from Félix *et al.* (2011) suggest at least some degree of relatedness between members of the mainland coastal humpback population and those humpbacks found across a nearly thousand mile stretch of ocean within the Galápagos Archipelago. From the 1980s through the present, NOAA Southwest Fisheries Science Center has conducted extensive and dedicated marine mammal surveys throughout the ETP, including areas within Ecuadorian waters, to assess the effects of the yellowfin tuna (*Thunnus albacares*) purse seine fishery on dolphin populations (*e.g.* Au and Perryman, 1985; Fiedler and Reilly, 1994; Gerrodette and Forcada, 2005)[3,4,5]. The STAR surveys provided reliable abundance estimates for cetacean species throughout the ETP region that encompasses Ecuador and the GMR.

Marine mammal surveys conducted aboard the *B/I Orion* in August 2000 and September 2001 sighted seven species of cetaceans within the oceanic and coastal waters of Ecuador. The absence of sperm whales, currently considered vulnerable by the International Union for the Conservation of Nature

[1]Lyrholm, T., Kerr, I., Galley, L. and Payne, R. (1992) *Report of the Expedición Siben, Ecuador 1988/89. Final Report* submitted by the Whale Conservation Institute to the Charles Darwin Research Station and the Galápagos National Park Service. Puerto Ayora, Islas Galápagos, Ecuador.

[2]Palacios, D.M. (1999) *Final report submitted to Galápagos National Park Service and Charles Darwin Research Station: Marine mammal research in the Galápagos Islands: The 1993–94 Odyssey Expedition.* Puerto Ayora, Islas Galápagos, Ecuador. [Available from Ocean Alliance, 191Weston Rd., Lincoln, MA 01773, USA]

[3]Gerrodette, T. and Palacios, D.M. (1996) Estimates of cetacean abundance in EEZ waters of the Eastern Tropical Pacific. National Marine Fisheries Service, Southwest Fisheries Science Center *Administrative Report LJ-96-10.* [Available from SWFSC <swfsc.noaa.gov>]

[4]Jackson, A., Gerrodette, T., Chivers, S., Lynn, M., Olson, P. and Rankin, S. (2004) Marine mammal data collected during a survey in the Eastern Tropical Pacific Ocean aboard the NOAA ships *McArthur* and *David Starr Jordan,* July 29-December 10, 2003. US Department of Commerce, National Oceanic Atmospheric Administration, Southwest Science Fisheries Center, NOAA-TM-SWFSC-366. [Available from SWFSC <swfsc.noaa.gov>]

[5]Gerrodette, T., Watters, G., Perryman, W. and Balance, L. (2008) Estimates of 2006 dolphin abundance in the Eastern Tropical Pacific, with revised estimates from 1986-2003. US Department of Commerce, National Marine Fisheries, Southwest Science Fisheries Center, *NOAA-TM-NMFS-SWFSC-422. [Available from SWFSC <swfsc.noaa.gov>]*

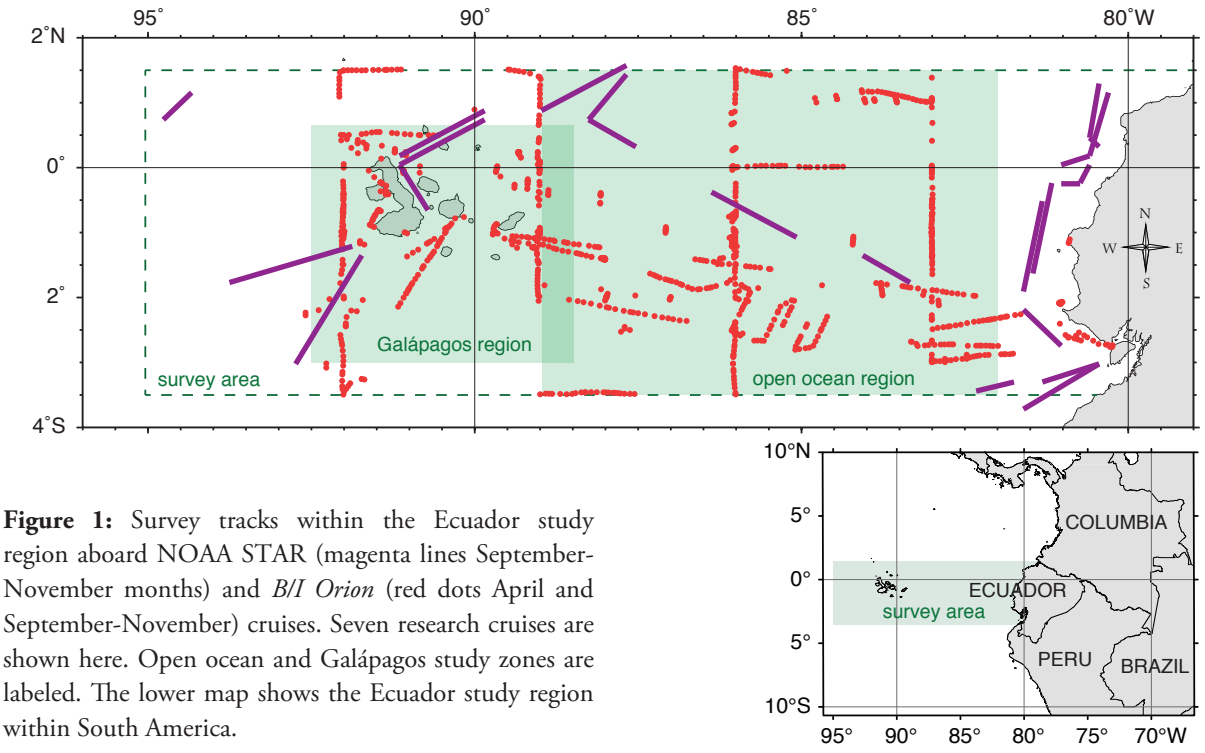

Figure 1: Survey tracks within the Ecuador study region aboard NOAA STAR (magenta lines September-November months) and *B/I Orion* (red dots April and September-November) cruises. Seven research cruises are shown here. Open ocean and Galápagos study zones are labeled. The lower map shows the Ecuador study region within South America.

