Marine Mammal Science

MARINE MAMMAL SCIENCE, **(*): ***–*** (*** 2011)

DOI: 10.1111/j.1748-7692.2010.00435.x

Using distance sampling techniques to estimate bottlenose dolphin (*Tursiops truncatus*) abundance at Turneffe Atoll, Belize

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ABSTRACT

Reliable abundance estimates are critical for management and conservation of coastal small cetaceans. This is particularly important in developing countries where coastal human populations are increasing, the impacts of anthropogenic activities are often unknown, and the resources necessary to assess coastal cetaceans are limited. We adapted ship-based line transect methods to small-boat surveys to estimate the abundance of bottlenose dolphins (*Tursiops truncatus*) at Turneffe Atoll, Belize. Using a systematic survey design with random start and uniform coverage, 34 dolphin clusters were sighted during small-boat line transect surveys conducted in 2005–2006. Distance sampling methods estimated abundance at 216 individuals (CV = 27.7%, 95% CI = 126–370). Due to species rarity in the Atoll, small sample size, and potential violations in line transect assumptions, the estimate should be considered preliminary. Nevertheless, it provides up-to-date information on the status of a regional population in an area under increasing threat of habitat loss and prey depletion via uncontrolled development and unsustainable fishing. This information will be useful as Belize develops a new conservation initiative to create a comprehensive and resilient marine protected area system. Our study illustrates the application of distance sampling methods to small-boat surveys to obtain abundance estimates of coastal cetaceans in a region lacking resources.

Key words: survey design, small-boat surveys, distance sampling, line transects, Distance 5.0, abundance, bottlenose dolphin, *Tursiops truncatus*, Turneffe Atoll, Belize.

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Although the common bottlenose dolphin (*Tursiops truncatus*) is well studied and widespread across various marine habitats in temperate and tropical waters (Wells and Scott 1999), its worldwide status is unknown. In the IUCN 2008 Red List of Threatened Species update, *T. truncatus* was classified as Species of Least Concern and listed habitat destruction and degradation, disturbance and harassment, prey depletion, pollution, and direct/indirect takes as specific threats of concern (Hammond *et al*. 2008). While these threats apply to the species as a whole, any one may impact certain regional populations more than others as seen in the Mediterranean (Bearzi and Fortuna 2006, Bearzi *et al*. 2008), Moray Firth, Scotland (Wilson *et al*. 1997, Sini *et al*. 2005), and Peru (Van Waerebeek *et al*. 1997). Declines in regional populations of apex predators, such as bottlenose dolphins, could have far reaching effects on the community structure of an ecosystem (Currey *et al*. 2009), as seen in western Alaska when increased killer whale predation on sea otters lead to a dramatic rise in sea urchins and subsequent decreases in kelp forests (Estes *et al*. 1998). For these reasons, coastal bottlenose dolphin populations should be assessed on a regional scale when evaluating status, managing threats, and implementing conservation measures (Reeves *et al*. 2003, Currey *et al*. 2009).

The effects of anthropogenic activities on coastal bottlenose dolphin populations are of particular concern as human populations continue to grow along coastlines, especially in developing countries (Aragones *et al*. 1997, Dawson *et al*. 2008). The extent of these activities, however, is generally unknown and the data needed to substantiate the impacts are rarely available. Without adequate knowledge about the status and life history of these populations future management actions are limited. Consequently, there is a strong need to conduct population assessment studies on coastal marine mammal populations in underdeveloped countries (Vidal 1993, Aragones *et al*. 1997, Hines *et al*. 2005, Dawson *et al*. 2008).

Line transect surveys using distance sampling protocols are a common method used to assess marine mammal populations (Buckland *et al*. 2001). Surveys of this type typically use large ships or fixed-wing aircraft, sophisticated equipment (high powered binoculars, navigational tools, *e.g.*, radar and electronic charts), and may traverse sizeable ocean expanses (Barlow 1988, 1995; Barlow *et al*. 1988; Calambokidis and Barlow 2004; Forcada *et al*. 2004; Mullin and Fulling 2004; Zerbini *et al*. 2007). As a result they are prohibitively expensive and inaccessible to developing countries with limited budgets and expertise and shallow coastal regions (Dawson *et al*. 2008). Adapting ship-based line transect methods to small-boat surveys (Vidal *et al*. 1997; Dawson *et al*. 2004; Williams and Thomas 2007, 2009) may be the best option to estimate coastal marine mammal populations in less affluent nations.

