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Guiana dolphin home range analysis based on 11 years of photo-identification research in a tropical estuary

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Home range studies provide significant insights on social organization and interactions, limiting resources and habitat use. Knowledge on home range and habitat use by Guiana dolphins, *Sotalia guianensis*, is still scarce. The aim of this study was to identify and analyze individual's home ranges of Guiana dolphins in the Cananéia Estuary (~25°03′S, 47°55′W), located in southeastern Brazil. Photo-identification efforts were conducted between 2000 and 2010. From a total of 135,918 pictures taken, 34,086 (25%) were useful for individual identification. Two-hundred and five individuals were cataloged based on permanent notches along dorsal fin borders. Of the cataloged individuals, 31 had been identified a minimum of 20 times, on distinct dates, prior to this analysis. Home ranges were estimated for these individuals using 4 methods: minimum convex polygon (MCP), adaptive kernel with least-squares cross-validation (AKLSCV), fixed kernel with reference bandwidth (FKHREF), and fixed kernel with least-squares cross-validation (FKLSCV). The sizes of the estimated home ranges varied between 2.2 and 43.8 km^2 ($\bar{X}$ = 17.5 km^2) with MCP, between 0.8 and 82.5 km^2 ($\bar{X}$ = 15.6 km^2) with AKLSCV, between 3.9 and 244 km^2 ($\bar{X}$ = 72.4 km^2) with FKHREF, and from 0.6 to 70.6 km^2 ($\bar{X}$ = 13.5 km^2) with FKLSCV. Significant differences in size and shape of the generated areas were detected when comparing the 4 tested methods. Variation of individual's home range sizes and an extensive overlap among home ranges of different Guiana dolphins in the Cananéia Estuary provide evidence that the region supports important resources for this species. Therefore, preventing habitat loss in this region is essential to guaranteeing the persistence of this population.

O estudo sobre o uso de área pode fornecer informações sobre organização social e interações, recursos limitantes e sobre o uso de habitat. Ainda é escasso o conhecimento sobre como o boto-cinza, *Sotalia guianensis* usa seu habitat. O objetivo deste estudo foi identificar e analisar as áreas de uso individuais de *S. guianensis* no estuário de Cananéia (~25°03′S; 47°55′W), localizado no sudeste brasileiro. Os esforços de foto-identificação foram realizados entre os anos de 2000 e 2010. De um total de 135.918 fotografias tomadas, 34.086 (25%) foram úteis para identificações individuais. Duzentos e cinco indivíduos foram catalogados através das marcas permanentes presentes em suas nadadeiras dorsais. Dentre os indivíduos catalogados, 31 foram identificados ao menos em 20 ocasiões, em dias distintos, antes destas análises. As áreas de uso foram estimadas para estes indivíduos utilizando quatro métodos distintos: mínimo polígono convexo (MPC), kernel adaptativo com largura determinada pelo método de validação cruzada de quadrados mínimos (AKLSCV), kernel fixo com largura de referência (FKHREF) e kernel fixo com largura determinada pelo método de validação cruzada de quadrados mínimos (FKLSCV). Os tamanhos das áreas de uso geradas variaram entre 2,2 e 43,8 km^2 ($\bar{X}$ = 17,5 km^2) com o uso do MPC, 0,8 e 82,5 km^2 ($\bar{X}$ = 15,6 km^2) com o uso do AKLSCV, 3,9 e 244 km^2 ($\bar{X}$ = 72,4 km^2) com o uso do FKHREF, e de 0,6 a 70,6 km^2 ($\bar{X}$ = 13,5 km^2) com o uso do FKLSCV. Foram detectadas diferenças significativas no tamanho e formato das áreas geradas pelos quatro métodos testados. Variações nos tamanhos das áreas de uso individuais e a extensa sobreposição entre diferentes áreas de uso dos botos-cinza no estuário de Cananéia fornecem evidências de que a região provê recursos importantes para esta espécie. Portanto, prevenir a perda de habitat na região é essencial para garantir a persistência dessa população.

Key words: Cetacea, Delphinidae, habitat use, *Sotalia guianensis*, spatial analysis

The Guiana dolphin, *Sotalia guianensis*, is a small delphinid (Cetacea, Delphinidae) that inhabits shallow waters and is often found year-round in bays and estuaries (Da Silva et al. 2010). The species is endemic to the Western Atlantic coastal waters of South and Central America, specifically spanning from Southern Brazil (27°35′S, 48°35′W) to Nicaragua (14°35′N, 83°14′W—Borobia et al. 1991; Flores and da Silva 2009). Although research efforts involving *S. guianensis* are becoming more prominent, several ecological aspects such as abundance estimates and habitat use are still poorly known (Santos et al. 2010a). Therefore, *S. guianensis* is classified as a "Data Deficient" species by the International Union for the Conservation of Nature (IUCN—Secchi 2012). The main concern regarding this classification is that most populations are susceptible to the impacts caused by the unplanned growth of the cities along the Brazilian coast (Azevedo et al. 2009). In 2014, the conservation status of *S. guianensis* on the Brazilian National List of Threatened Species was updated to vulnerable (MMA 2014). Potential threats that require monitoring and possible mitigation include the loss of habitat resulting from the establishment of marinas, ports, and aquaculture activities; chemical and noise pollution; intense vessel traffic (disturbance and strikes); and overexploitation of the marine living resources (Crespo et al. 2010). Such threats may have long-term effects and may operate cumulatively and synergistically (Azevedo et al. 2004).

