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Report of the Working Group on Population Abundance and Density Estimation

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Introduction

Population abundance can be considered as one of the most important demographic parameters for the conservation of top predators in highly impacted habitats (Sutherland, 2006). In the last 20 years, marine and freshwater *Sotalia* dolphins have been critically impacted by human activities (*e.g*. habitat destruction, interactions with fisheries, and overfishing) (see da Silva and Best, 1996; Santos and Rosso, 2007; Azevedo *et al*., 2009). Despite the relatively broad distributional range of *Sotalia* dolphins in South and Central America (see Flores and da Silva, 2009), to date there are less than 30 studies on population abundance or density estimation and most of these are from a few regions and covering small areas. Therefore, information is lacking for most of the range of *Sotalia* species.

This report presents a summary of the discussions of the Population Abundance and Density Estimation Working Group that took place during the 'Workshop on Research and Conservation of the genus *Sotalia*' held in Armação dos Búzios, Rio de Janeiro, Brazil, 19-23 June 2006. All available information on *Sotalia* abundance and density estimates were compiled for this report, including results that have been published since the workshop. Insights on the applicability of density and abundance estimation are also presented, and recommendations on the use of different techniques are provided.

Overview of available information

As of September 2010, a total of 28 documents on abundance and density estimates for *Sotalia* are available as abstracts/proceedings from scientific meetings, as theses and dissertations presented at universities as a partial requirement to obtain a bachelor's, master's, or doctoral degree, or as articles in the peer-reviewed literature (Tables 1 and 2).

Sotalia guianensis

Most studies were conducted with *S. guianensis* (n = 24), probably because of the proximity of research centres to coastal areas where the species is found. Seven documents were meeting abstracts, five were presented as partial requirement to obtain a bachelor's degree, and seven were master's or doctorate theses (Table 2). Five publications in peer-reviewed journals were available (Geise, 1991; Geise *et al*., 1999; Edwards and Schnell, 2001; Campos *et al*., 2004; Flach *et al*., 2008).

Dedicated studies for abundance or density estimation of *S. guianensis* have been conducted in a few places, usually in protected bays and estuaries, and mainly in southern and southeastern Brazilian waters. Abundance and/or density estimates have been made in waters of the states of Pará (Emboraí Bay), Rio de Janeiro (Guanabara and Sepetiba Bays), São Paulo (Cananéia Estuary), Paraná (Paranaguá and Guaratuba Estuaries) and Santa Catarina (Babitonga Bay) (see Table 2). There are also abundance estimates for the Gulf of Morrosquillo, Colombia, and density for the inner estuarine waters of Cayos Miskito Reserve, Nicaragua (see Table 2). Most studies (58%) applied line-transect methods, while the remaining ones were based on mark/recapture methods of photo-identified individuals. These studies have been published since 1999. With a few exceptions (see Geise *et al*., 1999; Pacífico, 2008), most investigations on *S. guianensis* have only covered portions of the bays and estuaries where the species can be found, usually in sub-areas that are not representative of the entire geographic range of a local population (see Bonin, 1997; Bisi, 2001; Acuña, 2002; Filla, 2004; Havukainen, 2004, Jaap, 2004).

The studies regarding *S. guianensis* showed that the population found in Guanabara Bay, southeastern Brazil, has decreased from the hundreds in the 1980s to 50 to 70 individuals in more recent times (see Geise,

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1989; 1991; Pizzorno, 1999; Azevedo *et al*., 2003[9]; Table 2). A few studies that have covered a broad area of the local distributions of Guiana dolphins showed that Sepetiba Bay, in Rio de Janeiro State, and the Cananéia Estuary, in São Paulo State, both in southeastern Brazil, host large populations of more than 500 individuals (Flach *et al*., 2008; Nery, 2008; Pacífico, 2008; Table 2).

Sotalia fluviatlis

From a total of four documents available, one was a meeting abstract, one was a doctoral dissertation, and two were publications in peer-reviewed journals (see Table 1).