Turneffe Atoll (Fig. 1), located in Belize, Central America, is the largest most biologically diverse of the nation's three atolls (Stoddart 1962) and the only one without long-term ecological protection. Turneffe Atoll provides year-round habitat to a small population of coastal bottlenose dolphins (Grigg and Markowitz 1997, Campbell *et al*. 2002). Photo-identification studies from the 1990s estimated a population of less than 90 individuals (Campbell *et al*. 2002). More than a decade later there have been no new abundance estimates. Protected from import/export, wildlife trade, and hunting by Belize's 1981 Wildlife Protection Act, threats from human induced mortality are currently minimal. However, unsustainable fishing (overfishing and illegal fishing) and rapid coastal development (mangrove clearing, dredging, and overdevelopment) have been identified as severe threats to the ecological integrity of Turneffe Atoll (World Resources Institute 2005, Granek 2006). There is a high probability that the small dolphin population could be threatened by

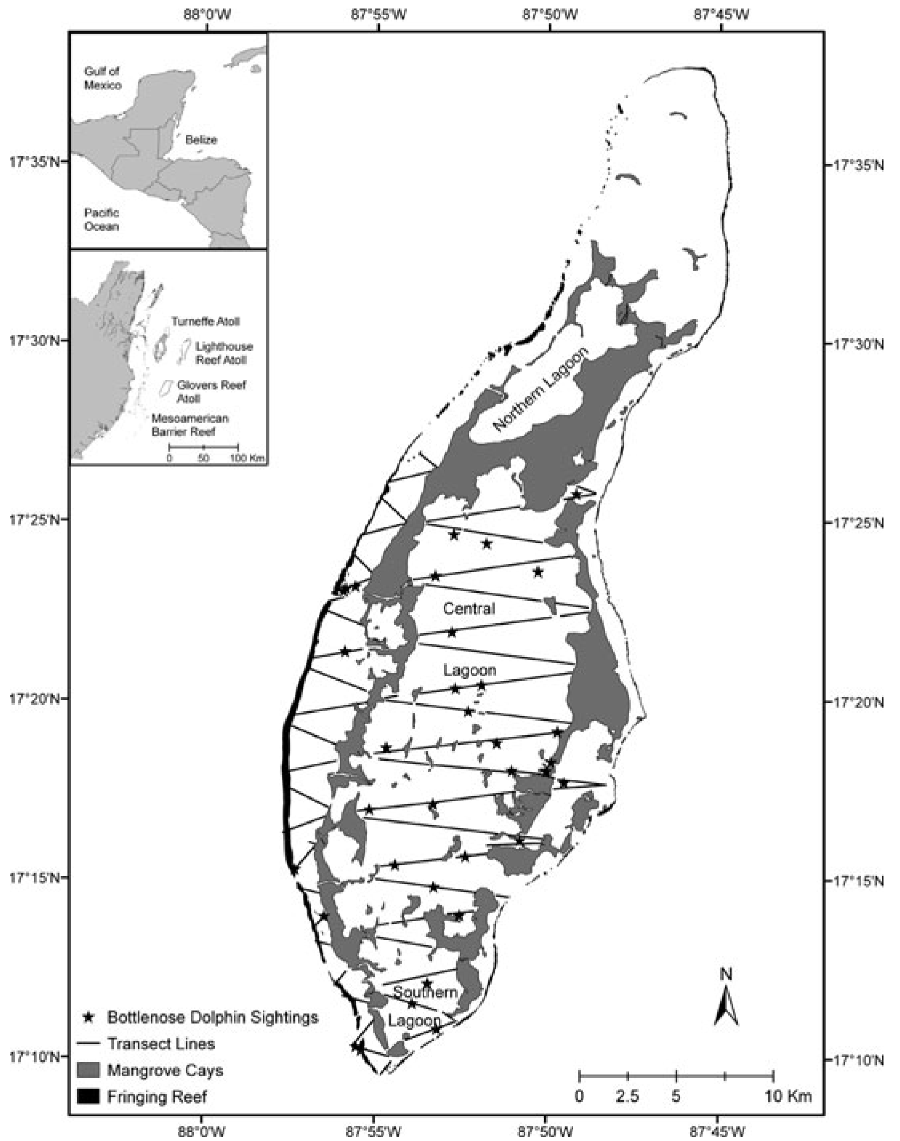

Figure 1. The location of Turneffe Atoll, Belize, the survey design, and the bottlenose dolphin sighting locations during small-boat surveys conducted in 2005–2006. The survey was created with the automated survey design function in Program Distance 5.0 release 2 using two substrata, the lagoon area and the western area between the mangrove cays and the fringing reef.

habitat degradation, prey depletion, vessel traffic, and pollution as the atoll's human population increases (Wells and Scott 1999). Obtaining an up-to-date abundance estimate for the population before further anthropogenic impacts occur is imperative to provide the baseline information necessary to guide future management and conservation actions.