The species avoidance response to the presence of boats, the lack of sexual dimorphism, and the small body size compared to other cetacean species provide some challenges to the study of *S. guianensis* in its natural habitat (Santos et al. 2000). Since the 1990s Guiana dolphins have been monitored in several bays and estuaries of Brazil through photo-identification efforts (see Simão et al. 2000; Santos et al. 2001; Azevedo et al. 2004; Flores and Bazzalo 2004; Rossi-Santos et al. 2007; Santos and Rosso 2008; Hardt et al. 2010; Cantor et al. 2012; Nery and Simão 2012; Batista et al. 2014).

Individual identification has become a ubiquitous tool used in cetacean field research as it provides the possibility of following naturally marked individuals through time and space (Würsig and Würsig 1977; Würsig and Jefferson 1990). It is also an important tool to investigate ecological aspects, life history, and to search for individual information within a population. This individual identification technique was first employed in Cananéia in 1996 and it is used until today in a long-term study of *S. guianensis* in one of the main areas of the species distribution along the southeast coast of Brazil. Ecological aspects such as site fidelity (Santos et al. 2001), social structure (Santos and Rosso 2008), and the 1st insights on individual's home ranges (Oshima et al. 2010) have been described in the Cananéia Estuary.

Home range was described by Burt (1943) as "the area traversed by the individual in its normal activities of food gathering, mating, and caring of young." There is a tendency for most animals to use particular areas of their home range in a more intense way than other parts (Dixon and Chapman 1980; Samuel et al. 1985). This non-random habitat use can be interpreted as an adaptation to maximize fitness and minimize costs imposed by competition and constraints of the environment (Mitchell and Powell 2012). A more updated interpretation of home range estimates is that they are a model of how an individual understands and uses its environment or even a model of its cognitive map (Peters 1978; Powell 2000; Börger et al. 2008; Spencer 2012), with information about important routes and sites with different resources available in an "area that an animal knows and maintains in its memory because it has some important value" (Peters 1978; Powell 2000; Kie et al. 2010).

Although several studies have described Guiana dolphins' range patterns and habitat use (e.g., Rossi-Santos et al. 2006; Azevedo et al. 2007; Wedekin et al. 2007), individual's home ranges of this species remain poorly known (Da Silva et al. 2010). Investigating individual's home ranges is important because individuals within a particular population can differ greatly in ranging patterns (Defran et al. 1999) and may shift between local site fidelity and longer movements away from the site where they were first identified (Würsig and Würsig 1979; Wells et al. 1990; Würsig and Harris 1990; Bearzi et al. 1997). The accurate estimation of the home range is an important step to explore a species' spatial ecology (Powell 2000; Boyle et al. 2009) and to plan conservation actions, but it can be a challenging task to interpret habitat selection (Acevedo-Gutierrez 2009). Therefore, the aim of this study is to investigate *S. guianensis* individual's home ranges in the Cananéia Estuary, southeastern Brazil, by comparing 4 different home range estimation methods for their effectiveness in portraying individual's space use patterns and identifying the main core areas used. The main difficulties of working with photo-identification data as the baseline information to acquire location data for home range analysis are also explored, as well as the effects of removing inhospitable areas included by the estimations.

Materials and Methods

Study area.—The Cananéia Estuarine System (CES; 25°03′S, 47°55′W) is a large mangrove-dominated estuary located along the southern coast of São Paulo state, Brazil (Schaeffer-Novelli et al. 1990). The availability of shelf sands and a moderate wave energy regime has led to the formation of an elongated (74 km) barrier island (Comprida Island) that encloses narrow water bodies in this estuary. Maximum water depth reaches 23 m, but the average is approximately 7 m (Santos and Rosso 2007). Salinity varies from 35–40 ppm at the main estuary entrance to 0 ppm in the middle and northern part of the estuary, in a place named "Tombo das Águas." In that region, a deviation of a river called "Valo Grande" placed at the northern edge of the estuary was made in the 1850s; therefore, the surrounding area came to more closely resemble a riverine habitat rather than estuarine due to the increase of fresh water input and silting (Schaeffer-Novelli et al. 1990; Mahiques et al. 2014). As a consequence, Guiana dolphins are found only in salty waters along the estuarine range (Santos and Rosso 2007). There are 2 entrances connecting the estuary to the sea: one on the northern end ("Icapara" entrance) and the other at the southern end of Comprida Island ("Cananéia" entrance—Schaeffer-Novelli et al. 1990). As the shallow inshore waters are darker, there is greater energy absorption and warming of these waters (Garcia-Occhipinti 1963). The Cananéia Estuary is part of a Federal Environmental Protected Area established in October 1984. In October 2008, a Marine Protected Area was also established along the coast of São Paulo state, and the Cananéia estuarine connections to the sea were included for conservation purposes.

The 132 km^2 surveyed area of waters circling Cananéia Island (Fig. 1) was divided into 3 smaller sub-areas, A0, A1–A4, and A5. There were no physical barriers isolating these sub-areas, which were stratified in order to survey more efficiently the entire estuarine area for dolphins. Based on the sub-area sizes and daylight time available for photo-identification, it was possible to survey the entire study site in 3 days. Sub-area A1–A4 has been surveyed since 2000, while A0 has been surveyed since 2001 and A5 since 2002.