Investigations reporting density estimates have been conducted at various locations of the Amazon River Basin, including Brazilian, Colombian and Peruvian waters (Table 1). Because of the habitat heterogeneity of the Amazon ecosystem, all surveys used combined methods including line- and strip-transect, as well as cue-counting. Those studies have been published after 1997 (see Table 1). All available studies for *S. fluviatilis* included information on density and showed a major concentration of individuals in lakes rather than in rivers or channels.

Consideration of survey design and shortcomings

Different field techniques and estimators can be used as tools to gather abundance or density data (see Buckland and York, 2009). The choice for each depends on the characteristics of the species and features of the habitat (Hammond *et al*., 1990). Both require specific survey designs and must meet specific assumptions. Researchers should be careful to avoid violating assumptions and to understand the shortcomings when choosing a specific technique and/or survey design.

Line-Transect Method

The application of line-transects depends on the use of specific protocols that must meet several assumptions (Buckland *et al*., 2001; 2004). Aspects on these assumptions as they relate to the application of this method on *Sotalia* species are discussed below:

(1) *The detection probability on the trackline [g(0)=1]*: *All animals directly on the survey line must be detected.* A set of factors must be considered to avoid violating this assumption. Sea state is important for individual detection. Therefore, it is essential to conduct surveys with proper sea conditions (Beaufort scale ≤ 2). Surveys must be conducted at low survey vessel speeds, preferably not exceeding eight to ten knots. Although regional variations may occur, diving time for *Sotalia* is relatively short. Thus, it is possible to assume that *g(0)* = 1 in most cases. However, when conducting aerial surveys (see discussion below), the calculation of *g(0)* becomes necessary because of the speed of the aircraft.
(2) *Objects must be detected prior to any responsive movement to the observer or the observation platform*: Most areas where *S. guianensis* is usually found present considerable boat traffic, which leads one to assume that dolphins are used to the presence of boats. However, it is not an easy task to determine with certainty that behavioral reactions regarding responsive movements to the survey vessel have taken place before a group is detected.

Table 1. *Sotalia fluviatilis* abundance/density estimates with emphasis on places where surveys took place, sampling period, area or length of survey, technique used, obtained results and source of information. Ind = individuals.

PLACE: BASIN/COUNTRY/STATE	SAMPLING PERIOD	AREA/LENGTH OF SURVEY	TECHNIQUE(S)	ESTIMATES	SOURCE
Amazon/Peru, Colombia, upper Brazilian Amazon River	5-26 Jun 1993	120km	line; strip transect	409 (CV = 0.13); 8.6 ind/km² (lakes); 2.8 ind/km² (banks); 2.0 ind/km² (islands)	Vidal *et al*. (1997)
Amazon/Colombia	Mar-Apr 2002	140km	line; strip transect; cue counting	26.7 ind/km² (lakes); 4.1 ind/km² (channels); 3.8 ind/km² (islands); 3.5 ind/km² (tributaries)	Marques *et al*.(2002)[10]
Amazon/Brazil	Mar 1999-Apr 2001	1402km strip transect; 810km line transect	line; strip transect	Mean 3.2 ind/km² (values presented for different habitats along time)	Martin *et al*. (2004)
Amazon/Peru; Pacaya-Samiria Reserve	Mar 1996 - Nov 2000	288km (rivers) 50km² (lakes)	line; strip transect	0.01-0.08 ind/km (rivers); 0.05-2.17 ind/km² (lakes)	McGuire (2002)

[9] AZEVEDO, A.F., OLIVEIRA, A.M., VIANA, S.C., LAÍLSON-BRITO JR., J., FRAGOSO, A.B.L. AND VAN SLUYS, M. (2003) *Estimativa do tamanho da população de botos (*Sotalia fluviatilis*) da baía da Guanabara (RJ), por meio da técnica de foto-identificação*. Pages 175-176 in Abstracts, VI Congresso de Ecologia do Brazil, 9 – 14 November, Fortaleza, Ceará, Brazil.