We sought to (1) develop and implement a repeatable and economically feasible systematic survey for use on bottlenose dolphins at Turneffe Atoll, (2) provide the first non-mark-recapture quantitative estimates of dolphin abundance in the study area, and (3) develop survey methods potentially applicable for other small cetacean coastal surveys in underdeveloped countries. This project is part of a long-term social and behavioral ecology research program of bottlenose dolphins conducted at Turneffe Atoll.

Materials and Methods

Study Area

Located 50 km east of mainland Belize and 18 km beyond the Mesoamerican Barrier Reef in the western Caribbean Sea, Turneffe Atoll is roughly 50 km long, 16 km wide at its widest point (average width 8–10 km), and encompasses approximately 531 km^2 (Fig. 1) (Stoddart 1962). The atoll contains >200 mangrove cays (islands), incorporates three shallow (<8 m) lagoons covered with seagrass, and is surrounded by a relatively continuous fringing coral reef. The climate is tropical to subtropical with prevailing wind and wave directions from the east to northeast (Gischler 2003). Tidal exchange is no greater than 30 cm; average surface water temperature is 29°C (Stoddart 1962, Gischler 2003). December through May is the dry season, while June to November is the wet or hurricane season (Platt *et al.* 2000).

Survey Design

Reliable results from distance sampling require a survey design and field methods that ensure line transect assumptions are met. In depth discussions on the theory and assumptions of line transect analysis (Buckland *et al.* 2001), survey design development (Thomas *et al.* 2007) and small-boat field methods (Dawson *et al.* 2008) already exist and will not be duplicated here.

A relatively cloud free ETM+ Landsat image (NASA Landsat Program 2004) of the study area was digitized into a Geographical Information System (GIS) (ESRI 2006) to create spatial data for the automated survey design function in Distance 5.0 release 2 (Thomas *et al.* 2010). Random placement and even distribution of transects occurred within two substrata (Thomas *et al.* 2007). A zigzag configuration maximized on-effort time and even coverage probability was obtained by defining a design axis and adjusting the survey line angle with respect to this axis (Thomas *et al.* 2002, Strindberg and Buckland 2004). Other influential factors included (1) the year-round presence of various age and sex classes of bottlenose dolphins (Grigg and Markowitz 1997, Campbell *et al.* 2002), eliminating the need to adjust for seasonal movement or specific age or sex biases; and (2) the design had to be practical and repeatable within the logistical and monetary constraints of the nonprofit organization sponsoring the research. The northern part of the atoll was excluded due to the prohibitive distance, time, and cost needed to reach and survey this area. The final survey design was an equally spaced zigzag configuration of 45 transects contained within the southern two-thirds of the atoll and the western area between the mangrove cays and the fringing reef (Fig. 1). The design was downloaded onto a Garmin GPSMAP 76 using the freeware DNR Garmin (Minnesota Department of Natural Resources 2008).

Survey Procedures/Field Work

Using the GPS unit to guide the boat along each transect line, surveys were conducted from either an 8.2 m skiff with two 85 hp outboard motors or a 6.4 m boat equipped with one 150 hp outboard motor. Boat speed was kept constant between 12 and 15 km/h and surveys were only conducted in Beaufort sea states of $\leq$3 and wave heights <1.5 m (Wilson *et al.* 1997, Dawson *et al.* 2004, Williams and Thomas 2007). Sea conditions were updated as needed; if conditions deteriorated mid-survey, effort was terminated until conditions improved. The effects of glare were minimized by the placement of transect lines either north or south of due west, traveling down-sun when possible (Dawson *et al.* 2004), and through the use of polarized sunglasses. Other variables that could impact visibility (*e.g.*, rain) or detectability (*e.g.*, tide) of dolphins were considered but ignored because surveys were not conducted in rain and tidal exchange was negligible. All surveys occurred during daylight hours between 0830 and 1800.