(Taylor *et al.*, 2008), was noted as the most significant departure from previous mammal surveys (Clarke *et al.*, 2001) and supported the findings of Whitehead *et al.* (1996) that also observed a rapid decline in the sperm whale population near the Galápagos Islands prior to and during this time period. By including marine mammal surveys in annual oceanographic cruises aboard a ship of opportunity, *B/I Orion* (the research vessel for Ecuador's Instituto Oceanográfico de la Armada, INOCAR), remote and oceanic areas of Ecuadorian waters were regularly surveyed over several years (2008-2011). The results from these surveys are compared to sightings and survey work aboard three NOAA *Stenella* Abundance Research (STAR) Surveys[4,6,7], and utilized in conjunction with two other surveys to provide an overall summary of marine mammal presence within oceanic waters adjacent to the coastlines of Ecuador. A summary list of cruises is presented in Table 1. The results also inform improvements that can be made to ships-of-opportunity marine mammal surveys.

[6]Kinzey, D., Gerrodette, T., Barlow, J., Dizon, A., Perryman, W. and Olson, P. (2000) Marine mammal data collected during a survey in the Eastern Tropical Pacific Ocean aboard the NOAA ships *McArthur* and *David Starr Jordan,* July 28-December 9, 1999. US Department of Commerce, National Oceanic Atmospheric Administration, National Marine Fisheries, Southwest Science Fisheries Center, *NOAA-TM-NMFS-SWFSC-293.* [Available from SWFSC <swfsc.noaa.gov>]

[7]Kinzey, D., Gerrodette, T., Dizon, A., Perryman, W., Olson, P. and Rankin, S. (2001) Marine mammal data collected during a survey in the Eastern Tropical Pacific Ocean aboard the NOAA ships *McArthur* and *David Starr Jordan*, July 28-December 9, 2000. US Department of Commerce, National Oceanic Atmospheric Administration, National Marine Fisheries, Southwest Science Fisheries Center, *NOAA-TM-NMFS-SWFSC-303.* [Available from SWFSC <swfsc.noaa.gov>]

Methods

Field Surveys

Between 2008 and 2011, marine mammal surveys were conducted aboard a vessel of opportunity as a collaboration between Texas A&M University and INOCAR. The *B/I Orion* is a 70m oceanographic vessel for INOCAR and maintains average survey speeds of 7-10 knots. In 2001, Clarke *et al.* (2001) conducted a similar marine mammal survey aboard the *B/I Orion.* During 2001-2011, cruises of the *B/I Orion* followed pre-determined North-South tracklines and East-West transit lines and made regular oceanographic measurements. These surveys were conducted within a region bounded by 1°30'N, 3°30'S and 79°0'W, 95°0'W and encompassing 895480km2 (Figure 1).

The visual surveys were conducted from the flying bridge, 9.8m above the waterline (measured distance from the average observer's eye height while standing), during all daylight hours (approximately 06:00-18:30h). Effort was suspended when the ship stopped for CTD (Conductivity Temperature Depth) measurements, 30-minute meal times, and times when weather conditions did not permit a clear view of the sea surface (heavy rain and Beaufort sea states >5).Observers numbered 2-4 depending on volunteers available (number and skill level of observers on watch were recorded with observing conditions). Observers used Bushnell 7x50mm binoculars to scan continuously from forward of the ship out to each beam (90° from the bow to port and starboard) and from the ship hull to the horizon. Field observation during the 2008-2011 surveys followed, as closely as possible, the line-transect methods described in Mullin and Fulling

Table 1. Summary of survey cruises within the Ecuador study region 1991-2011.

Year	Dates of Effort in Survey Area	Ship Name
1999	12 Oct, 18 Oct, 8 Nov to 10 Nov	*R/V Jordan*
2000	6 Oct to 10 Oct, 5 Nov to 9 Nov	*R/V McArthur II*
2001	17 Sep to 8 Oct	*B/I Orion*
2003	10 Oct to 12 Oct, 7 Nov to 9 Nov	*R/V McArthur II*
2008	23 Sep to 10 Oct	*B/I Orion*
2009	2 Apr to 21 Apr	*B/I Orion*
2009	7 Oct to 30 Oct	*B/I Orion*
2010	4 Jun to 14 Jun	fishing boats
2010	25 Sep to 9 Oct	*B/I Orion*
2011	25 Sep to 9 Oct	*B/I Orion*

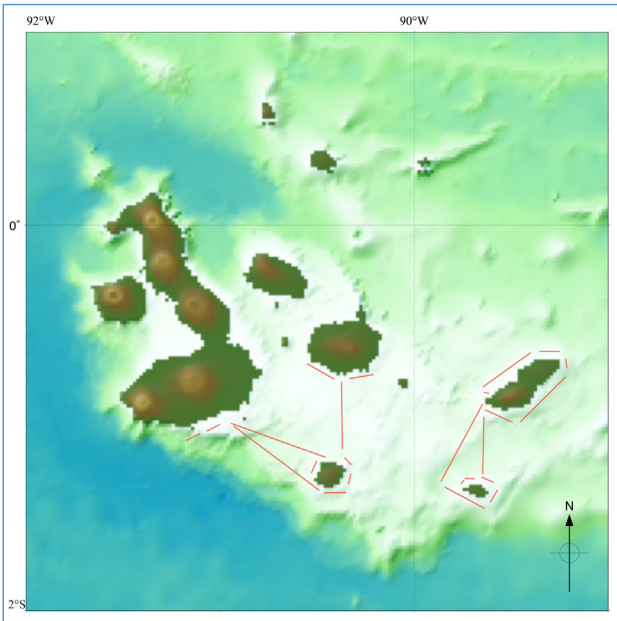

Figure 2. Survey tracks for a small boat survey near the Galápagos Islands, June 2010. Nine days of survey effort are shown.