[10] MARQUES, F.C.M., TRUJILLO, F., HEDLEY S.L. AND DIAZGRANADOS, M.C. (2002) *Estimativas de densidade de* Inia geoffrensis *e* Sotalia fluviatilis *na Amazônia Colombiana: Considerações e resultados preliminares*. Page 102 *in* Abstracts, X Reunión de Trabajo de Especialistas en Mamíferos Acuáticos de América del Sur, 14 – 19 October, Valdívia, Chile.

Throughout its range, it is known that *Sotalia* does not approach boats (da Silva and Best, 1996; Santos *et al*., 2000). This behavioral aspect is likely to reduce the violation of this assumption, but on the other hand it may amplify the possibility of the opposite response; that of platform avoidance. This aspect must be investigated for each survey area regardless of the level of human impacts. (3) *The perpendicular distance between the object or cluster of objects and the observer are accurately measured*; (4) *Detection of objects of interest is independent*; (5) *Objects are correctly identified*; and (6) *If objects occur in clusters, cluster size is accurately estimated*.

These four assumptions all underscore the importance of using properly trained observers, as bias induced by collecting faulty data by inexperienced observers can severely affect the analyses and results.

Important aspects of reducing and/or avoiding the violation of assumptions when conducting line-transect surveys for abundance estimates of riverine *Sotalia* can be found in Vidal *et al.* (1997) and Martin *et al*. (2004). One aspect which has a significant effect on *S. fluviatilis* abundance estimates has been the use of additional observers in the back of boat-based platforms when conducting line-transect surveys to estimate the fraction of individuals that are missed during strip transects (see Vidal *et al*., 1997; Marques *et al*., 2002[10]). This issue arises from difficulties in observing *S. fluviatilis*, as it usually avoids boats, forms small groups and is considered small when comparing to other delphinid species.

Table 2. *Sotalia guianensis* abundance/density estimates with emphasis on places where surveys took place, sampling period, area or length of survey, technique used, obtained results and source of information.

PLACE: BASIN/COUNTRY/STATE	DATE	AREA/LENGTH OF SURVEY	TECHNIQUE(s)	ESTIMATES	SOURCE
Cayos Miskito Reserve/Nicaragua	Apr-May 1996; Mar-May 1997/1998	152.4km²; 4389km (boat)	boat (line transect) + aerial surveys	Different results for different subareas Mean: 0.647 ind/km² (coast); 0.578 ind/km² (inlets); 0.486 ind/km² (lagoons)	Edwards & Schnell (2001)
Gulf of Morrosquillo/Colombia	Nov 2002 - May 2006	43km	Photo-identification	70-90 individuals	Dussán-Duque *et al*. (2006)[11]
Guanabara Bay/Rio de Janeiro/Brazil	1983-1984; 1987-1988	70km²; 37km (1983-84); 57km (1987 – 1988)	line transect	1983-1984: 7.6 ind/km² 1987-1988: 5.7 ind/km²	Geise (1989; 1991)
Guanabara Bay/Rio de Janeiro/Brazil	1995-1998	N/A	Photo-identification	67-75 ind (3 different capture-recapture models)	Pizzorno (1999)
Guanabara Bay/Rio de Janeiro/Brazil	Sep 2002 - Sep 2003	300km² (dolphins found in 130km²)	Photo-identification	54-73 ind (Chapman's Modified Estimator)	Azevedo *et al.* (2003)[12]
Sepetiba Bay/Rio de Janeiro/Brazil	Apr 2006 - Apr 2007	145km² (dolphins found in 519km²)	Photo-identification	965-1067 ind (Schnabel) 1004-1117 ind (Schumacher-Eschemeyer)	Nery (2008)
Sepetiba Bay/Rio de Janeiro/Brazil	Aug 2002 - Jul 2003	526km² (3219km precluded in total sampling)	line transect	2.79 ind/km²; 1,269 ind (739-2,196 ind)	Flach *et al.* (2008)
Sepetiba Bay/Rio de Janeiro/Brazil	Feb 1994 - Dec 2001 (with interval)	519km²	Photo-identification	Up to 1998: 235-449; Up to 2001: 365-722 (Schnabel and Schumacher-Eschemeyer estimators)	Campos *et al.* (2004)
Cananéia estuary/São Paulo/Brazil	Mar 1987 - Feb 1988	82km (10 surveys)	line transect	3.38 ± 1.76 ind/km² 704.8 ± 367.7 ind	Geise (1989); Geise *et al*. (1999)
Cananéia estuary/São Paulo/Brazil	Jan-Sep 2001	12km²	line transect	0.41 ind/km²	Bisi (2001)
Cananéia estuary/São Paulo/Brazil	1999-2001	N/A	line transect	N/A	Rollo Jr (2002)

