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# Mark-recapture vs. line-transect abundance estimates of a coastal dolphin population: a case study of *Tursiops truncatus* from Laguna, southern Brazil

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**Abstract.** Cetacean populations in coastal habitats are increasingly threatened by multiple anthropogenic impacts. Monitoring these populations to obtain robust estimates of abundance and detect trends over time is critical to achieve conservation goals. Here, we conducted a pilot study to evaluate the effectiveness of two commonly used abundance estimation methods: mark-recapture and distance sampling line-transect. Surveys were conducted to estimate the abundance of bottlenose dolphins in Laguna, southern Brazil. We implemented power-analysis models and compared both techniques in terms of cost, time and effectiveness to detect trends over a five-year period. Mark-recapture models were analyzed in MARK and resulted in an abundance of 50 individuals (CI = 39-64) with a coefficient of variation (CV) of 0.13. The line-transect models were implemented using the program DISTANCE and resulted in an estimate of 62 individuals (CI = 38-103), with a CV of 0.24. Comparing both approaches, mark-recapture resulted 1.30 time more expensive than line-transect for a single season of effort, but was twice as effective in terms of precision. As a consequence, the probability of detecting a 5% trend during a five-year period is 2.08 times higher with mark recapture. Conversely, the final cost to detect a trend with distance sampling is 1.19 time higher but considering six more years of effort. These results highlight the importance of selecting *a-priori* sampling design techniques that include developing pilot studies that evaluate the bias, precision and accuracy of estimates while considering costs involved. Considering the small population size estimated herein, the sensitivity of both approaches for detecting trends is not sufficient because the original population would be markedly reduced by the time a declining trend was detected. Thus, a precautionary approach is still imperative, even when robust estimates are obtained.

**Resumo.** Populações costeiras de cetáceos estão expostas a múltiplos impactos antropogênicos, sendo o monitoramento destas populações essencial para questões conservacionistas. Para isto, estimativas robustas de abundância são necessárias, principalmente quando o objetivo é detectar tendências populacionais. Por um estudo piloto, foi avaliada a efetividade de dois métodos comumente utilizados, captura-recaptura e transecção linear, para estimar a abundância do boto-da-tainha *Tursiops truncatus*, em Laguna, sul do Brasil. Ambas as técnicas foram comparadas em termos de custos, tempo e poder em detectar tendências, considerando um programa hipotético de cinco anos de monitoramento. Os modelos de captura-recaptura, analisados no programa MARK, geraram uma abundância de 50 indivíduos (IC = 39-64) com um coeficiente de variação (CV) de 0,13. O método de transecção linear, utilizando o programa DISTANCE, estimou uma abundância de 62 indivíduos (IC = 38-103), com um CV de 0,24. Comparando as duas abordagens, quando considerado apenas um ano de esforço, o método de captura-recaptura foi 1,30 vez mais dispendioso que o de transecção linear, porém duas vezes mais efetivo em termos de precisão. A probabilidade do método de captura-recaptura detectar uma tendência de declínio de 5% em cinco anos de monitoramento foi 2,08 vezes maior do que para as transecções lineares. Assim, o custo final para detectar uma tendência seria 1,19 vez maior para transecção linear, já que este esforço exigiria seis anos a mais de monitoramento. Este resultado destaca a importância da escolha do método e exemplifica a necessidade de estudos pilotos antes de planejar esforços futuros. Considerando o pequeno tamanho populacional estimado aqui, a sensibilidade de ambos os métodos em detectar tendências não seria suficiente, já que o tamanho da população inicial, no momento da detecção, estaria consideravelmente reduzido. Desta forma, a aplicação do princípio da precaução ainda é imperativa, mesmo quando estimativas robustas forem obtidas.

## Introduction

The constant and massive influx of humans to coastal areas causes increasing exposure of coastal ecosystems to anthropogenic threats (Small and Nicholls, 2003). In general, populations of small coastal cetaceans are particularly vulnerable, considering the combination of their biological and ecological traits such as high longevity, low reproductive rates, high degree of residency to certain areas and the prevalence of small isolated populations (Soulé, 1987; Beissinger and McCullough, 2002). The vulnerability of cetacean populations is further heightened in environments susceptible to impacts such as increased chemical and biological pollution, habitat destruction, boat traffic, overfishing and incidental captures in fishing nets (Pandolfi *et al.*, 2003; Wedekin *et al.,* 2005). Given these conditions, the development of long-term monitoring programs for coastal cetacean populations is critical for conservation efforts (Thompson *et al.,* 2000).