(2004) and those protocols from other ships-of-opportunity studies as in Palacios *et al.* (2009) and Williams *et al.* (2006). Field methods employed during the 2001 *B/I Orion* cruise and NOAA SWFSC STAR cruises are described in Clarke *et al.* (2001) and Gerrodette *et al.*[5], respectively. There were several important differences between cruises aboard the *B/I Orion* and NOAA ships. First, the NOAA STAR cruises are dedicated marine mammal surveys where the ships diverted from tracklines to approach and identify groups of animals. In contrast, *B/I Orion* surveys were conducted in passing mode as the ship transited to the sites of hydrographic stations and therefore the ship did not deviate from its course to approach sighted groups of cetaceans. NOAA STAR cruises were staffed by a large number of trained observers that rotated watches on regular intervals. These observers used 25x150mm 'Big Eye' binoculars that enabled them to reliably observe cetaceans over a much greater distance (a larger half-strip width) than the smaller 7x50mm binoculars used by observers on the *B/I Orion*. The *B/I Orion* cruises were also used as training cruises for graduate students new to marine mammal observing, with at least one expert observer (with both theoretical and field training aboard NOAA line transect marine mammal surveys) working with the student observers during each shift.

During the June 2010 small boat survey (Figure 2), a 50ft. fishing boat, *Lancha Cucaracha*, was chartered out of Puerto Ayora, Santa Cruz, Galápagos for a three day survey between Puerto Ayora, Isla Floreana, and Puerto Villamil, Isabela. Observers watched from the flying bridge helm during daylight hours while traveling at an average speed of 10 knots. While handheld 7x50 binoculars were available, naked-eye observation was more common. Sighting conditions (Beaufort sea state, cloud cover, sun glare) and GPS positions were noted every 30 minutes. A 65ft fishing vessel, *Niño Ronny Jesus*, was chartered out of San Cristobal for a six-day survey around San Cristobal and Española Islands. Observing conditions were better and sea state was lower, during this portion of the survey.

Analytical Methods

Data were compiled from ten separate cruises conducted over a 12-year time period (Table 1). Eight of these cruises took place during the September/October rainy season, five of which were conducted aboard the *B/I Orion* and three of which were conducted as part of the NOAA STAR program. Published sightings from the NOAA STAR cruises[4,6,7] were compared to sighting rates from the *B/I Orion.* One cruise was conducted during the April dry season aboard the *B/I Orion* and another small boat survey conducted between the Galápagos Islands took place during the month of June. These last two surveys were the only survey data utilized from seasons outside the rainy season.

The abundances of striped (*Stenella coeruleoalba*) and short-beaked common dolphins (*Delphinus delphis*) were calculated using a modified distance sampling method. Since the NOAA cruises encompassed the entire ETP, only those sightings and survey effort that occurred within our study area of 1°30'N, 3°30'S and 79°0'W, 95°0'W were used to calculate NOAA specific abundances. Published $f(0)$ values for striped and common dolphins from the NOAA STAR cruises were used when calculating abundances of these species within Ecuadorian waters.

The computer program Distance 6.0 (Thomas *et al.*, 2010) was used to model a probability density function from the initial sighting distances between shipboard observers and cetacean groups during the 2008 and 2011 *B/I Orion* cruises. Radial sighting distances were calculated according to the formula from Lerzack and Hobbes (1998), and radial distances were used to calculate the perpendicular distances between observers aboard the *B/I Orion* and sighted cetaceans.

$$P = R \times \sin(\theta)$$

where P is the horizontal distance between the trackline and sighted animal and θ is the horizontal angle between the trackline and the animal.

Due to insufficient number of sightings of each species, a single probability density function or $f(0)$ was modeled for all cetacean sightings aboard the *B/I Orion*.

A hazard rate model for sighting distances made aboard the *B/I Orion* was selected based on the calculated Akaike Information Criterion (AIC) values from several models considered.

$$f(x) = 1 - \exp\left\{-\left(\frac{x}{b}\right)^{-c}\right\}$$

where $\boldsymbol{x}$ is the perpendicular distance from the survey line, and $\boldsymbol{b}$ and $\boldsymbol{c}$ are constants.

The detection probability, $\boldsymbol{g(0)}$ is often assumed to equal 1 (that all animals on the trackline were detected). This assumption is likely an overestimation, particularly during survey effort in which the Beaufort sea state was greater than 1 or 2. Barlow (2015) calculated Beaufort specific $g(0)$ values for several cetacean species in the ETP. Published $g(0)$ values at each Beaufort state were included in abundance calculations for striped and common dolphins using *B/I Orion* sightings. Abundance (N) was calculated from the probability density function as described in Buckland *et al.* (1993; 2001), where the sampling unit for these estimates was the cruise year, not individual tracklines. These abundance estimates from *B/I Orion* sightings were compared to those calculated from sightings made during NOAA surveys.

$$N_{NOAASurveys} = \sum_{1999}^{2003} \frac{s_n \times f(0)}{2 \times L} \qquad N_{OrionSurveys} = \sum_{2001}^{2011} \frac{s_n \times f(0)}{2 \times L \times g(0)_B}$$

Where $\boldsymbol{n}$ is the number of sightings of cetacean groups, $\boldsymbol{s}$ is the group size at sighting n, $\boldsymbol{f(0)}$ is the probability density function at zero distance from the transect line, $\boldsymbol{L}$ is the total length of the transect lines, and $\boldsymbol{g(0)}$ is the detection probability at each discrete Beaufort sea state.

The distance from the ship at which observers could reliably spot marine mammals was calculated from the effective half-strip width. The effective half-strip width or μ is the distance from the trackline where the number of groups seen at distances greater than μ equals the number not seen at distances less than μ. The half-strip width was calculated from $f(0)$ by the following, as shown in Buckland *et al.* (1993):

$$\mu = \frac{1}{f(0)}$$

This calculation assumes that all animals on the trackline were observed, which is likely an overestimation.