Data collection.—Fieldwork was conducted from May 2000 to July 2010. Efforts were unevenly distributed in time and space because the number of field work days was different in each year and surveys in each sub-area have started in different years. Small motor-powered boats (15 and 60 hp) were used to survey sub-areas. A zigzag survey path was applied to maximize group encounter chances. Surveys were conducted in Beaufort sea states from 0 to 2. When an individual dolphin or a group of dolphins was found, the boat approached the animal(s) in a parallel orientation and low velocity (approximately 5 km/h) for the photo-identification efforts. Group/individual initial position was recorded with a handheld Garmin global positioning system (GPS—average accuracy of 15 m) using datum WGS 84. On most occasions, all individuals in a group, including calves, were photographed using 35 mm reflex cameras with 75–300 or 400 mm telephoto zoom lenses. Digital cameras were used from 2004 on. Pictures were taken at distances ranging from 2 to 15 m. Individuals were included in the reference catalog only when they presented distinct and conspicuous notches along their dorsal fin borders, which allowed identification, following the procedure described by Karczmarski and Cockcroft (1998). Other details on the protocols of photo analysis and the determination of sex for the cataloged individuals are described in Santos and Rosso (2008).

Data analysis.—Using ArcGIS 9.2 tools (ESRI 2006), a digital cartographic base was created by manually converting a remotely sensed image (ETM+/Landsat-7, orbit 220/77, 26 September 1999, projected coordinate system WGS 84-22S zone) to vector format. We created shapefiles containing the geographic locations of each photo-identified Guiana dolphin with > 20 independent geographic locations collected, with each location collected on a different sampling day. If a dolphin was photographed more than once in a day, only the 1st sighting was used for analysis to avoid autocorrelation of data. The home range for each individual was calculated using the extension Home Range Tools 1.1 (HRT—Rodgers et al.

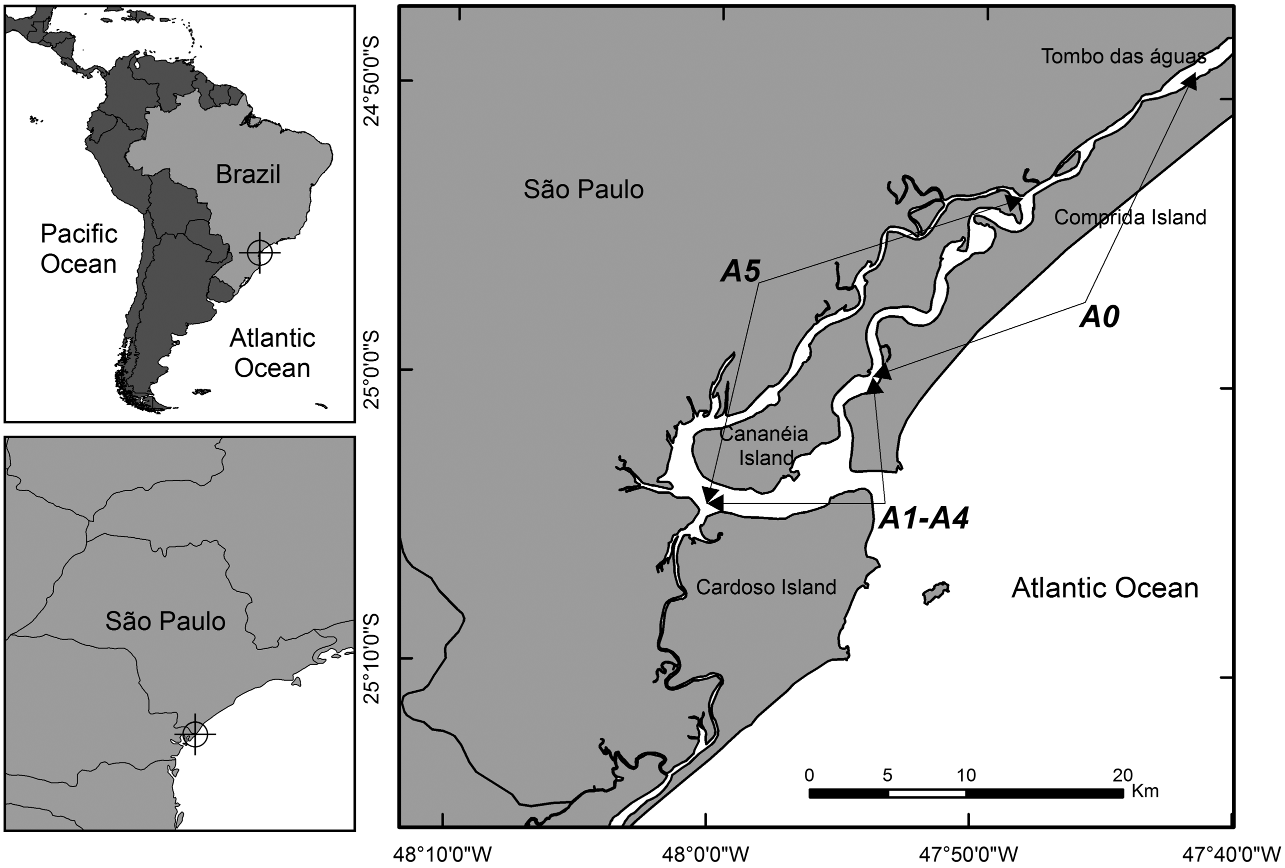

Fig. 1.—The Cananéia Estuary located in southern São Paulo state, Brazil. The surveyed area was divided into 3 smaller sub-areas, A0, A1–A4, and A5.