Continued

[11] DUSSÁN-DUQUE, S., WELLS, R.S. AND BASSOS-HULL, K. (2006) *Distribución, uso de habitat y abundancia de* Sotalia guianensis *en el Golfo de Morrosquillo, Colombia*. Page 15 *in* Siciliano, S., Borobia, M., Barros, N.B., Marques, F., Trujillo, F. and Flores, P.A.C. (Eds) Book of Abstracts, Workshop on Research and Conservation of the genus *Sotalia*, 19-23 June 2006, Armação dos Búzios, Rio de Janeiro, Brazil. *Latin American Journal of Aquatic Mammals* 8(1-2) (supplement). http://dx.doi.org/10.5597/lajam00147.a005

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conclusion

PLACE: BASIN/COUNTRY/STATE	DATE	AREA/LENGTH OF SURVEY	TECHNIQUE(s)	ESTIMATES	SOURCE
Cananéia estuary/São Paulo/Brazil	May 2003 - May 2004	15.71km²	line transect	12.41 ind/km²	Havukainen (2004)
Cananéia estuary/São Paulo/Brazil	May 1998 - Oct 1999	20km²	Photo-identification	156-380 ind (4 different capture-recapture estimators)	Acuña (2002)
Cananéia estuary/São Paulo/Brazil	May 2000-Jul 2003	~16 to 125km²	Photo-identification	290-360 ind (Pollock Robust Design)	Santos & Zerbini (2006)[13]
Cananéia estuary/São Paulo/Brazil	Summer 2007	~125km²	Photo-identification	697-730 ind Petersen, Chapman, Schnabel, Schumacher & Eschmeyer	Pacífico *et al.* (2007[14], 2008[15]); Pacífico (2008)
Guaratuba Bay/Paraná/Brazil	Jul 2002 - Jun 2003	40km²	line transect	0.15 ind/km²	Filla (2004)
Paranaguá Estuarine Complex/Paraná/Brazil	Apr-Sep 1997	193.5km	line transect	Three sectors: (A) 0 ind/km²; (B) 0.04 ind/km²; (C) 35.0 ind/km²	Bonin (1997); Bonin & Monteiro-Filho (1998)[16]
Paranaguá Estuarine Complex/Paraná/Brazil	Mar 1999 - Feb 2000	38.84km²	line transect	11.56 ind/km²	Filla (2004)
Antonina Bay/Paraná/Brazil	Mar 2003 - Apr 2004	28km²	line transect	23.16 ind/km²	Japp (2004)
Babitonga Bay/Santa Catarina/Brazil	2001-2003	160km²; 1147km	line transect	231 (147-365; 95% CI) in 2001 (1.44 ind/km²); 137 (78-240) in 2002 (0.85 ind/km²); 154 (71-332) in 2003 (0.96 ind/km²).	Cremer *et al.* (2006)[17]; Cremer (2007)

N/A = Not Available, Ind = Individuals.