It is important to gather unbiased, precise estimates of abundance and detect trends over time to monitor, model risk assessment and develop suitable conservation strategies (O'Grady *et al.,* 2006). In general, detecting population trends over time is hampered by a lack of precise, unbiased and accurate abundance estimates (Hammond, 1987; Williams and Thomas 2009), which reduces the statistical power to identify significant population changes (Taylor and Gerrodette, 1993). For example, over 90% of current dolphin or porpoise stock monitoring programs in the United States had extremely low power (<50% chance of correctly rejecting the null hypothesis that the population is not declining) to detect precipitous (greater than 50% decrease in abundance over 15 years) population declines (Taylor *et al.*, 2007). As a result, longer-term monitoring programs are required to accurately detect changes (Taylor and Gerrodette, 1993), which increases financial costs and logistical requirements.

Although they are often difficult to implement, especially in developing countries, long-term monitoring programs are being more commonly established in Brazil (Regalado, 2010). However, planning a long-term program requires balancing cost and efficacy (Sutherland, 2000). Inadequate monitoring efforts (*i.e.* the inability to reach the proposed goals; Taylor *et al.*, 2007) are prevalent, and in many cases, it is imperative to consider that a poorly designed monitoring program may be even worse than no monitoring effort (Conroy and Carroll, 2009). For instance, when the target population is small, and therefore it is not possible to obtain accurate abundance estimates, it may be more relevant to focus on conservation efforts (Chades *et al.,* 2008) following a precautionary approach (Thompson *et al.,* 2000).

Here we focus on two well-known techniques used to estimate abundance of delphinids: line-transect surveys that implement distance sampling techniques (Buckland *et al.,* 2001) and mark-recapture applied to photo-identification data (Hammond, 1987). Both techniques are widely used to estimate population parameters of small cetaceans (for line-transect: Secchi *et al.,* 2001; Forcada *et al.,* 2004; Dawson *et al.,* 2004; Cremer and Simões-Lopes, 2008; Flach *et al.*, 2008; Lukoschek and Chilvers, 2008; Cremer *et al.*, 2011; for mark-recapture: Wilson *et al.,* 1999; Read *et al.,* 2003; Currey *et al.,* 2007; Silva *et al.,* 2009; Cantor *et al.,* 2012). Selecting a method depends on the objectives of the study, resource availability, biological characteristics of the target species and characteristics of the study area. Each technique can address a number of other issues in addition to abundance (Read *et al.,* 2003; Lukoschek and Chilvers, 2008).Under some circumstances, financial constraints may dictate which method may be implemented. In such situations, pilot studies allow evaluating preliminary estimates and assist identifying the most cost-effective method for a monitoring program (Sutherland, 2000).

In this study we evaluate distance sampling and mark-recapture to develop a long-term monitoring plan for a population of bottlenose dolphins, *Tursiops truncatus*, in Laguna, southern Brazil. In this region, bottlenose dolphins are resident and are well-known for a unique fishing technique with humans. A subset of dolphins (45%) interact with local artisanal fishermen (see Simões-Lopes *et al.*, 1998 for a detailed description). This interaction seems to be a mutualistic cooperation that occurs mostly during the mullet season in the austral autumn and it may present implications to the evaluation of spatial pattern and social structure (Daura-Jorge *et al.*, 2012). The local population was previously estimated at 51 individuals from data