Sighting rates were calculated from total number of sightings divided by total kilometers surveyed within each cruise. Since low sighting numbers of individual species prevented species specific estimates, for each survey a sighting rate based on total combined cetacean sightings was calculated. This combined cetacean annual encounter rate allowed for interannual variability comparisons between cruises, seasons, and survey years.

$$\frac{n}{L}$$

In order to better compare sighting rates between the two different survey programs, NOAA STAR and *B/I Orion*, sighting rates were also calculated for each survey relative to the total trackline area that was reliably observed. The trackline area observed was calculated from μ.

$$\frac{n}{2 \times \mu \times L}$$

The number of observers on watch, skill level of observers, cloud cover, and the Beaufort sea state displayed linear relationships with overall encounter rates. Beaufort sea state was determined to be the most significant factor influencing sighting rates and included in sighting rate estimates for relative comparisons.

$$\frac{n}{l} = \sum \frac{1 - (R_a \times a)}{2 \times ESW \times l}$$

where $\boldsymbol{n}$=number of sightings for each survey, $\boldsymbol{l}$=length in km of survey effort for each survey, $\boldsymbol{a}$=Beaufort sea state of each sighting, $\boldsymbol{R}$=correlation coefficient between the observing condition (Beaufort sea state) and sightings for each survey, $\boldsymbol{ESW}$=effective strip width (1.7km).

The variance of encounter rates among surveys was calculated according to Buckland *et al.* (1993).

$$\mathrm{var}\left(\frac{n}{L}\right) = \frac{\sum_{i=1}^{k} \frac{l_i}{L}\left(\frac{n_i}{l_i} - \frac{n}{L}\right)^2}{k-1}$$

where $\boldsymbol{L}$=total survey effort for all cruises, $\boldsymbol{n}$=total number of sightings of all cruises, $\boldsymbol{i}$=survey (1999-2011), $\boldsymbol{n_i}$=number of sightings for each cruise, $\boldsymbol{l_i}$=length of survey effort of each cruise, $\boldsymbol{k}$=number of surveys.

Sighting counts were also combined across years, in order to calculate encounter rates for two different zones within the Ecuador study region (Figure 1). Sightings for an open ocean area between 82°0'W, 89°0'W longitude and 1°30'N, 3°30'S latitude were compared with those sightings surrounding the Galápagos Islands within an area defined by 88°54'W to 92°30'W and 1.0°N to 1°30'S (Figure 1). Only sightings from the September/October NOAA and *B/I Orion* cruises were used in this analysis, in order to avoid potential seasonal variations.

Results

In total, 12 different species of cetaceans were identified during the ten NOAA, *B/I Orion*, and small boat surveys within waters between mainland Ecuador and just westward of the Galápagos Islands (Table 2). A similar composition of species of marine mammals was identified within the rainy season during September/October surveys as during those surveys conducted in the drier season of April and June (with the exception of migratory humpback whales which were present along the coasts of mainland Ecuador and the Galápagos Islands during the rainy season). Sperm whales, short-finned pilot whales (*Globicephala macrorhynchus* which was not distinguished visually from *Globicephala melas*, but based on distribution maps, all pilot whales are presumed to be of the species *G. macrorhynchus*), blue whales (*Balaenoptera musculus*) and Bryde's whales (*Balaenoptera edeni*) were some of the most commonly identified large cetaceans (Figures 3 and 4).

Sighting rates varied among years, seasons, and survey programs (Table 3). The effective half-strip width for surveys aboard the *B/I Orion* was 1.7km. For the NOAA surveys examined in this study, the half-strip width (as determined by averaging half-strip widths from a variety of species observed throughout the ETP during NOAA surveys) was 3.0km. When the NOAA and *B/I Orion* sighting rates are expressed as sightings per area effectively searched (transect length times twice the effective half-strip width), sighting rates throughout the study area are 13% higher during NOAA STAR surveys than surveys aboard the *B/I Orion*.

Table 2. Cetacean and pinniped sightings made from *B/I Orion*, NOAA vessels, and small boats within the Ecuador study region 1999-2011.

Sightings per species/group	Oct 1999	Oct 2000	Sep 2001	Oct 2003	Sep 2008	Apr 2009	Oct 2009	Jun 2010	Oct 2010	Sep 2011
Blue whale	1	1	1	0	0	1	3	0	2	8
Bryde's/Sei whale	4	1	0	1	0	2	0	8	1	1
Humpback whale	0	0	4	5	2	0	1	0	3	2
Short-finned pilot whale	2	3	5	1	3	4	2	1	0	2
Orca	0	0	1	0	1	0	0	0	0	1
Sperm whale	1	0	0	0	0	3	6	1	1	4
Bottlenose dolphin	0	6	6	3	0	4	3	11	2	2
Common dolphin	14	7	2	7	2	6	4	3	4	4
Pantropical spotted dolphin	0	0	2	6	1	0	0	0	0	0
Risso's dolphin	0	1	0	0	0	0	0	0	0	1
Striped dolphin	12	5	1	7	0	2	1	0	5	2
Galápagos sea lion	0	0	0	0	24	18	11	83	8	8
Cuvier's beaked whale	2	0	0	0	0	0	0	0	0	0
Stenella sp.	0	1	0	0	0	0	0	0	0	0
Unidentified baleen whale	0	0	0	0	3	2	3	4	2	4
Kogia sp.	0	0	0	0	0	1	0	0	0	0
Unidentified beaked whale	0	0	0	0	0	0	1	0	0	0
Unidentified large whale	0	2	0	1	3	0	7	3	5	7
Unidentified dolphin	13	0	7	4	10	48	7	4	6	7
Unidentified odontocete	0	0	1	0	0	4	1	0	4	2
Unidentified small whale	1	0	0	1	8	0	0	0	0	0
Unidentified ziphiid	4	1	0	0	0	0	0	0	0	0
Unidentified mesoplondont	4	3	0	0	0	0	0	0	0	0