Mark/Recapture Method

The photo-identification technique has been applied to *S. guianensis* since the 1990s. As with most delphinids, photo-identification in *Sotalia* has been based on individual markings and morphology of the dorsal fin. Attempts to apply this technique on *S. fluviatilis* have been conducted (see Trujillo, 1994; McGuire and Henningsen, 2007; McGuire, 2010 this volume), but no results have been presented regarding abundance estimates. Most photo-identification studies on *S. guianensis* have been conducted in protected bays, inlets and estuaries.

Mark-recapture methods have been described elsewhere (see Seber, 1982; White *et al*. 1982; Amstrup *et al*., 2005). In all cases, it is recommended that researchers avoid the violation of assumptions regarding each estimator. One important aspect regarding the violation of assumptions in capture-recapture models is the bias caused by choosing individuals with evident marks to be photographed when collecting data in the field

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[15] PACÍFICO, E.S., OSHIMA, J.E.F., SILVA, E. AND SANTOS, M.C. O. 2008b. *Comparação de diferentes estimadores de abundância por captura-recaptura: caso do boto-cinza,* Sotalia guianensis*, no estuário de Cananéia (SP)*. CD-ROM *in* III Congresso Brazileiro de Oceanografia, 20-24 May, Fortaleza, Ceará, Brazil.

[16] BONIN, C. AND MONTEIRO FILHO, E.L.A. (1998) *Estimativa de densidade populacional do golfinho Sotalia fluviatilis guianensis (Delphinidae), da baia de Guaraqueçaba, litoral do estado do Paraná*. Page 27 *in* Abstracts, VIII Reunião de Trabalho de Especialistas em Mamíferos Aquáticos da América do Sul, 25-29 October, Olinda, Recife, Brazil.

[17] CREMER, M.J., HARDT, F.A.S. AND TONELLO JR, A.J. (2006) *Estimativas de abundância e densidade populacional de* Sotalia guianensis *na Baía da Babitonga, sul do Brazil*. Page 41 *in* Siciliano, S., Borobia, M., Barros, N.B., Marques, F., Trujillo, F. and Flores, P.A.C. (Eds) Book of Abstracts, Workshop on Research and Conservation of the genus *Sotalia*, 19-23 June 2006, Armação dos Búzios, Rio de Janeiro, Brazil. *Latin American Journal of Aquatic Mammals* 8(1-2) (supplement). http://dx.doi.org/10.5597/lajam00147.a031

(Hammond *et al*., 1990). This tendency has not been observed for *S. guianensis*, probably because of its small dorsal fin size, elusive behavior, and characteristics of the environment (*e.g.* usually dark waters), which lead photographers to take pictures of all surfacing individuals (Santos *et al*., 2000; Santos and Rosso, 2008).

Acoustic Techniques

Acoustic detections can provide estimates of density and abundance of marine mammal populations as well (see Mellinger and Barlow, 2003; Whitehead, 2009). *Sotalia* has an acoustic repertoire (see Azevedo and Van Sluys, 2005) that could be used as the basis for estimating the abundance and density of populations. This approach has been used for other odontocete species such as *Tursiops truncatus* (Cockroft *et al.*, 1992), *Phocoena phocoena* (Chappell *et al*., 1996), *Delphinus* sp. (Goold, 1998) *Sousa chinensis* (Van Parijs *et al*., 2002), and *Physeter macrocephalus* (Barlow and Taylor, 2005).