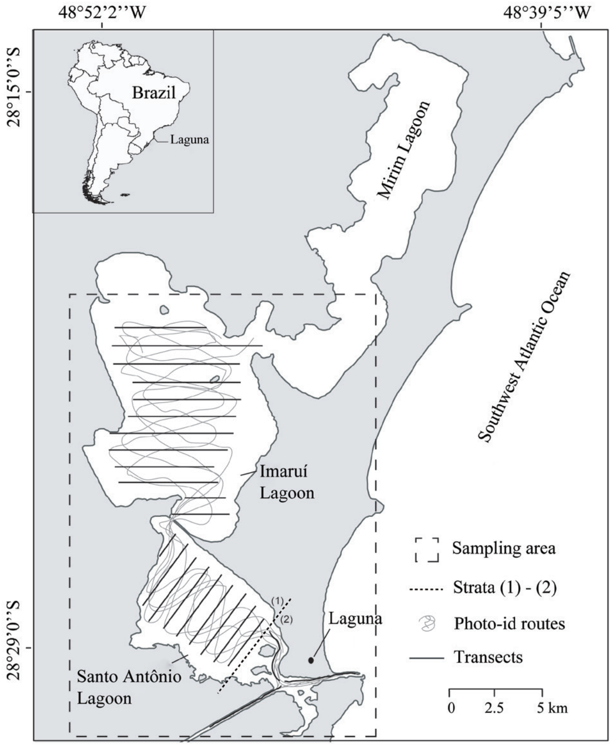

**Figure 1.** Location of the Santo Antônio-Imaruí-Mirim lagoon system, southern Brazil, and sampling design. The sampling area is highlighted by the dotted square and the dashed line divides strata (1) and (2). Solid lines show the location of boat transects and gray line the routes followed during the photo-id effort.

collected in the 1990s (Simões-Lopes and Fabian, 1999). More recently, abundance was estimated between 50 to 60 dolphins (Daura-Jorge *et al.*, 2013). In this local population, dolphins display a high degree of residency (Simões-Lopes *et al.*, 1998) and it seems that temporary emigration rates are low (Daura-Jorge *et al.*, 2013).

Here, we conducted a short-term pilot study to evaluate the application of the mark-recapture and line-transect methods. Population estimates were compared, especially in terms of precision by assessing their coefficients of variation. Additionally, we used a statistical power analysis to detect the time required by each survey type effort and technique to detect a significant population trend with satisfactory probability (*i.e.* Taylor *et al.*, 2007). Finally, we conducted a cost analysis for the proposed study durations for each technique to determine the most cost-effective way for monitoring and identifying changes in population density of the Laguna dolphins. In addition to the direct application of our findings to the population concerned, our study exemplifies the benefits of conducting pilot surveys for planning monitoring programs for populations with similar ecological characteristics (high degree of residency, low spatial requirements and small population size; Daura-Jorge, 2011).

## Materials and Methods

### *Study design and field effort*

Surveys were conducted in one of the largest coastal systems in southern Brazil, consisting of three lagoons - Mirim, Imaruí and Santo Antônio (Figure 1). Based on previous distribution data (Daura-Jorge, 2011) and because of logistical constraints, the study focused around the Imaruí and Santo Antônio lagoons. This area comprises several habitat types such as coastal mangroves, sand beaches, rivers, lagoons and channels. Line-transect and photo-identification mark recapture surveys were conducted during autumn 2009 (April-May) with the intention of comparing methodologies to estimate abundance of bottlenose dolphins in this coastal system. In this region, dolphins cooperate with fishermen during the mullet season (*Mugil* spp.) aiding in entrapping fish (Simões-Lopes *et al.*, 1998). The mullet season commences in April, which coincides with the beginning of our study. During this season, there appears to be a higher dolphin abundance.

Field surveys were conducted from a small 5m boat with a 2m maximum elevation at eye level. Each survey was conducted every two weeks, and we alternated days for each type of effort (*i.e.* line-transect efforts were conducted the first day and mark-recapture the second). Overall, we spent six field days for each method, with approximately five hours of effort per day (Table 1). If several surveys were conducted using the same method on consecutive days, these were not included to ensure data independence (*i.e.* avoid pseudoreplication). A group of dolphins was defined as a set of individuals within a radius of 50m (adapted from Lusseau *et al.,* 2003). The maximum size of the group was counted during the first minutes after its detection.

### *Line transect routine*

For the line-transect method, we stratified the study area into two strata, considering physiography and previous information on the distribution of the species. In total, 21 parallel transects were conducted along the first stratum, covering the area of the two surveyed lagoons. Three transects were conducted on the second stratum, covering the channels and rivers (Figure 1). The length of transects in the first stratum ranged from 1.4 to 4.4km, and from 2.5 to 3.5km for the second. A total of 55km$^2$ were covered by line transect (50km$^2$ for the first stratum and 5km$^2$ for the second) after excluding all sand banks and shallow areas. For each sampling day, eight linear transects in the first stratum and two in the second stratum were chosen at random without replacement. A transect was surveyed at a constant speed (10km/h) and was only conducted in favorable sea conditions (Beaufort Sea state $\leq 2$).

During data collection two observers stood on the bow of the vessel observing the line transect but each covering a different side of the boat (right/left). The boat driver also surveyed the line transect, as well as recorded data. When a sighting was made the following data were recorded: the angle of the sighting in relation to the transect line (using a compass), the radial distance (m) from the boat to the group of dolphins and group size. Additional data recorded included time, geographic location (GPS position), transect line label, tide, wind strength and cloud cover.