2007; Rodgers and Kie 2010) in ArcGIS 9.2. The minimum convex polygon (MCP), fixed kernel density estimator (FK), and adaptive kernel density estimator (AK) were employed to estimate Guiana dolphins' home ranges. The fixed mean was used for the MCP estimates; it calculates the arithmetic mean of all x and y coordinates and then selects the requested percentage of points (in this case 100%) closest to that arithmetic mean point (Rodgers and Kie 2010). The least-squares cross-validation (LSCV) and the reference bandwidth (HREF) were tested as smoothing parameters for the kernels. LSCV is the most common method applied to calculate a smoothing parameter (*h*—Powell 2000). The LSCV method attempts to determine a value of *h* that minimizes the mean integrated square error (e.g., Worton 1995; Rodgers and Kie 2010). The reference bandwidth (HREF) method is effective if the underlying utilization distribution (UD) is unimodal and the calculation of HREF assumes that data are normally distributed in a bivariate space (Silverman 1986; Worton 1995). This is the default method of bandwidth selection in the HRT (Rodgers and Kie 2010).

The time spent in each geographic area was quantified using a probability density function known as the UD. The UD is used to evaluate intensity of use (Powell 2000; Fieberg and Börger 2012). Isopleths of 95% and 50% were defined to investigate the UD in the home ranges and also to compare sizes of the estimated areas and their possible cores. It is also possible to determine the raster format output in the HRT extension, so raster cell size was defined as 50 m. The volume of the UD estimated generates small values to each raster cell, which has no effect on the isopleths, but to avoid loss of information due to truncation we used a scaling factor of 1,000,000 (Rodgers and Kie 2010). The HRT provides an output of the kernel analysis as both raster and polygon features. The polygon features were used to determine the sizes of the home ranges. The home range polygons usually had parts estimated on land due to the proximity of several location points on shallow waters and mangrove borders.

Areas that overlapped with land were extracted using the *ERASE* tool in ArcGIS 9.2 as areas that were inhospitable (e.g., terrestrial areas for aquatic organisms) must be excluded from home range estimates (Powell and Mitchell 2012). Polygon sizes were recalculated after exclusion and the percentage of original estimated areas kept after extraction was measured to compare which methods had included more inhospitable areas on the estimate. A Friedman test and block design analysis of variance (ANOVA) with a post hoc Tukey test were used to compare home range sizes estimated by the methods explained above. A 5% significance level was adopted for all tests. Cumulative curves were calculated using the MCP data to verify if home range sizes reached an asymptote. We opted to use only this method for cumulative curves because MCP provides a more sensitive estimate of locations in the outlined boundaries.

RESULTS

From 2000 to 2010, 216 days of fieldwork were conducted in the Cananéia Estuary, resulting in approximately 650 h of direct observations of Guiana dolphins. A total of 1,076 groups were observed (Table 1), which rendered 135,918 dorsal fin photos, of which 34,086 (25%) were useful for identification purposes.

The photo-identification catalog comprises 205 individuals. Discovery rates of new individuals were decreasing through time, dropping from 32.5% in the first year to 2.9% in the last year (Fig. 2). Six individuals were observed in all 11 years of photo-identification efforts: KN #15, KN #51, KN #75, KN #86, KN #88, and KN #157. Thirty-five individuals (17.1% of the total cataloged) were photographed in just 1 year of our surveying efforts. Throughout the entire study, individuals were sighted between 1 and 44 times on distinct days (Fig. 3). Most individuals (47.8%) were sighted from 2 to 9 times. Twenty-two individuals (10.7%) were not re-sighted. Thirty-one individuals were sighted at least 20 times on distinct days, which represented 15.1% of the total cataloged individuals. These were the individuals used for the home range estimates.

The 95% home range outlines for the 31 evaluated individuals varied between 2.2 and 43.8 km^2 ($\bar{X}$ = 17.5 km^2 ±

Table 1.—Survey efforts for the photo-identification study of *Sotalia guianensis* in the Cananéia Estuary of southeastern Brazil from 2000 to 2010. The number of days of field work, minutes of direct observation, number of groups observed, number of photos taken, and percentage of useful photos for identification purposes are shown.