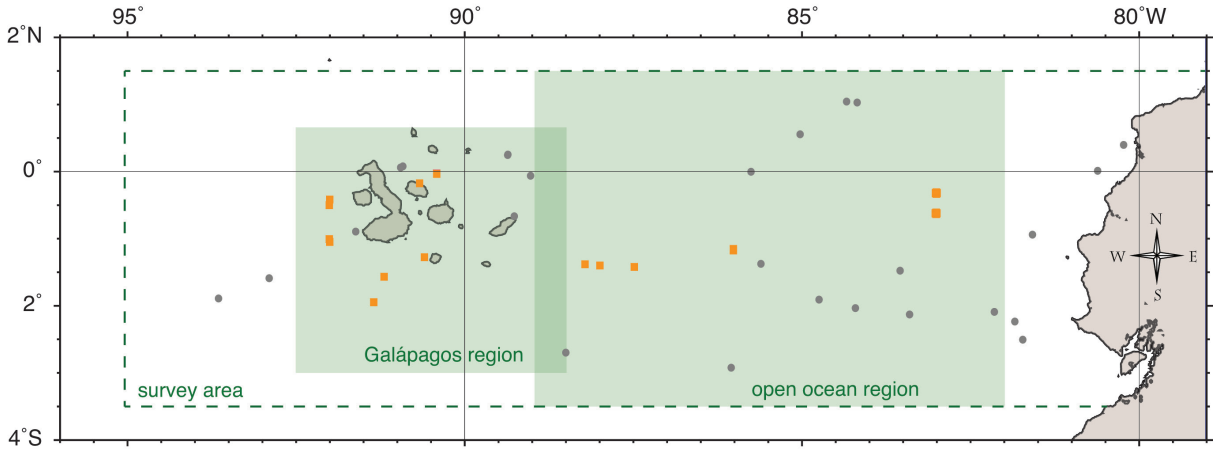

Figure 3. Sperm whale (yellow squares, n=18) and pilot whale (grey circles n=17) sightings for all NOAA cruises (1999, 2000, 2003) and *B/I Orion* cruises (2001-2011).

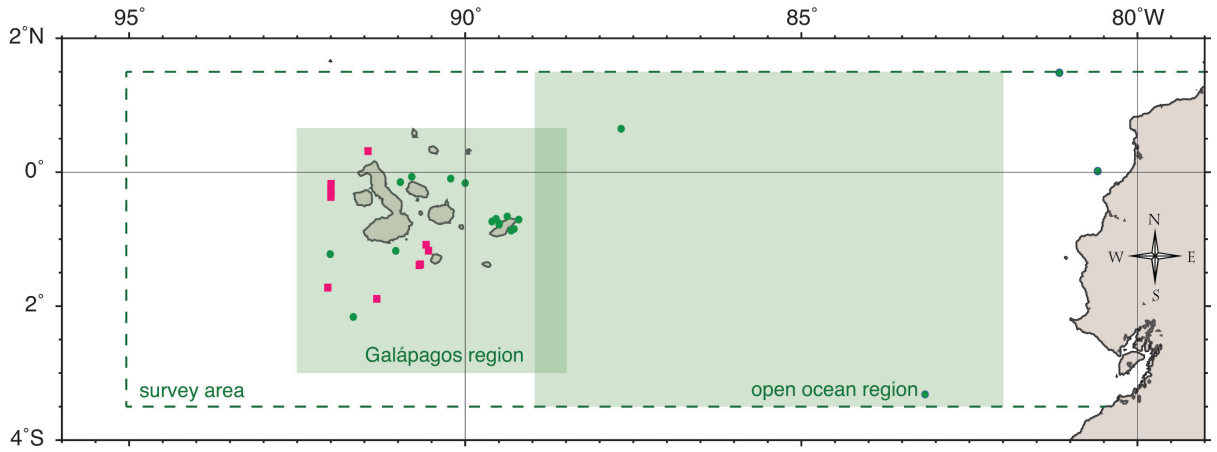

Figure 4. Blue whale (fuchsia squares n=16) and Bryde's whale (green circles n=15) sightings for all NOAA cruises (1999, 2000, 2003) and *B/I Orion* cruises (2001-2011).

The highest sighting rate took place in 1999, 0.013 animal/km in 1999 (*R/V Jordan).* The lowest rate was also during a NOAA cruise in 2003, 0.0038 animal/km in 2000 (*R/V McArthur*). The 2000 cruise only surveyed areas just off the Ecuadorian coast (within our study area), which more likely explains the low sighting rate, rather than true interannual variation.

During cruises aboard the *B/I Orion* in September/October of 2009 and 2010, sighting rates were fairly similar, 0.017 animal/km (CI 0.011-0.021). The sighting rate in September 2011, however, was 1.5 time the rate in September 2008, 0.021 animal/km (CI 0.017-0.026) compared to 0.014 animal/km (CI 0.0090-0.019) in 2008. The survey during April 2009 had the highest sighting rate for surveys made aboard the *B/I Orion*, 0.027 animal/km (CI 0.022-0.031). The sighting rate during April 2009 is significantly greater than the encounter rates during all September/October cruises with the exception of the 2011 cruise.

Sighting conditions (Beaufort sea state, cloud cover, glare) as well as the individuals working as observers varied among survey cruises. When sightings were weighted to account for the Beaufort sea state, the April 2009 sighting rate is still statistically different from the September/October cruises, excluding the 2011 cruise.

The mean estimated group size of cetacean groups also varied between survey programs. Mean group size (based on visual estimates made by observers) was 26 on *B/I Orion* surveys. The mean group size during NOAA surveys in this region was 69. Mean group size for common dolphins was two-thirds lower during *B/I Orion* (56.6) than during NOAA surveys (170). For striped dolphins, *B/I Orion* mean group size (42.8) was only one fifth lower than NOAA mean group size estimates (53.2).