The radial distance was estimated visually by eye. Before conducting a survey, observers practiced estimating distance. More specifically, distances between stationary objects (buoys) 50 to 400m apart were estimated visually and validated through the use of a laser range finder (Cremer and Simões-Lopes, 2008; Lukoschek and Chilvers, 2008). Data collection was initiated only when observers estimated the distance with a maximum error of 20% in at least three of five trials.

The program DISTANCE 6.0 was used for data analysis[1]. Perpendicular distance data were right-truncated at 250m and the standard detection function models (*i.e.* uniform, half-normal and hazard-rate) were fitted to the data (*cf.* Buckland *et al.,* 2001). Instead of selecting the most parsimonious model by the adjusted Akaike Information Criterion method (AICc, *cf.* Burnham and Anderson, 2002), we used a weighted average of all plausible models to find the probability density function at zero $\hat{f}(0)$. In addition, we used nonparametric bootstrap (with 10000 replicates within each stratum) to estimate variance (Buckland *et al.*, 2001). For all models, encounter rate and cluster size were estimated by stratum, while the detection function was estimated globally (considering the sample size). Density and abundance were estimated globally and also by stratum. For this pilot study, we assumed a perfect detection probability on the transect line, or $g(0)=1$, which may underestimate abundance. However, we believe the bias is minimal, considering the optimal sampling conditions, the low vessel speed, the high detectability of the species in the area and the short submersion time of bottlenose dolphins (approximately 62.6s when traveling; López *et al.,* 2008). Abundance was estimated as

$$\hat{N} = A.\hat{D},$$

where $A$ is the size of the study area and $\hat{D}$ is the density, which was estimated as

$$\hat{D} = \left(\frac{n.\hat{f}(0).\hat{s}}{2L}\right),$$

where $n$ is the number of groups sighted; $\hat{s}$ is the estimated mean group size; $\hat{f}(0)$ is the probability density function of the perpendicular distance evaluated at the origin; and $L$ is the length of transect line surveyed (Buckland *et al.,* 2001).

*Mark–recapture routine*

To implement the mark-recapture method, boat surveys were conducted to collect photo-identification data on bottlenose dolphins (Hammond *et al.,* 1990). We followed pre-defined zigzag and circular routes that covered the study area evenly. When a group was encountered, it was followed for 20 minutes for photo-identification sessions. To ensure that all the dolphins in the group were photographed, we attempted to obtain at least four pictures for each animal, from both sides, while avoiding any bias for a specific individual (Würsig and Jefferson, 1990). To minimize misidentification, individual identification was based on long-lasting natural marks on the dorsal fin such as nicks, scars, deformities and skin diseases (*e.g.* Würsig and Jefferson,1990; Williams *et al.,* 1993). Only high-quality photographs (determined by angle, sharpness, exposure and focus), capture occasions with fine weather conditions (Beaufort Sea state ≤ 2) and capture occasions where the pre-defined route was completely covered were considered. Surveys on consecutive days were excluded to ensure the independence of capture events (Wilson *et al.*, 1999). For a detailed description of data collection and sampling design we refer readers to Daura-Jorge *et al.* (2013).

A capture event was defined as one day, and the entire database was used to create a capture history for each individual. We assumed the population was closed (no gains or losses) during the course of our study considering the short period between the first and last capture occasion. This allowed us to implement classical closed population models (Otis *et al.,* 1978). Briefly, closed models assume the population is closed demographically (no births or deaths) and geographically (no migration), incorporating three sources of variation in capture probabilities: time M(t), behavioral responses M(b), individual heterogeneity M(h), and all possible combinations – M(th), M(tb) - (Otis *et al.,* 1978). Models accounting for behavioral response were not considered here, since we did not report avoidance or attraction behaviors. All other models, including a null model M(0) that assumed equal capture probabilities, were built using the full likelihood parameterization implemented in the program MARK (White and Burnham, 1999), which estimates the parameters of interest by maximum likelihood. The most parsimonious model was selected by the AICc. To take into account uncertainty in model selection, we used the average of the abundance (and precision) estimates across all models based on the AICc weights (Burnham and Anderson, 2002). Violation of models assumptions such as constant capture probabilities may promote extra binomial variation (overdispersion) - a common feature of cetacean data (*e.g.* Hammond *et al.*, 1990). To date there is not an appropriate way to measure overdispersion for closed models (Williams *et al.*, 2002), but we applied a goodness-of-fit test to investigate violation of assumptions (Burnham *et al.*, 1987).