Year	Days	Minutes	Groups	Photos	% useful photos
2000	14	3,727	95	7,067	18.8
2001	24	5,500	115	10,297	19.7
2002	31	3,539	76	5,782	26.0
2003	22	2,670	78	6,181	23.9
2004	14	2,885	73	4,974	29.5
2005	15	2,338	71	9,238	20.3
2006	14	2,508	58	8,969	26.0
2007	25	4,739	142	19,062	36.8
2008	20	4,325	170	24,673	33.6
2009	15	3,100	95	14,211	20.5
2010	22	3,814	103	25,464	15.1
Total	216	39,145	1,076	135,918	25.1

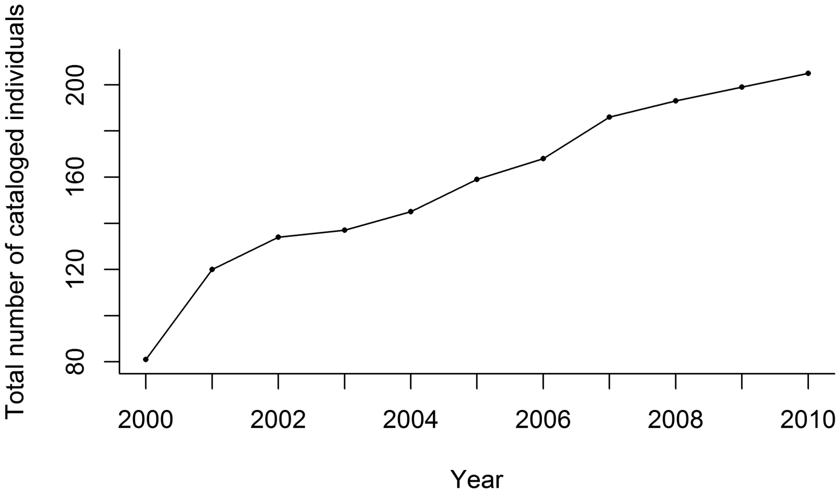

Fig. 2.—Discovery curve showing new individual identifications of *Sotalia guianensis* from 2000 to 2010 in the Cananéia Estuary of southeastern Brazil.

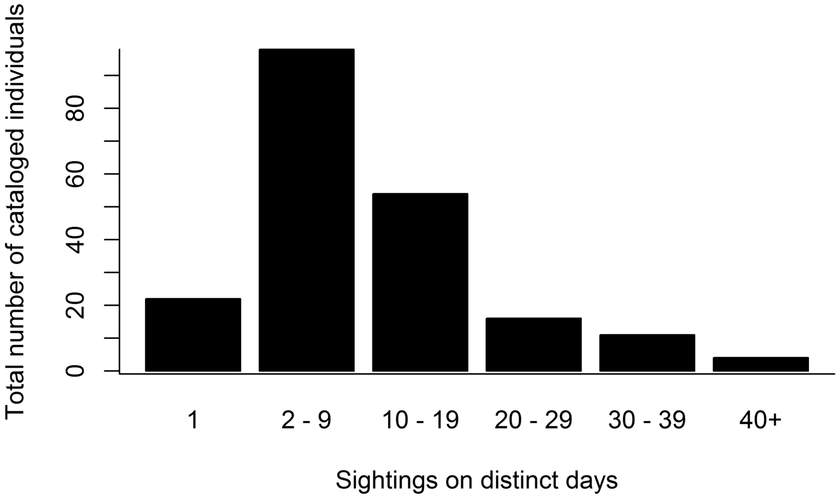

Fig. 3.—Number of Guiana dolphins (*Sotalia guianensis*) sightings reported on distinct days using photo-identification in the Cananéia Estuary of southeastern Brazil from 2000 to 2010.

12.4 *SD*) for the MCP estimates, between 0.8 and 82.5 km^2 ($\bar{X}$ =15.6 ± 15.7 km^2) for the AKLSCV estimates, between 3.9 and 244 km^2 ($\bar{X}$ = 72.4 ± 67.7 km^2) for the FKHREF estimates, and from 0.6 to 70.6 km^2 ($\bar{X}$ = 13.5 ± 13.8 km^2) for the FKLSCV estimates (Table 2). The smallest home range estimated was 0.6 km^2 for individual KN #160 with the FKLSCV, and the largest was 244 km^2 for individual KN #283 with the FKHREF.

For each method used, home range polygons exhibited different mean percentages of the original estimated areas after the extraction of inhospitable areas, as follows: MCP 44.1%, AKLSCV 68%, FKHREF 44.2%, and FKLSCV 71.4% (Supporting Information S1). The AK and FK methods with LSCV resulted in smaller proportions of the original estimated area being extracted because estimations by these methods were less smooth than the kernel with the reference bandwidth parameter and the MCP.

Due to these differences in home range estimates, variances among the 4 methods were not homogenous ($F_{calc} = 29.7 > F_{max} = 1$). Significant differences were detected (Friedman test: $\chi^2 = 69.38$, *d.f.* = 3, $P < 0.0001$). Fixed kernel with the HREF parameter produced over-smoothed areas when compared with the areas estimated by the other 3 methods (Fig. 4).

In a 2nd evaluation, the results of the FKHREF were excluded. Therefore, to detect if there were differences among the observed results comparing the 3 remaining methods, gathered data were squared root transformed to meet assumptions of normality and thus homogeneous variances were verified ($F_{calc} = 1.27 < F_{max} = 1.85$). The residual analysis showed a normal distribution of the transformed data (Shapiro–Wilk test $P = 0.341$). The block design ANOVA test results indicated that, on average, the areas estimated for the 3 methods had statistically different sizes ($F_{2,60} = 5.6$, $P = 0.006$), at a 5% significance

Table 2.—Estimated home range sizes (km^2) for Guiana dolphins (*Sotalia guianensis*) in the Cananéia Estuary of southeastern Brazil from 2000 to 2010. Given are the number of sightings on distinct days (*n*) and estimated size of individual's home ranges using the following methods: minimum convex polygon (MCP), adaptive kernel with least-squares cross-validation (AKLSCV), fixed kernel with reference bandwidth (FKHREF), and fixed kernel with LSCV (FKLSCV). Polygons were outlined by 95% isopleths for kernels and by a fixed mean of 100% of the points for MCP.