Two experienced observers continuously scanned for dolphins by eye and intermittently with 7 × 50 binoculars. During all surveys, the lead observer (D.M.D.) scanned the area directly ahead to 90° on either side of the vessel with an eye height of 2.7 m; scans beyond 90° on both sides of the vessel occurred every few minutes. When dolphins were sighted, time, sea state, GPS location, cluster size, detection mode, sighting angle, and angle of declination were recorded. To maintain consistency, distance measurement data were collected by the lead observer from the highest accessible point. Sighting angles were measured using an angle board. The enclosed nature of the survey area by mangrove cays, the lack of an available horizon for most sightings, and the absence of a nautical chart for the region made the use of binoculars with reticles impractical and required a nonstandard method to determine sighting distance. We used a Suunto clinometer to measure the angle of declination from which the sighting distance was calculated using a trigonometric formula: $x_s = v\tan(90° - \theta)$, where x_s is the sighting distance, v is the observer's eye height, and θ is the angle of declination.

Dolphin groups were slowly approached (closing mode) to record cluster size, general age composition, and behavioral and environmental data. All data, except environmental (*e.g.*, salinity, depth, air, and water temperature), were collected by the lead observer and relayed to the data recorder(s). A cluster was defined as any number of dolphins ($\geq$1) in apparent association who were moving in the same direction, often exhibiting the same behavior (Shane 1990). Cluster size determination was not affected by closing mode; cluster sizes were small ($\leq$12 animals) and easy to count, thus no additional dolphins were sighted and added to the initial count due to closing on the group. Final cluster size was estimated by a consensus between the two lead observers. After the encounter, the boat returned to the break position and completed the transect line. If the transect could not be completed at that time, the boat would return to the break point at another time and finish the transect line then. To ensure data could be pooled for analysis, no transect lines were traveled more than once until the entire 45 lines within the survey area had been surveyed completely.

Abundance Estimation

Sighting distances and angles were used to calculate perpendicular distances using simple trigonometry (Buckland *et al.* 2001). Data were examined for heaping, responsive movement, and outliers. Truncation of detections beyond 90 m removed one outlier at around 200 m, allowing better model fit (Buckland *et al.* 2001). Distance 5.0 release 2 (Thomas *et al.* 2010) was used to estimate detection probability using Conventional Distance Sampling (CDC) and Multiple Covariate Distance Sampling (MCDS) (Buckland *et al.* 2001, 2004). Unlike CDC, which assumes the detection of an object is the sole function of its distance from the line, MCDS allows for the inclusion of additional variables that are likely to impact the detection probability. For cetacean surveys, Beaufort sea state is a common covariate (Palka 1996, Barlow *et al.* 2001) and was used here. Following Buckland *et al.* (2001), several standard detection function models in CDS and MCDS were fitted to the data. The Kolmogorov–Smirnov goodness-of-fit test for each model was used to examine the absolute fit of the model (Buckland *et al.* 2004). Estimates from the model with the lowest Akaike's Information Criterion (AIC) were selected (Buckland *et al.* 2001).

Results from a size-biased regression (the default method in Distance) indicated weak evidence of dependence between cluster size and distance ($r_s = 0.19$, $P = 0.14$). Mean sample cluster size ($\bar{s}$) was considered an unbiased estimator of the estimated mean cluster size of the population ($\hat{E}(s)$) (or $\hat{E}(s) = \bar{s}$) (Buckland *et al.* 2001). Bottlenose dolphin abundance ($\hat{N}$) within the survey area was estimated using (Buckland *et al.* 2001, Marques and Buckland 2003):

$$\hat{N} = A \cdot \frac{n \cdot \bar{s}}{c \cdot 2L \cdot \mu},$$

where $\hat{N}$ is the estimated abundance, A the size of the study area, n the number of clusters seen, $\bar{s}$ the mean sample cluster size, c the constant (or multiplier) indicating the number of times each line was surveyed, L the total length of transect line, and μ the effective strip half-width.