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[1] Thomas, L., Laake, J.L., Strindberg, S., Marques, F.F.C., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Hedley, S.L., Pollard, J.H. and Bishop, J.R.B. (2004) Distance 4.1 Release 2. (Research Unit for Wildlife Population Assessment, University of St. Andrews: UK.) Available at http://www.ruwpa.st-and.ac.uk/distance/.

**Table 1.** Summary of the sampling effort and basic results for each survey type during the pilot study in Laguna, southern Brazil.

| Method | Effort (days) | Effort (hours) | Effort (km) | Sighted groups | Mean group size (%CV) |
|---|---|---|---|---|---|
| Line transect | 6 | 37 | 324 | 97 | 1.59 (7.44) |
| Mark-recapture | 6 | 33 | 271 | 78 | 1.89 (5.32) |

To estimate the total abundance of bottlenose dolphins in the area ($\hat{N}_{Total}$), the abundance of marked individuals estimated from the selected model ($\hat{N}$) was corrected according to the proportion of identifiable individuals ($\hat{\theta}$) in the groups encountered (Wilson *et al.,* 1999). Thus, $\hat{\theta}$ was estimated by dividing the number of marked individuals by the total number of individuals in each encountered group. Calves were considered as unmarked individuals. The variance of total abundance was estimated by the delta method, following Wilson *et al.* (1999) as

$$Var(\hat{N}_{Total}) = \hat{N}_{Total}^{2}\left(\frac{var(\hat{N})}{\hat{N}^{2}} + \frac{1-\hat{\theta}}{n\hat{\theta}}\right)$$

where $n$ is the total number of schools (sample size) used to estimate $\hat{\theta}$. The confidence interval of total abundance was estimated following Burnham *et al.* (1987), dividing or multiplying the total abundance by a factor C calculated as

$$C = \exp\left[z_{\frac{\alpha}{2}} \times \sqrt{\ln(1+[CV(\hat{N}_{Total})]^{2}}),\right]$$

in which $z$ is the normal deviate, CV is the coefficient of variation and $\alpha = 0.05$.

*Effectiveness, cost and statistical power*

The cost of each technique was quantified considering all expenses during the sample period (accommodation, food, petrol, laboratory expenses and others). These costs vary by study and are not costs of the method *per se*, but of its application to the present study under our logistical conditions. Simultaneously, the effectiveness ($E$) of each approach, defined as the ratio between the estimated standard error of each method (Burnham *et al.,* 1985), was evaluated. Effectiveness was expressed by the standard error of the abundance estimated by one technique, divided by the standard error of the abundance of the other technique, as follows:

$$E = \frac{SE(\hat{N}_1)}{SE(\hat{N}_2)}$$

Based on these results, the models proposed by Gerrodette (1987) were used to assess and compare the power of the five-year monitoring programs for each technique in identifying significant changes (trends) in abundance. The following questions were assessed: (1) what is the probability of being able to detect a population decline of 5% per year, and (2) how many years must the population be monitored to detect a population decline of 5% per year with 95% probability. These simulations were performed with the software TRENDS (Gerrodette, 1993), considering the following program options: one-tailed test (the focus here is a decreasing trend), level of significance (α) of 0.05, an exponential model, a *Student-t* distribution, a CV proportional to the square root of abundance for mark-recapture data and a CV proportional to the inverse square root of abundance for line-transect data (as recommended by Gerrodette, 1987). Finally, based on the power analysis projections, we compared the total cost for implementing each monitoring program during the time needed to identify the change stipulated.