Individual	*n*	MCP 100%	AKLSCV 95%	FKHREF 95%	FKLSCV 95%
KN #15	44	42.0	22.8	164.7	20.1
KN #19	27	17.7	22.8	79.9	20.4
KN #30	31	2.3	2.9	3.9	2.3
KN #43	40	12.5	7.6	12.9	4.5
KN #51	34	31.8	12.7	78.2	10.7
KN #75	41	17.8	17.7	66.9	15.7
KN #83	34	5.0	6.5	9.8	4.5
KN #86	36	19.3	8.3	80.9	6.5
KN #88	38	19.2	9.9	92.4	8.7
KN #97	34	27.9	17.5	81.6	14.9
KN #98	20	43.8	11.8	202.4	10.4
KN #147	39	2.2	1.5	4.2	1.2
KN #154	24	32.6	26.8	92.4	22.4
KN #155	21	17.5	25.9	90.9	22.2
KN #157	40	16.7	2.6	10.2	1.9
KN #160	20	8.7	0.8	11.6	0.6
KN #178	22	2.9	3.8	16.6	2.8
KN #179	28	11.7	16.1	62.4	15.3
KN #186	21	9.5	17.1	33.0	17.0
KN #193	24	2.4	3.2	5.9	2.3
KN #197	30	22.6	23.2	87.0	20.5
KN #198	27	4.6	2.6	10.4	2.0
KN #215	22	9.8	3.7	14.6	2.7
KN #230	22	7.7	17.4	32.5	14.7
KN #231	32	13.1	7.3	31.5	6.2
KN #236	31	3.1	3.7	10.2	3.0
KN #244	33	35.4	26.5	148.3	24.9
KN #277	21	18.7	32.4	222.3	29.8
KN #283	21	41.3	82.5	244.0	70.6
KN #285	21	25.0	32.2	118.9	28.1
KN #304	23	18.5	15.0	122.8	12.5
$\bar{X}$		17.5	15.6	72.4	13.5
SD		12.4	15.7	67.7	13.8

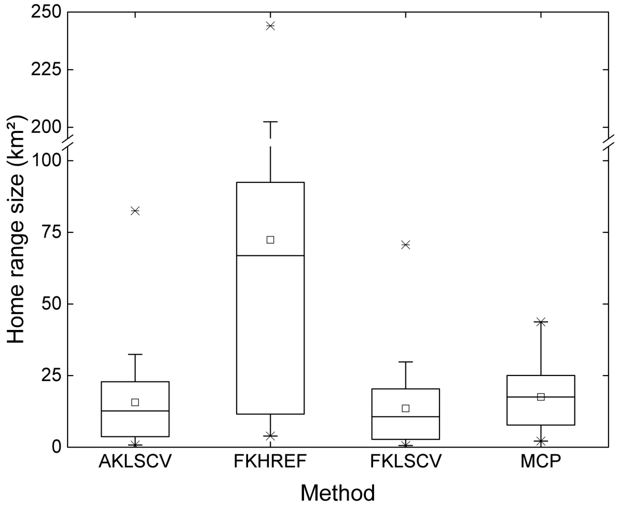

Fig. 4.—Minimum and maximum values, median, lower quartile, and upper quartile (km^2) observed for home range estimates of Guiana dolphins (*Sotalia guianensis*) in the Cananéia Estuary of southeastern Brazil from 2000 to 2010. The methods of minimum convex polygon (MCP), adaptive kernel with least-squares cross-validation (AKLSCV), fixed kernel with reference bandwidth (FKHREF), and fixed kernel with LSCV (FKLSCV) were used.

level. A Tukey test was performed and showed that the average values produced by the MCP were greater than the average values produced by the FKLSCV. On the other hand, the values observed for the 2 remaining methods were similar (Fig. 4).

The 50% UD for each individual was tested to indicate possible core areas and produced the following results for the 3 methods: AKLSCV 0.1–18.1 km^2 ($\bar{X}$ = 3.6 km^2 ± 3.8 *SD*), FKHREF 0.9–53.1 km^2 ($\bar{X}$ = 15.5 ± 13.8 km^2), and FKLSCV 0.1–19.1 km^2 ($\bar{X}$ = 4.1 ± 4.2 km^2; Table 3). As polygons had inhospitable extracted areas, part of the core areas were also extracted, but the proportion lost from the original estimates was smaller when compared with the 95% outlined areas, due to the central position of cores. The fixed kernel with the HREF was the method which rendered the largest core areas, and they were statistically different from the other tested methods (Friedman test: $\chi^2 = 59.12$, *d.f.* = 2, $P < 0.0001$), at a 5% significance level.

Discussion

Discovery rates of newly marked individuals did not show complete stabilization, which was expected for 11 years of

Table 3.—Guiana dolphins (*Sotalia guianensis*) possible core areas (km^2) estimated through the adaptive kernel with least-squares cross-validation (AKLSCV), fixed kernel with HREF (FKHREF), and fixed kernel with LSCV (FKLSCV) based on photo-identification data collected between 2000 and 2010 in the Cananéia Estuary of southeastern Brazil. Polygons were outlined by 50% isopleths for kernels.