Cetaceans were sighted about every 32km traveled during the June 2010, small-boat survey near the Galápagos Islands. Given that the small boat was a very different observing

Table 3. Summary of encounter rates from *B/I Orion* and NOAA vessels within the Ecuador study region 1999-2011. Area effectively searched refers to the trackline of search effort multiplied by twice the effective strip width. The observing condition corrections include adjustments for Beaufort sea state and number of observers on watch. Encounter rates that were adjusted for observing conditions should be used for relative comparisons between *B/I Orion* surveys.

Survey	Encounter rate (# sightings/ km survey effort)	95% CI	Encounter rate per area effectively searched	95% CI	Encounter rate per area effectively searched adjusted for sea state	95% CI	Sightings (#)	Survey effort (km)	Effective half-strip width
NOAA September 1999	0.080		0.0134		NA		57	709	3
NOAA September 2000	0.023		0.0038		NA		37	1626	3
NOAA September 2003	0.046		0.0076		NA		36	789	3
September/ October 2008	0.014	0.0090-0.019	0.0041	0.0027-0.0054	0.0067	0.0043-0.0091	34	2396	1.7
April 2009	0.027	0.022-0.031	0.0078	0.0064-0.0092	0.012	0.0096-0.014	76	2854	1.7
October 2009	0.017	0.011-0.021	0.0047	0.0033-0.0061	0.0062	0.0038-0.0086	42	2552	1.7
September/ October 2010	0.017	0.011-0.021	0.0047	0.0033- 1 0.006	0.0071	0.0047-0.0095	39	1389	1.7
September/ October 2011	0.021	0.017-0.026	0.0063	0.0049-0.0077	0.011	0.0086-0.013	35	2111	1.7

platform than the *B/I Orion*, these surveys were mainly intended to provide additional information on species composition near the islands outside the usual September/ October survey months. Sighting data collected from open ocean habitat for all *B/I Orion* and NOAA cruises between 82°0'W and 89°0'W resulted in sighting rates one half of those within waters near the Galápagos (0.0073 sighting/km, CV = 0.36 compared to 0.015 sighting/km, CV=0.24).

Galápagos sea lions were the only other species of marine mammal sighted during surveys aboard the *B/I Orion* (Figure 5). While pinnipeds are difficult to identify at sea, the larger size and more robust heads of the Galápagos sea lion generally permitted confident identifications by the experienced observers onboard. Photographs were often used to confirm identifications. However, given that many of these observations were made by volunteers and students still in training, it is possible that the Galápagos fur seal (*Arctocephalus galapagoensis*), which is known to inhabit the islands, particularly rocky outcroppings, was confused with the sea lions. These sightings occurred mainly near the Galápagos Islands, and were often associated with groups of bottlenose dolphins. Only two sightings of sea lions were made outside the Galápagos marine area, near 2°0'S: one sighting of a dead sea lion floating at the surface in the open ocean and one sighting just offshore of the mainland coast. These sightings were in similar areas as open ocean balaenopterid sightings.

Striped dolphins are more evenly distributed across latitudes within the study region than common dolphins. Common dolphins were more frequently sighted in the more southerly latitudes than striped dolphins (Figure 6).

The latitudinal and geographical variation in distribution observed between striped and common dolphins can also be seen in broader taxonomic groupings. In general, odontocete cetaceans, which feed primarily on nektonic species within and well below the photic layer, were found throughout the study area. Balaenopterid whales, which feed primarily within the photic zone of the ocean on plankton and small nektonic species, were generally observed along the Ecuadorian coast and near the Galápagos Islands, but sparsely north of 1°N and south of 2°S latitudes (Figure 7).

Two of the most commonly sighted cetacean species were short-beaked common dolphins and striped dolphins.

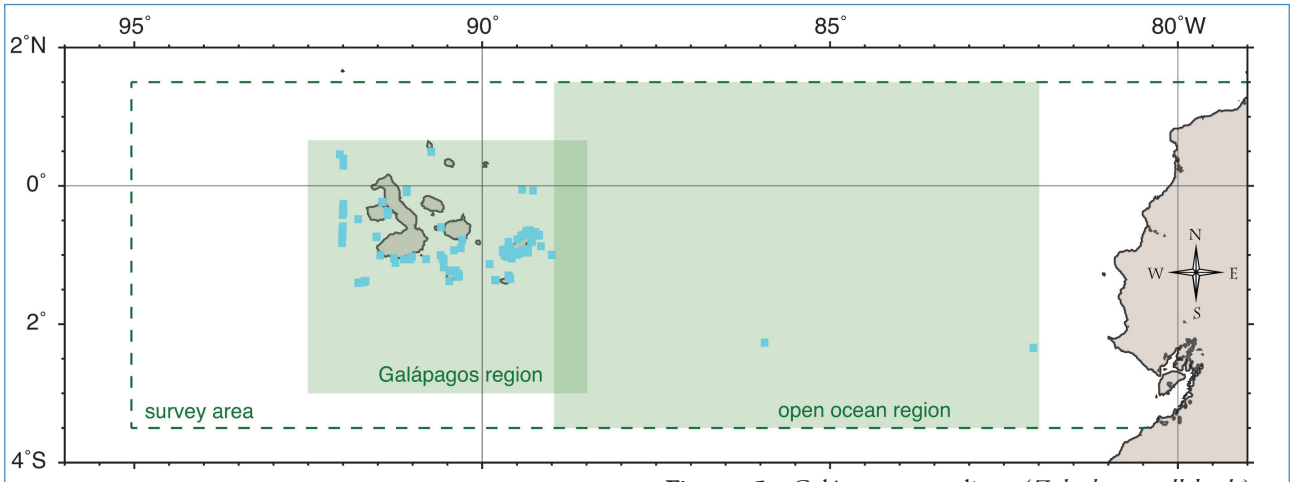

Figure 5. Galápagos sea lion (*Zalophus wollebaeki*) sightings (n=144) for all NOAA cruises (1999, 2000, 2003) and *B/I Orion* cruises (2001-2011).