## Results

*Line transect and mark-recapture estimates*

Through line transect effort, a total of 324km of track-line were surveyed during the six days of the pilot study. A total of 97 groups were recorded, with 71 groups remaining after truncation (Tables 1 and 2). Data were grouped into six distance intervals of 50m for a better fit. Dolphin group size ranged from one to four individuals, and the mean group size was 1.59 (CV=7.44%). The regression of group size against detection probability was not significant, therefore we used the average group size to estimate density. Because the use of the study area by dolphins was unequal, encounter rate was the main component explaining the density variance in both strata (35% of variance in the density of the first stratum and 46% of the variance in the density of the second stratum). All models fitted well to the data (Chi-square GOF test; $p > 0.05$). The best-fitting detection function, following the smaller AIC, was half-normal with no adjustment terms (Figure 2, Table 3). However, as uniform key function with no adjustment terms also supported the data, we used a model averaging approach to account for uncertainty in model selection. For this averaged model a population density of 0.91 individual/km$^2$ (95% CI=0.61-1.39) was estimated for the first stratum and 2.94 individuals/km$^2$ (95% CI=1.94-4.41) for the second stratum. Global population density was 1.13/individual/km$^2$ (95% CI=0.64-1.56). The abundance estimate for the channel areas (stratum 2) was 15 individuals and for the internal lagoons (stratum 1) was 47 individuals, per km$^2$ respectively. Thus, the overall abundance estimated with the line transect method was 62 individuals (95% CI=38-103) (Table 4).

A total of 34 adult dolphins were observed using mark-recapture surveys. The proportion of marked individuals (*theta* $(\hat{\theta})$= average proportion in all groups encountered) was 0.76, and the discovery curve stabilized close to the last occasion (Table 2). The most parsimonious model M(0) suggested a constant capture probability (0.38, 95% CI = 0.31-0.46) for all individuals in all time periods, and no other model supported the data (Delta AIC for M(t), M(h) and M(th) higher than 2; Burnham and Anderson, 2002) (Table 3). The abundance of marked dolphins was estimated at 38 animals. Correcting for the unmarked proportion of the population ($N_T=N_m/\hat{\theta}$)), the overall abundance during the sampling period was estimated at 50 individuals (95% CI=39-64) (Table 4).

### *Precision, cost and statistical power for each method*

Comparing the coefficients of variation from both estimates, the mark-recapture estimate was considerably more precise (CV=0.13) than the line-transect (CV=0.24; Table 4). Although almost twice as effective in terms of precision (E = 2.28), mark-recapture was 1.30 time more expensive than line-transects for a single sampling season (Table 4).

Considering the projections for our five-year monitoring program, the higher effectiveness of the mark-recapture method was even more evident (Table 5). The probability of detecting a population decline of 5% per year for bottlenose dolphins in Laguna was 27% for mark-recapture and 13% (approximately 2.08 times less) for the line-transect approach. Regarding the monitoring period required to detect a change of 5% with 95% probability, the line-transect method required at least 17 years of effort, while mark-recapture required 11 years. The cost ratio between the two methods indicated it would cost almost 1.19 more time for the line-transect method than for the mark-recapture to detect a change of 5% with 95% probability. For line-transects, the population size at the time of the trend detection would be 56% lower than the original population, while for mark-recapture, it would be 40% lower. These results highlight how critical precision is for our monitoring goals.

## Discussion

The abundance estimates obtained by both methods seem to be reliable and indicated a small number of dolphins reside in Laguna, southern Brazil. However, the main objective of our research was not aimed at obtaining abundance estimates, but to explore the most cost-effective techniques to obtain abundance and trends over time. Recently, two years of mark-recapture surveys were analyzed using Pollock's Robust Design (Pollock, 1982), with seasonal abundance and results suggested that 50 to 60 dolphins live in the area (Daura-Jorge *et al.,* 2013). This suggests that the estimates from both methods used in this pilot study are within the range expected for this local unit. Although coastal bottlenose dolphins populations are often small, with estimates ranging from 56 to 290 individuals (Wells and Scott, 1990; Wilson *et al.,* 1999; Haase and Schneider, 2001; Currey *et al.,* 2007; Bearzi *et al.,* 2008; Fury and Harrison, 2008; Fruet *et al.*, 2011), estimates presented here (50 individuals by mark-recapture and 61 by line-transect) suggest that the bottlenose dolphin population from Laguna is one of the smallest among those measured by the aforementioned studies. This number demonstrates the vulnerability of this population to local anthropogenic impacts and justifies the need for developing an effective long-term monitoring program (Sutherland, 2000).

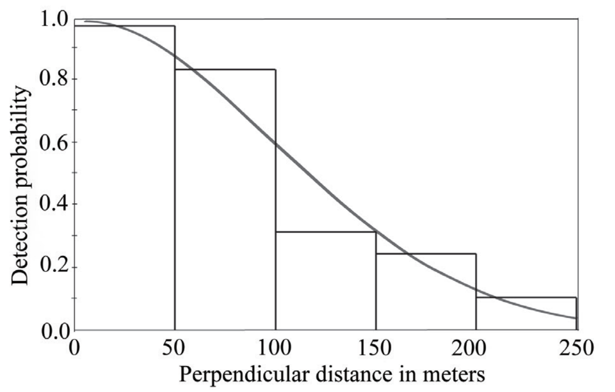

**Figure 2.** Histogram of the observed distances (grouped in intervals) from line transects, with the detection function (solid gray line) from the most parsimonious model (half-normal with no adjustment terms).