Individual	AKLSCV 50%	FKHREF 50%	FKLSCV 50%
KN #15	5.3	29.0	6.0
KN #19	5.5	16.9	6.3
KN #30	0.4	0.9	0.4
KN #43	0.6	2.2	0.7
KN #51	2.3	14.9	2.6
KN #75	3.7	15.8	4.4
KN #83	0.6	1.8	0.8
KN #86	1.5	21.6	1.5
KN #88	2.0	19.3	2.3
KN #97	3.8	17.5	4.1
KN #98	2.5	53.1	2.5
KN #147	0.3	0.9	0.3
KN #154	7.0	15.2	7.6
KN #155	5.7	28.3	6.6
KN #157	0.4	2.0	0.4
KN #160	0.1	2.2	0.1
KN #178	0.5	3.3	0.6
KN #179	4.8	18.2	5.2
KN #186	7.0	15.2	8.0
KN #193	0.4	1.4	0.5
KN #197	5.7	22.9	6.6
KN #198	0.4	1.9	0.4
KN #215	0.5	2.8	0.6
KN #230	4.5	7.0	5.0
KN #231	1.4	6.1	1.6
KN #236	0.6	2.4	0.7
KN #244	6.1	28.3	7.5
KN #277	10.2	44.9	11.5
KN #283	18.1	37.2	19.1
KN #285	6.6	27.9	8.1
KN #304	3.2	20.4	3.8
SD	3.6	15.5	4.1
$\bar{X}$	3.8	13.8	4.2

data from a species that has a fission–fusion social structure (Santos and Rosso 2008) with individuals that were constantly interacting, thus creating new marks in their dorsal fins. However, the rates of new individuals registered were similar in the last 2 years of monitoring. In photo-identification efforts at Sepetiba Bay (22°S), Rio de Janeiro, where large aggregations of Guiana dolphins can be found, the discovery rates of new individuals also did not reach complete stabilization (Nery and Simão 2012). In 2 other areas, the Caravelas River Estuary (17°S) and Babitonga Bay (26°S), where smaller numbers of Guiana dolphins have been found, authors reported a stabilization of the discovery curve after shorter periods of monitoring (see Rossi-Santos et al. 2007; Hardt et al. 2010). Differences in stabilization times among those populations were affected by the size of the *S. guianensis* populations inhabiting those bays and estuaries. Based on the available data, populations using the Cananéia Estuary and the Sepetiba Bay are some of the largest populations of Guiana dolphins in Brazil, consisting of 700 to > 1,000 individuals (Geise et al. 1999; Flach et al. 2008; Santos et al. 2010b; Nery and Simão 2012). Abundance estimates evaluated at Babitonga Bay varied from 142 to 422 individuals (Cremer et al. 2011) and recent estimates indicated a population of 57 to 124 dolphins in the Caravelas Estuary (Cantor et al. 2012).

Re-sighting rates were also affected by individuals' frequency of use of the inner estuarine waters of Cananéia. Individual dolphins may spend different amounts of time within the surveyed areas, as seen in Zolman (2002) for bottlenose dolphins in southern California. In the Caravelas River Estuary and Sepetiba Bay, re-sighting events were similar to the ones observed in the Cananéia Estuary, with a pattern in which a few individuals were constantly re-sighted and most individuals had low re-sighting histories over the years (see Rossi-Santos et al. 2007; Cantor et al. 2012; Nery and Simão 2012).

Home range estimations are significantly affected by sample size (Seaman and Powell 1996; Seaman et al. 1999; Powell 2000; Owen et al. 2002). It is expected that the rate of information gain will achieve an asymptote as sampling increases (Turchin 1998). Thus, the asymptote value is commonly used as a proxy to indicate a trustable estimation of a home range (Harris et al. 1990; Fernandez 1995). The asymptote in cumulative curves with MCP estimates (Supporting Information S2) showed patterns of stabilization for 5 individuals: KN #43, KN #88, KN #97, KN #154, and KN #231. Individual KN #88 was re-sighted in all 11 years of monitoring. An asymptote was not reached for the remaining 26 individuals, which indicates that the home ranges kept changing over time, which is expected for data acquired in long-term home range studies because individuals are constantly learning new information about how resources are distributed in a dynamic environment and adapting their habitat use to their needs (Powell 2000). It is also important to consider that MCP estimates tend to increase when considering long-term efforts (Worton 1995; Moorcroft and Lewis 2006); therefore, this estimator is likely to result in Type I error (Bekoff and Mech 1984), including areas that are not frequently used by the individual. By contrast, estimates of home ranges gathered from a kernel density estimator often decrease with sample size (Fieberg 2007), and home ranges may fragment into multiple polygons as data set gets larger, which could exclude corridors among habitat patches from the estimates. As a consequence, this analysis may result in Type II error (especially by oversmoothing) with small data sets and Type I error with large data sets (Fieberg and Börger 2012).