The coefficient of variations (CV) for n, μ, and $\bar{s}$ were each calculated individually. Empirical estimation of $CV(n)$, as recommended by Buckland *et al.* (2001), plus an adjustment for multiple visits to transect lines followed:

$$CV(n) = \sqrt{\frac{\text{var}(n)}{n^2}}$$

$$\text{where var}(n) = \frac{T_L \sum_{i=1}^{k} t_i \cdot l_i \cdot (n_i/(t_i \cdot l_i) - n/T_L)^2}{k-1},$$

T_L is the total line length traveled, represented by, $T_L = \sum_{i=1}^{k} t_i \cdot l_i$, t_i the number of times a line was traveled, l_i the length of transect line i, n_i the number of detections on line i, k the number of transect lines. $CV(\mu)$ and $CV(\bar{s})$ were each calculated by dividing the standard error of the estimator by itself. Individual CVs were used to compute the abundance estimate CV using (Buckland *et al.* 2001):

$$CV(\hat{N}) = \sqrt{[CV(n)]^2 + [CV(\mu)]^2 + [CV(\bar{s})]^2}.$$

Results

Survey Design

The total planned survey effort was 220.54 km across 310.25 km^2. Due to shallow areas inaccessible to the boat, the realized survey effort was 175.21 km across 298.5 km^2 (about 80% of planned) for a set of transect lines. Six survey sets were completed, totaling 1,051.26 km of effort over 471.7 h during the rainy seasons of 2005 (November–December) and 2006 (June–August and October–December) and during a two-week period (March–April) in the 2006 dry season.

Abundance Estimation

Thirty-four dolphin clusters, totaling 97 animals, were sighted on-effort (Fig. 1). Small sample size ($n = 33$ after truncation) precluded stratification by season; ungrouped perpendicular distances were pooled across all survey sets for analysis. Cluster size ranged from 1 to 12, with a mean cluster size of 2.61 (CV = 17%, 95% CI = 1.85–3.68). The majority of sightings (84.5%) were of clusters $\leq$3 dolphins.

Model results and the best fitting plotted detection function are presented in Table 1 and Figure 2. Estimated abundance and density for the study area was 216 dolphins (CV = 27.7%, 95% CI = 126–370) and 0.749 dolphins/km^2 (CV = 27.7%, 95% CI = 0.437–1.282), respectively. A detection probability of 0.50 (CV = 15%, 95% CI = 0.372–0.681) occurred within the study area.

Discussion

Our study produced a new abundance estimate for a species of conservation concern in a region where such estimates are scarce and without governmental financial support. Only two prior studies from the 1990s, both using photo-identification,

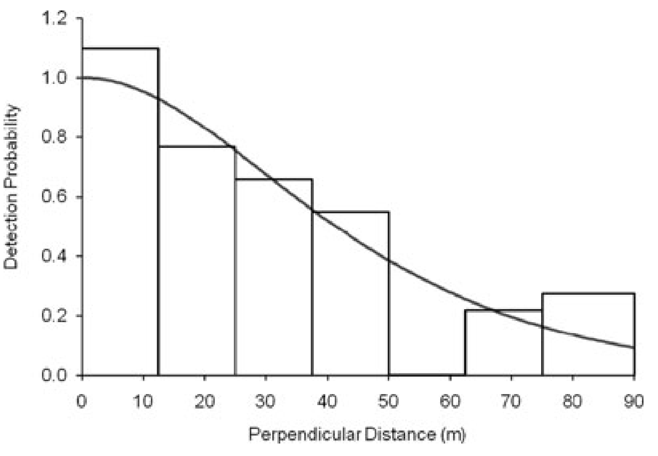

Figure 2. Histogram of perpendicular sighting distances truncated at 90 m and the fitted detection function for the best fitting model, MCDS half-normal model (no adjustment parameters) with sea state as a covariate. One sighting at 200 m was truncated.

Table 1. Model results for each of the tested models. Data were ungrouped, pooled across all surveys sets, and truncated at 90 m ($n = 33$).

Model	No. of parameters											
(Key + Adjustment)	Key	Adjustments	AIC	$\hat{N}_s$	CV(%)	$\hat{D}$	CV(%)	$\hat{D}_s$	CV(%)	P	CV(%)	K-S p
CDS												
Uniform + cosine	0	1	287.75	220	25.6	0.763	25.6	0.306	21.2	0.57	10.0	0.195
Uniform + simple polynomial	0	1	288.04	204	25.0	0.707	25.0	0.272	20.5	0.64	9.0	0.153
Half-normal + cosine	1	0	287.35	227	27.0	0.785	27.0	0.317	22.8	0.55	13.0	0.210
Half-normal + hermite	1	0	287.35	227	27.0	0.785	27.0	0.317	22.8	0.55	13.0	0.210
MCDS with Beaufort sea state as a covariate												
Half-normal + cosine	1	0	285.05	216	27.7	0.749	27.7	0.347	23.8	0.50	15.0	0.246
Half-normal + hermite	1	0	285.05	216	27.7	0.749	27.7	0.347	23.8	0.50	15.0	0.246
Hazard-rate + cosine	2	0	291.05	216	28.0	0.749	28.0	0.347	24.1	0.52	15.0	0.243