Ferguson and Barlow[8] estimated mesoscale density of cetaceans based on line-transect surveys conducted throughout the ETP between 1986 and 1996. Abundance estimates were made for gridded subsections of the ETP. Based on the summed abundance estimates for those subsections that encompass our Ecuador study area, Ferguson and Barlow[9] predict an abundance of 269686 (the CV for each subsection ranges from 0.0678-0.2474) striped dolphins and 1390943 (the CV for each subsection ranges from 0.74-2.74) common dolphins within our Ecuador study area. These results agree closely with abundance estimates calculated using sighting data from NOAA cruises 1999-2003. Striped dolphins number 266050 (CV=0.214) and common dolphins number 1031000 (CV=0.273).

Using the more recent sighting data collected by *B/I Orion* (September/October of 2008-2011) within the Ecuador study area yielded abundance estimates for striped dolphins of 47640 (CV=0.173) and common dolphins of 138800 (CV=0.206).

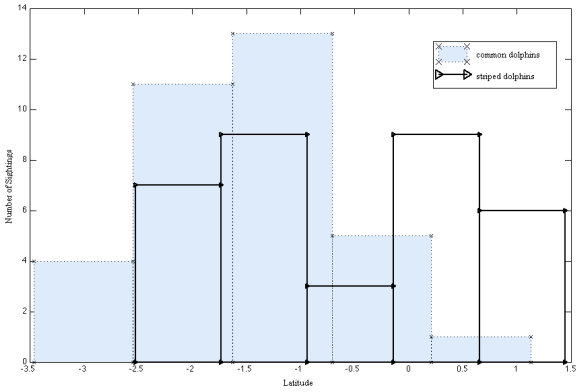

Figure 6. Number of common dolphin (blue bars) and striped dolphin (transparent bars) sightings relative to latitude during September/October cruises.

Discussion

Oceanic and coastal waters adjacent to Ecuador provide biologically productive habitat for a wide variety of marine mammals. While the abundance of cetacean species appears to fluctuate between years and possibly between seasons, the cetacean species composition is fairly consistent. The only species demonstrating definitive seasonal affiliation is the humpback whale. Multiple sightings of humpback whales were mother/calf pairs, both near the mainland and Galápagos coasts. Other balaenopterid whales may have similar seasonal patterns, however most of the marine mammal survey data available has been obtained during the rainy season months of September and October. The only surveys conducted outside the rainy season that were analyzed in this study came from April 2009 aboard the *B/I Orion* and the small boat surveys in June 2010. Bryde's whales were sighted during all seasons examined. The small boat survey observed a Bryde's pair closely followed by another individual Bryde's whale. Blue whales were also sighted in groups as well as individuals. The blue whales observed west of Fernandina Island in 2011 were believed to be feeding, given the repetitive peduncle arches and dives.

Sperm whales were also one of the more commonly identified odontocetes, which was encouraging given the multiple decades in which sperm whales appeared to have vacated the Galápagos Marine Reserve and other Ecuadorian waters (Whitehead *et al.*, 1996). Between 1999 and 2008, just one sperm whale sighting was recorded[9]. From 2009-2011, 15

[8]Ferguson, M.C. and Barlow, J. (2001) Spatial distribution and density of cetaceans in the Eastern Tropical Pacific Ocean based on summer/fall research vessel surveys in 1986-96. *SWFSC Administrative Report No. LJ-01- 04.* 61pp plus addendum. [Available from SWFSC, 8604 La Jolla Shores Dr., La Jolla, CA 92037, USA]

[9]Kinzey, D., Gerodette, T., Barlow, J., Dizon, A., Perryman, W. and Olson, P. (2000) Marine mammal data collected during a survey in the Eastern Tropical Pacific Ocean aboard the NOAA ships *McArthur* and *David Starr Jordan, July 28-December 9, 1999. NOAA Technical Memorandum NMFS: NOAA-TM-NMFS-SWFSC-293. National Oceanic and Atmospheric Administration.*

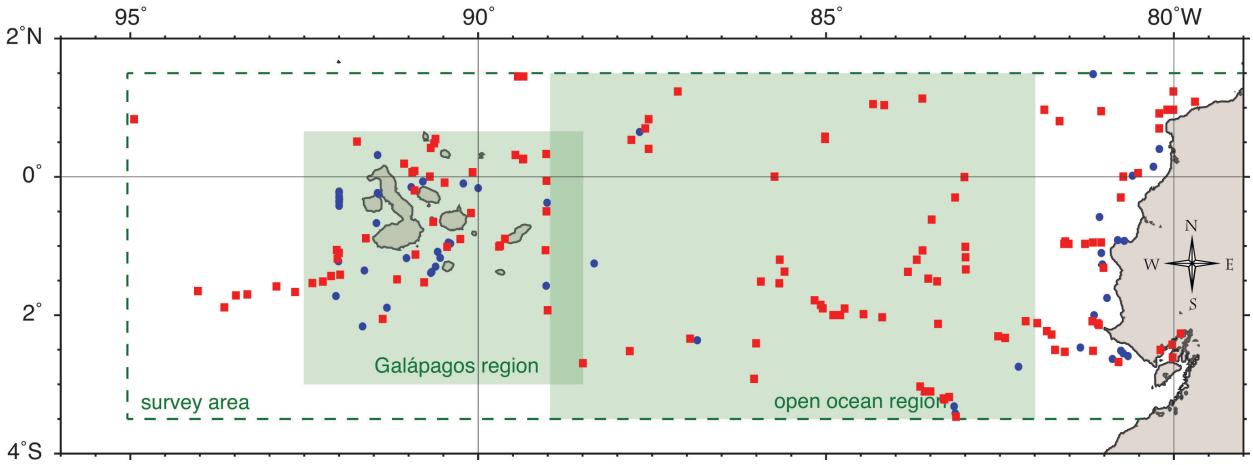

Figure 7. Balaenopteridae (blue squares, n=56) and Odontocete (red squares, n=146) sightings for all NOAA cruises (1999, 2000, 2003) and B/I Orion cruises (2001-2011).

sperm whale sightings were recorded. During April 2009, the sighting included at least one juvenile. Just over half of the sperm whale sightings came from within the marine reserve. The other sperm whale groups were observed in open-ocean habitat.