In general, mark-recapture methods provide abundance estimates of all animals using the area during the duration of the study whether or not they were present during sampling. The line-transect method estimates reflect the density or abundance of only animals present at a given moment in time within a prescribed area (Calambokidis and Barlow, 2004). This conceptual difference may weaken conclusions drawn from a direct comparison between both methods because each method represents different estimates (Evans and Hammond, 2004). However, considering the high degree of residency, the population closure, our short sampling period, and the high capture or detection probabilities of bottlenose dolphins inhabiting the Laguna area (Daura-Jorge, 2011), similar results are expected from both methods. Our results indicate that despite the smaller estimate derived from the mark-recapture method, it lays within the confidence intervals of the transect estimates, suggesting no significant differences in accuracy between methods.

Other comparative studies conducted by Lukoschek and Chilvers (2008) for a bottlenose dolphin population in Moreton Bay (Australia) and by Williams and Thomas (2009) for killer whales in British Columbia (Canada) estimated slightly smaller abundances by the line-transect effort than for mark-recapture; however, in those cases, the implementation of the methods during different time periods makes the interpretation of the results more difficult. This is because the population estimated may have changed (*i.e.* temporarily emigrated). In our study, both methods were implemented within the same period of time, and thus, we have assumed

**Table 2.** Summary of the sampling effort per day for line-transect and basic results for both methods.

| Day | Line-transect | | Mark- recapture | |
|---|---|---|---|---|
| | Effort (km) | Nº sightings | Dolphins marked | Dolphins recaptured |
| 1 | 49 | 15 | 15 | - |
| 2 | 55 | 19 | 6 | 4 |
| 3 | 53 | 17 | 4 | 12 |
| 4 | 56 | 16 | 5 | 8 |
| 5 | 58 | 18 | 5 | 12 |
| 6 | 52 | 12 | 0 | 14 |

**Table 3.** Candidate models for each method. Models are ranked by AICc values. Delta AICc is the difference between the AICc of each model and the most parsimonious model. Half-normal with no adjust term was the most parsimonious model for line transect analysis. M0 (null model) was the most parsimonious model for mark-recapture. Uncertainty in model selection was accounted by model average procedures.

| Line transect | | | Mark-recapture | | |
|---|---|---|---|---|---|
| Model | AICc | Delta AICc | Model | AICc | Delta AICc |
| Half-normal | 196.82 | 0.00 | M0 | 281.92 | 0.00 |
| Uniform + cosine | 197.56 | 0.74 | Mh | 283.92 | 2.00 |
| Hazard-rate | 197.62 | 0.80 | Mt | 288.71 | 6.79 |
| Half-normal + cosine | 198.30 | 1.48 | Mth | 290.78 | 8.86 |
| Half-normal + hermite | 198.93 | 2.11 | | | |
| Hazard-rate + cosine | 199.94 | 3.12 | | | |

**Table 4.** Summary of estimates for both methods: abundance (N), coefficient of variation (CV), confidence interval (95% CI), cost in US dollars (US$) and effectiveness (E) for each approach.

| Method | N | CV | 95% CI | US$ | E |
|---|---|---|---|---|---|
| Line transect | 62 | 0.24 | 38-103 | 1 | 1 |
| Mark-recapture | 50 | 0.13 | 39-64 | 1.30 | 2.28 |

that the same closed population existed for both sampling efforts (Evans and Hammond, 2004). Nevertheless, the line-transect survey was apparently more sensitive to the weaknesses of our simple pilot effort. The geography of the study area and the heterogeneous distribution of the species made it difficult to establish an appropriate sampling design for line-transects, increasing the chance of inaccurate estimates. Especially for the second stratum, formed mainly by channels, the encounter rate was likely positively skewed due to bottleneck effects that could overestimate density. Underestimates of distance measures (taken by visual estimation) could have also overestimated abundance (Buckland *et al.*, 2001), though the training period probably minimized this. Another issue was that our small boat may not have been an adequate platform, and some sightings could have been missed on the track line ($g(0) < 1$), underestimating density. On the other hand, we believe our study met all the assumptions of the mark-recapture theory (see details in Otis *et al.,* 1978). The *theta* value (proportion of marked animals) used to inflate the abundance estimate could bias the final mark-recapture results if not properly calculated. Our data, however, were re-analyzed by the recently developed mark-resight approach (McClintock *et al.*, 2006), which also includes the unmarked dolphins into the models. The results were similar both in terms of abundance and precision (data not shown).