Note: AIC = Akaike Information Criterion; $\hat{N}_s$ = abundance estimate for survey area; $\hat{D}$ = estimated density of dolphins/km^2; $\hat{D}_s$ = estimated density of clusters/km^2; P = detection probability; CV = coefficient of variation; K-S p = Kolmogorov–Smirnov goodness-of-fit p-value.

report abundance estimates for regional bottlenose dolphin populations in Belize: Campbell *et al*. (2002) estimated 82–86 individuals at Turneffe Atoll and Kerr *et al*. (2005) reported 122 individuals in the Drowned Cayes, located 16 km west of Turneffe within the Mesoamerican Barrier Reef. The different dolphin abundance estimates for Turneffe is not surprising, primarily because the two methods measure slightly different things and are therefore, not directly comparable. Mark-recapture sampling estimates the abundance of the overall biological population whether or not all individuals are present at a moment in time, while line transect sampling estimates the size of the population within the study area during the survey interval (Calambokidis and Barlow 2004). Nevertheless, the abundance estimates for this region are small and suggest the population cannot withstand high levels of mortality.

To our knowledge there are no reports of hunting, fisheries bycatch, or boat strikes of dolphins at Turneffe, and Campbell *et al*. (2002) reported an absence of crescent-shaped scars indicative of shark predation. Moreover, bottlenose dolphins are fully protected under Belize's 1981 Wildlife Protection Act. This would suggest threats to the dolphins at Turneffe are currently minimal. However, mounting evidence indicates that continued unsustainable fishing (overfishing and illegal fishing) and rapid development are impacting the ecological integrity of the Atoll (World Resources Institute 2005, Granek 2006). Within Belize, fisheries are primarily artisanal; ongoing commercial fisheries heavily and unsustainably exploit Caribbean spiny lobster and queen conch, and a small-scale fishery targets snapper, grouper, and other fish species (Gillet 2003, FAO 2005). Coblentz (1997) demonstrated artisanal fisheries to be unsustainable and can quickly alter reef communities. Furthermore, gill nets, recognized as a leading cause of cetacean mortality worldwide (Read *et al*. 2006), are one of several techniques used in this fishery, often by illegal Guatemalan and Honduran fishers (Gillet 2003, FAO 2005, Perez 2009). The threat of entanglement in gill nets is cause for concern to bottlenose dolphin populations in Turneffe and the rest of Belize.

Removal of mangroves and dredging of seagrass beds for private and commercial development are increasing at Turneffe. As important nursery areas for reef fish (*e.g.*, snappers, grunts, and parrotfish), elimination of either habitat type can have significant impacts to adjacent reef fish communities and may lead to cascading effects at higher trophic levels (Nagelkerken *et al*. 2002, Mumby *et al*. 2004, Manson *et al*. 2005). Although quantitative diet studies for Turneffe dolphins do not yet exist, if unsustainable fisheries and development are left unchecked, changes to the atoll's ecosystem could potentially lead to prey depletion. This is especially concerning because females with neonatal and older, but presumed nursing, calves are sighted year-round suggesting the atoll may be an important calving area (Grigg and Markowitz 1997, Campbell *et al*. 2002). Prey depletion could have negative ramifications on reproductive success since lactating females have much higher energy requirements than non nursing individuals (Oftedal 1984, Cheal and Gales 1991).

On a larger scale, site fidelity patterns indicate a high proportion of dolphins are transient and use a much larger area than Turneffe (Campbell *et al*. 2002). Belize is a small western Caribbean country and the dolphins observed at Turneffe could move beyond the country's borders. Extensive gill net use occurs in Mexican, Honduran, and Guatemalan artisanal fisheries and bottlenose dolphins have been historically found entangled or dead in these nets (Vidal *et al*. 1994, FAO 2000). To better understand the impacts of these threats on Turneffe dolphins, surveys should continue at the atoll in conjunction with studies that focus on dolphin movement beyond the atoll, including a Belize-wide bottlenose dolphin population assessment, and the development of a method for monitoring and reporting fisheries interactions.

Potential Violations of Line Transect Assumptions and Considerations for Future Surveys

Survey design—Although it is possible to design a survey based on the amount of effort required to attain a certain level of precision (Buckland *et al.* 2001), often practical considerations will dictate the survey design, as was the case in this study. This is the first rigorous systematic survey conducted at Turneffe and its use is expected to continue. The choice of an equally spaced zig-zag design, with a few minor adjustments (see further), was considered successful.