Using sighting rates per area effectively searched, multiple *B/I Orion* cruise sighting rates overlap with sighting rates aboard NOAA cruises. When available, using the area effectively searched (trackline survey distance multiplied by twice the effective half-strip width) may be a more meaningful way to compare sighting rates between surveys. This finding also suggests that there were no drastic changes in overall cetacean abundance between the 1999 NOAA cruise and the 2011 *B/I Orion* cruise.

The abundance estimates for striped and common dolphins using NOAA data did not agree well with the estimates made using *B/I Orion* data. Several factors likely account for the differences. First, the group size estimates for common dolphins were on average 50% greater during NOAA surveys than *B/I Orion* surveys. For striped dolphins the NOAA survey estimates were on average 20% greater. After accounting for this difference, estimates for the striped and common dolphin abundances calculated using NOAA survey data were still about twice as high as those calculated using *B/I Orion* survey data. NOAA surveys also spent about 20% more time than *B/I Orion* within the Galápagos Islands study area where cetacean sightings were twice as frequent relative to open-ocean habitat. However, even after considering these factors, it is likely that some groups of animals on the trackline were not observed during *B/I Orion* surveys. The probability of detecting an animal directly on the trackline or $g(0)$, relative to varying Beaufort sea states, was calculated by Barlow (2015). However, accounting for only the Beaufort sea state impact on $g(0)$ does not sufficiently explain the smaller *B/I Orion* abundance estimates.

The encounter rate from the April survey was 1.5 time greater than the average sighting rate for rainy September/October surveys aboard the *B/I Orion.* This difference was statistically significant for raw encounter rates, however when the effects of sea state are included, the 2011 September cruise sighting rates are not statistically different from the April sighting rates. Additional surveys during the drier season months like April (including a more rigorous collection of observing conditions) would provide a greater understanding of intra-annual fluctuations in species density in this area.

One improvement that could be made to the ships-of-opportunity program aboard the *B/I Orion* and likely other similar programs is the use of high-power binoculars. NOAA surveys utilized more powerful binoculars ('big eye' 25x150mm mounted binoculars) than the 7x50mm hand held binoculars used by *B/I Orion* observers. More powerful binoculars increase the distance at which cetaceans can be reliably seen from a ship. The NOAA surveys, while spending about half as much time within the survey region as the *B/I Orion* surveys, observed about the same number of sightings as the *B/I Orion* surveys. Given that population abundance and density estimates require a certain threshold of actual sightings for each species to be statistically viable, ships-of-opportunity programs could be substantially more cost-effective by utilizing high-power binoculars in order to increase the effective half-strip width. These high-power binoculars are only useful and will only increase the effective half-strip width of survey programs on larger ships (> ~30m). They also require more frequent rotation of observers to avoid fatigue, which would require more total observers to maintain a continuous search.

Higher power binoculars also enabled observers to identify species from further distances than during *B/I Orion* surveys. Ship avoidance by delphinids (Scott and Chivers, 2009) and lack of closing protocol (deviation from the survey track to

approach and identify animals) during *B/I Orion* surveys limited the ability of observers to identify the species of cetacean groups sighted. Observers frequently noted apparent avoidance behavior when the *B/I Orion* approached large groups of dolphin species. On average, half of the sightings made aboard the *B/I Orion* were identified to species whereas three-quarters of the sightings were identified to species level during NOAA cruises. A greater number of highly trained marine mammal scientists also likely improved species identification during NOAA cruises.

Beaked whales (Family Ziphiidae), a group of deep-water cetaceans difficult to observe at sea due either to ship avoidance or long dive cycle duration (Santos *et al.*, 2001), were observed in greater numbers during NOAA surveys than surveys aboard the *B/I Orion*. In total, 14 beaked whale sightings were made during NOAA cruises (1999-2000). Just one recorded beaked whale sighting was made aboard the *B/I Orion* (September 2009). Given the elusive nature of these animals, it is likely that observers were simply not able to identify beaked whales before they left the surface, a trend reflected in the greater proportion of unidentified sightings made during *B/I Orion* cruises.

Conclusion

Ships-of-opportunity programs can effectively supplement dedicated marine mammal surveys and provide an economical means to obtain data from areas of mid to low marine mammal density. Key considerations regarding ships-of-opportunity surveys resulting from this analysis include the following:

- Ships-of-opportunity could readily increase the quantity of sightings and species identifications they provide by including high-powered binoculars;
- Measuring the distance between observer and marine mammal sightings provides an important means for estimating the actual area of ocean surveyed and provides a more quantifiable estimate of sighting rates and marine mammal densities;
- At least one expert observer in field identification of cetaceans should participate on each observer watch during opportunistic surveys. Much of what we know about marine mammal distributions is based on visual identifications at sea, so accurate and reliable identifications are paramount;
- Elusive and more difficult to identify species such as beaked whales are the most likely cetaceans to be under-represented in opportunistic surveys;
- Combining ships-of-opportunity with dedicated surveys can provide a cost effective means of exploring and monitoring marine mammal distributions. Since marine mammals can be observed visually at the surface, particularly on ships that do not pass out of the observable range within typical dive cycle durations (ships not traveling faster than 8-12 knots) observers need not interfere with the ship's other activities.
- Monitoring marine mammal distributions will become increasingly important as the scientific community continues to assess the impacts of a changing climate on the world's oceans. Ships like the *B/I Orion* already engaged in regularly repeated surveys provide an excellent opportunity to assess potential trends and fluctuations in marine mammal populations, particularly in areas that are less well represented in marine mammal surveys due to low cetacean densities. These kinds of programs should be actively utilized for future survey work.

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