Recommendations

- Abundance and density estimation surveys should be carefully designed and should take into account logistic limitations and analytical methods to be applied.
- In general, it is recommended that pilot surveys be conducted to evaluate local distribution and density patterns in order to help deciding the most appropriate scale and sampling design.
- Comparisons between methods should be conducted in each area where surveys on abundance or density estimates are planned. In areas where little or no biological information on *Sotalia* species is available, abundance/density estimates should be the priority, as well as in areas that have been affected by human activities.
- It is necessary to promote training of human resources through series of specific workshops on abundance estimation methods. Different research groups should try to meet to share knowledge and experiences.
- *Sotalia* habitats can and must be surveyed covering larger areas to provide representative information on the local population abundances.
- Aerial surveys may be suitable for *S. guianensis*. High-wing, twin-engine aircraft with bubble windows is recommended in aerial line-transect surveys (Dawnson *et al*., 2008). A flying speed of 80 to 90 knots and a flying altitude of 500 to 600 feet are recommended (Buckland *et al*., 2001). Aerial surveys allow large areas to be surveyed quicker and possibly at lower costs. If aircraft with bubble windows is not available, the effects of the blind zone immediately beneath the plane must be taken into account when estimating detection probabilities (Buckland *et al*., 2001). For safety reasons, it is strongly recommended to avoid using single-engine aircraft when surveying far from the coast. As of September 2010, one aerial survey has been conducted for *S. guianensis* (Edwards and Schnell, 2001). Thus, further studies should be conducted in order to assess the application of the method throughout the range of the species.
- In the case of boat-based line-transect surveys, boats with high observation platforms relative to the sea level and navigation speed of around 8-10 knots are recommended (Dawson *et al*., 2008). Nevertheless, the costs probably would be higher and the surveyed area would be smaller if compared to the use of aircraft in the same conditions in coastal areas (Aragones *et al*., 1997). Engine noise should be minimized to reduce avoidance of dolphins to boats, as well as to meet the assumption that dolphins do not react prior to detection. As an attempt to minimize the number of individuals missed on the trackline, the use of adequate binoculars is recommended (Aragones *et al*., 1997). Regarding the sampling design, surveys should consider the conditions of the area and to previous information on the presence of the species and location of isobaths. A zig-zag pattern or a set of perpendicular or diagonal transects to the coastline are especially useful for open-sea areas (Buckland *et al*., 2001). For small bays or gulfs and estuaries, parallel lines covering the whole area are suitable. These surveys should cover a representative area where the species may be found. For abundance/density estimates of *S. fluviatilis* it is recommended that stratified line- or strip-transect surveys be conducted taking into account the physiography of the habitat.
- The use of digital cameras with ≥ 6 megapixels is recommended in photo-identification studies. The use of ≥ 300mm lenses with image stabilizers is also recommended, although better results with small dolphins have been obtained with 400mm lenses (Mazzoil *et al*., 2004). Taking and analyzing photographs should follow the recommendations proposed by Würsig and Jefferson (1990) and Mazzoil *et al.* (2004). The use of software to compare new photographs with existing catalogues should be tested for *S. guianensis*. It is important to conduct surveys with proper sea conditions (Beaufort scale ≤ 2). Trained photographers are recommended. Discovery curves are suggested in all studies to detect important characteristics of the surveyed population (Hammond *et al*., 1990). In recent years, the use of specific software (*e.g.* Capture, Mark) has become common in studies of abundance estimation. It is strongly recommended that researchers have adequate training and theoretical background to use such tools. When describing the applied estimators in each study, it is important to report all steps in detail for further comparisons.
- Regarding effective acoustic censuses, calibration methods must be determined through visual studies. Studies related to estimating the calling rate, the proportion of individuals that emit sound, and the acoustic detection distances are recommended (Mellinger and Barlow, 2003).

Conclusions

Based on the described scenario, it is clear that much work is still needed regarding the estimation of population abundance along the range of both *Sotalia* species.

Priority should be given to areas that have been affected by human activities. Precise demographic parameters are deemed necessary in order to better evaluate the conservation status of the genus. Considering the vast expanse of the Amazonian ecosystem, abundance studies should be listed as priorities in light of the known degradation process of the riverine system. The same must be applied to coastal areas recently impacted by housing developments, oil prospection and pollution.

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