One particular issue arose during field surveys that required additional consideration. The full length of most transects between the mangrove shoreline and the fringing reef on the western side and several areas within the lagoons could not be surveyed; coral heads and shallow sand bars made these areas inaccessible. Instead, the areas were scanned for dolphins from the closest point that could be reached by the boat. Thomas *et al.* (2007) reported a similar experience and suggested this problem may be avoided by using high-resolution maps during the survey design process; however, such items are not available for this region. The issue was resolved by excluding the unsurveyed areas from the total line length traveled during analysis (Thomas *et al.* 2007). Because unsurveyed areas often occurred at the apexes of the zigzags, exclusion of these areas had the added benefit of further improving even coverage probability (Dawson *et al.* 2008).

Abundance estimation—Visibility bias or incomplete detection at distance zero ($g(0) < 1$) can be problematic in marine mammal surveys and cause negatively biased estimates. This bias is classified in two ways: (1) animals may not be available to be seen by observers (availability bias) because they are not at the water's surface where they can be seen (*e.g.*, during diving), and (2) animals may potentially be visible to an observer but are not detected (perception bias) because of factors such as environmental conditions (*e.g.*, sea state) (Marsh and Sinclair 1989). Consequently, species with longer dive times or found in smaller clusters are more likely to be missed by observers, thereby impacting the assumption $g(0) = 1$ (Dawson *et al.* 2008). Bottlenose dolphins have relatively short dive durations in shallow areas. For example, along Florida's Gulf Coast in areas with depths ranging between 1 and 5 m, average dive times for this species were recorded to be 20–25 s off Sanibel Island (Shane 1990), 30–40 s in Sarasota Bay (Irvine *et al.* 1981), and 28.5 s in Tampa Bay (Mate *et al.* 1995). Similar environmental conditions, including shallow waters, sand flats, and seagrass beds, occur at Turneffe Atoll; therefore dive times are likely to be comparable to those recorded in Florida. This short dive duration makes it unlikely that dolphins missed detection on the transect line because of being underwater. In addition, despite the small mean observed cluster size, almost 85% of the sightings were of clusters with ≤ 3 dolphins indicating smaller group sizes were not being missed. Introduction of significant bias to the abundance and density estimates from the assumption $g(0) = 1$ is, therefore, not expected.

Responsive animal movement either toward or away from the survey vessel prior to detection will introduce bias (Turncock and Quinn 1991, Palka and Hammond 2001). Bottlenose dolphins are known to bow-ride, and in at least 15% of the sightings, dolphins were first detected as they were quickly approaching the boat and just prior to bow-riding. Attraction to vessels is seen in other small cetacean species including Dall's porpoise (*Phocoenoides dalli*, Turncock and Quinn 1991), Pacific white-sided dolphins (*Lagenorhynchus obliquidens*, Williams and Thomas 2007), and white-beaked dolphins (*Lagenorhynchus albirostris*, Palka and Hammond 2001). Lemon *et al*. (2006) noted behavioral changes by Indo-Pacific bottlenose dolphins (*T. aduncus*) to an approaching boat at 100 m. Calculated distances from this study found all but one sighting occurred at ≤90 m, suggesting that the presence of the boat may have already attracted dolphins to the boat prior to detection. During future surveys, every effort should be made to ensure dolphins are sighted as far ahead of the vessel as possible. Correction factors, to account for attractive movement and positively biased estimates, should be developed through the collection of animal orientation data (Palka and Hammond 2001).

Measurement accuracy also influences estimates and can be problematic regardless of survey platform type, although it can be exacerbated in small-boat surveys. Estimation of distances and angles is common (Vidal *et al*. 1997, Hammond *et al*. 2002); however, it may lead to measurement rounding and biased estimates. For this reason, estimation is not recommended unless observers are well trained and continually tested throughout the survey or correction factors are developed (Buckland *et al*. 2001, Dawson *et al*. 2008). Lerczak and Hobbs (1998) and Buckland *et al*. (2001) describe several acceptable methods for acquiring measurements using tools such as angle boards and binoculars with reticles and/or compasses. An angle board was used to measure sighting angles and it helped to avoid angle rounding. A nonstandard method was used to determine sighting distances due to site-specific limitations, primarily that the horizon was rarely visible due to the enclosed nature of the atoll. A clinometer was chosen, as it is self-leveling and does not require the horizon as a reference point. However, declination angles $<5^\circ$, as was the case in about 60% of the measurements, can be problematic and decrease precision (Lerczak and Hobbs 1998). A negative bias in the angle of declination will underestimate abundance and density, while overestimation occurs when declination angles are positively biased. Declination angle bias can be minimized by using an accurate measure of the observer's eye height and calibrating with a known distance (Buckland *et al*. 2001) in conjunction with developing observer-specific clinometer correction factors. Williams *et al*. (2007) describe some distance calibration experiments to account for measurement errors during line transect surveys that could be applied in future surveys.