More than the abundance estimates, the higher sensitivity of the line-transect method to our pilot survey design or to the population and environmental features was reflected in

**Table 5.** Parameters of the power analysis for each method considering our five-year monitoring plans. Power is the probability of detecting a decline of 5% per year. Period is the years of effort required to detect a decline of 5% with 95% power (type 2 error of 5%). Cost ratio is the comparison between the financial costs of each approach to reach the goal of detecting a 5% decline in the population with 95% power. Decline is the reduction of the original population at the time of the trend detection.

| Parameters / Methods | Line-transect | Mark-recapture |
|---|---|---|
| Power (-5%/year) | 13% | 27% |
| Period (change of 5% with 95% power) | 17 years | 11 years |
| Cost ratio | 1.37 | 1 |
| Decline | -56% | -40% |

the poor precision of the abundance estimate. In general, mark-recapture methods offer more precise abundances than line-transect methods (Evans and Hammond, 2004; Gormley *et al.*, 2005; Lukoschek and Chilvers, 2008; Williams and Thomas, 2009), especially in coastal dolphins that are found in small groups. Indeed our abundance estimates from mark-recapture were much more precise than from line-transect. This difference is clearly a result of the issues mentioned above, especially the variability in encounter rate resulting from the unequal distribution of individuals in the area. Perhaps a more sophisticated design (or a more appropriate platform) could minimize this difference in the future, improving precision of the line-transect method, which seems to be 'over punished' by our pilot design. On the other hand, the small sample size of our pilot study forced the fit of one single detection function for both strata, which could underestimate the precision. Therefore, the cost of the line-transect could be even higher than projected here. Despite being a pilot study, the estimate from mark-recapture had a particularly high precision not commonly reported for cetaceans (Whitehead *et al.,* 2000).

High precision of abundance estimates increases the power to detect a trend and decreases the monitoring length (Taylor *et al.,* 2007). The differences found here have important implications for defining an effective monitoring program. This relationship was clear when comparing the statistical power for the detection of a population trend between our two hypothetical programs. The greater precision from estimates produced by mark-recapture significantly increased the statistical power to detect a population decline of 5%. Although the cost of the annual effort was slightly larger for mark-recapture, this was offset by the reduction of the total monitoring time required. Thus, although both approaches were powerful tools for estimating abundance, for our study site and probably for other coastal populations of small cetaceans, a mark-recapture design seems more effective when the focus of the monitoring program is to assess population changes over time. Nevertheless, we highlight that despite the better precision of mark-recapture estimates, both methods had poor sensitivity for detecting trends because the original population would be markedly reduced by the time a decline is detected. Therefore, for the Laguna bottlenose dolphins, taking a precautionary approach is imperative (Thompson *et al.,* 2000), even when robust abundance estimates are obtained.

In addition to measuring abundance, each technique has other advantages and disadvantages that can be considered when selecting the most effective monitoring program, and both methods are complementary (Evans and Hammond, 2004). Line-transect methods do not require individual recognition (a limiting factor for poorly marked species) and allows the study of more than one species at the same time (Evans and Hammond, 2004; Cremer and Simões-Lopes, 2008; Lukoschek and Chilvers, 2008). However, because individual recognition is fundamental to mark-recapture, other demographic parameters and ecological and behavioral aspects can be estimated using this method (Read *et al.,* 2003). The choice of the technique ultimately depends on several factors, such as a clear definition of the study aims, the time available for the study and the financial and logistic conditions available (Evans and Hammond, 2004). Pilot studies of short duration, as presented here, clearly can help researchers to choose the most appropriate method, answering the question: at what variance levels does the line-transect analysis become more efficient than mark-recapture? Such approach is critical for planning and improving the sampling design (Buckland *et al.,* 2001; Evans and Hammond, 2004). Conducting pilot studies is especially useful when long-term projects that aim to identify population trends are being developed. For the population of bottlenose dolphins in Laguna, mark-recapture was the most effective and appropriate method, but our focus here also highlights the importance of defining this *a priori*, keeping in mind one of the most important aims of a monitoring program: to accurately assess population trends.

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