Buckland *et al*. (2001) recommend 60–80 observations are necessary to obtain reliable estimates from line transect analysis. Even after pooling the data from all six survey sets, this was not achieved. Over 470 h of survey effort resulted in the detection of 34 cluster sightings. Small sample sizes are a frequent problem in studies of rarely occurring species. Increasing survey frequency, especially during the dry season (December–May) when surveys during this period were lacking, could boost sample size. The increase in sample size would allow for more flexibility during analysis such as abundance/detectabilty estimation on an annual or seasonal basis. Allocating some effort to transit legs (non transect line travel) or high density areas could increase the number of sightings for detection function estimation, provided these sightings are not included in abundance estimate (Williams and Thomas 2009). Model averaging to account for detection function uncertainty can also be useful, especially if model results are dissimilar (Williams and Thomas 2009).

Although the survey design was successfully implemented, the detection function decreased with increasing distance, and the CVs reported are well within the range of other small cetacean abundance studies (*e.g.*, 27.9% short-beaked common dolphin (*Delphinus delphis*), 48.1% bottlenose dolphin (Barlow 1995); 15.7% Hector's dolphin (*Cephalorhynchus hectori*) (Dawson *et al*. 2004); 29.2% Dall's porpoise, 35.3% Pacific white-sided dolphin (Williams and Thomas 2007), the abundance (216 dolphins, CV = 27.7%) and density (0.749 dolphins/km^2, CV = 27.7%) reported here for Turneffe Atoll are the best estimates given the conditions and should be considered preliminary. The development of correction factors to help account for potential line transect analysis violations is strongly recommended. Future surveys would also benefit from a higher observation platform and the consistent use of binoculars; however, this should only be done after careful thought as protocol modification after six survey sets will impact the ability to detect trends.

Being able to obtain reliable abundance estimates and identify critical habitats are vital to the creation and success of marine protected areas for cetaceans (Hoyt 2005). Our results provide an up-to-date population assessment for the area and should serve as a baseline as Belize moves forward with the development of a new conservation initiative to create a comprehensive and resilient marine protected area system. The year-round presence of dolphins, including mom/calf pairs (Grigg and Markowitz 1997, Campbell *et al*. 2002), suggests this area may be an important calving/nursery site and should be a priority for protection. Moreover, the high frequency of sightings near mangrove shorelines and atoll openings,[2] suggests these areas are important habitat features to the dolphins and should remain undeveloped.

This and other recent studies (Vidal *et al*. 1997; Dawson *et al*. 2004, 2008; Williams and Thomas 2009) have shown that line transect surveys can be successfully modified for small-boats, provided the survey design is well planned and field methods are designed to address the main assumptions of line transect analysis. As coastal human populations continue to grow and the threats to small cetacean species increase, the reduction in cost and the improved accessibility to shallow areas through the use of small-boats will provide more opportunities for underdeveloped nations to assess their coastal marine mammal populations.

Acknowledgments

We thank L. Thomas for providing helpful guidance during the survey design phase, S. G. Allen, B. Holzman, and H. Edwards for their reviews of earlier drafts of this paper, M. Christman, C. Keller, and P. Kubilis for their statistical advice, and R. Williams and an anonymous reviewer for comments on the manuscript. We are grateful to the many Oceanic Society and Elderhostel volunteers who helped in the field. Financial and logistical support was provided by Oceanic Society Expeditions. D. Dick received financial support from San Francisco State University's Department of Geography and the College of Behavioral and Social Sciences Graduate Stipend. All research was approved by the Office for the Protection of Human and Animal Subjects at SFSU and conducted under a research permit issued to the Oceanic Society from the Ministry of Natural Resources Forest Department, Belize.

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[2]Unpublished data provided by Dorothy Dick, 5227 $^1/_2$ 27th Avenue S, Gulfport, Florida 33707, July 2009.

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Received: 3 August 2009
Accepted: 16 July 2010