There is no consensus about which is the minimum best sample size that should be used for home range estimation. Authors have used simulations to test what is the minimum ideal sample size and indicate values varying between 20 and 100 locations per individual to guarantee independence between samples and the estimated home range (Mares et al. 1980; Schoener 1981; Seaman et al. 1999; Urian et al. 2009). In the present study, the minimum number of locations was 20 for each individual and the maximum was 44. These numbers are quite similar to 2 other studies on Guiana dolphins' home ranges conducted in Brazilian waters, which varied from 10 to 58 locations (Flores and Bazzalo 2004; Batista et al. 2014).

In our study population, individual variation in home range sizes was observed and had been previously reported for 7 individuals (Oshima et al. 2010). Previous research indicates that individual's home ranges may vary for individuals of the same species and individual's home ranges may vary with time (Powell and Mitchell 2012) since traits intrinsic to the organisms themselves may affect their ability to exploit certain habitats, determining their distribution (Acevedo-Gutierrez 2009). Individuals change their cognitive maps because they may use different areas as they age, grow, and enter new life-history stages (Burt 1943; Powell 2000). Individual variation was previously described for other mammals like carnivores (Boydston et al. 2003), rodents (Mares and Lacher 1987), marsupials (Sanches et al. 2012), and also cetaceans (e.g., Wells 1991; Gubbins 2002; Flores and Bazzalo 2004; Rossi-Santos et al. 2007; Rayment et al. 2009; Oshima et al. 2010; Batista et al. 2014). An interesting example that shows how these factors may affect the estimation of home ranges can be observed by considering individual KN #157 and its mother, KN #147. For 2 years, KN #157's geographic locations were recorded in close geographic proximity to its mother locations. However, after October 2002, the individuals were observed in distinct locations on some occasions and together on others. By analyzing KN #157's locations over time, we likely recorded a transition stage to its adult phase, where it began to explore different areas from the ones it used when it was younger and living exclusively with its mother.

Individuals KN #30, KN #43, KN #83, KN #147, KN #157, KN #160, KN #178, KN #193, KN #198, KN #215, and KN #236 had considerably smaller home ranges when compared to other estimates for Guiana dolphins, with 4 of them < 3.0 km^2. Possibly, the restriction of boat surveys to inner estuarine waters has driven these results. Our surveys did not extend into outer coastal waters, however, individuals could wander into these areas and could therefore have larger home ranges than we detected in our study. Geise et al. (1999) proposed the existence of daily movements of Guiana dolphins in and out of the Cananéia Estuary, which we also observed during field work for this study. At Guanabara Bay and Baía Norte, both along the coast of Brazil, the same kind of movements was suggested for *S. guianensis* (Geise 1991; Wedekin et al. 2007). Therefore, the use of coastal areas by the surveyed population should be explored for a better understanding of these individuals' home ranges.

Behavioral strategies in response to habitat characteristics (Defran et al. 1999) and important resources like reproductive areas (Scott et al. 1990) and food (e.g., Ballance 1992; Defran et al. 1999) have also been hypothesized to influence cetaceans' home range size and movement patterns in heterogeneous environments (Gubbins 2002; Wedekin et al. 2007). In general, individuals in habitats of high productivity tend to have smaller home ranges when compared with individuals in habitats of lower productivity (Harestad and Bunnel 1979). In the Cananéia Estuary, home ranges of the surveyed individuals were concentrated in A1–A4 sub-area. Overlapping core areas occurred in the main entrance of the Cananéia Estuary for 26 of the 31 estimated home ranges (Supporting Information S3), providing evidence for the importance of this highly dynamic area to most of the dolphins we surveyed. Only 1 individual (KN #285) had their core area located in sub-area A5. Location of the core areas may have been influenced by uneven sampling efforts. On the other hand, the main entrance of the Cananéia Estuary, which was surveyed since the early beginning of this study, showed the largest aggregations of Guiana dolphins performing foraging and feeding behaviors on a regular basis (see Geise et al. 1999; Santos and Rosso 2007). This area has the deepest waters in the surveyed estuary (Santos and Rosso 2007). Batista et al. (2014) observed most concentrations of Guiana dolphins at the main entrance to the Paraguaçu River, where depths varied from 20 to 30 m. In Guanabara Bay (22°S), groups were found mostly in depths ranging between 5.1 and 15.0 m (Azevedo et al. 2007). Other studies also showed that steeply sloping benthic topography may provide high concentrations of prey fish or facilitate foraging activities for dolphins (i.e., Ballance 1992; Wilson et al. 1997; Maze and Würsig 1999; Ingram and Rogan 2002). Thus, topography may play an important role in core areas used by coastal delphinid species.

We detected variation in the size and shape of an individual's home range depending on the methods used to estimate its home range. Home range estimates for different species of mammals have shown that estimates can vary greatly depending on the estimation method used (Moraes Junior and Chiarello 2005; Börger et al. 2006; Boyle et al. 2009; Kauhala and Auttila 2010); this is the main reason that it is important to use more than 1 estimator. Also, the standard deviation in our results was higher for estimates produced by the FKHREF method, compared with the other 3 methods we used (Fig. 4). Only the individual KN #30 showed similar estimates for all 4 methods used, presumably because its geographic locations were observed in a relatively small spatial distribution when compared to the 30 other individuals surveyed.

Estimates conceived by the FKLSCV and the AKLSCV were not statistically different. The general effect observed for the AK in comparison with FK was a smoother estimate for the 95% UD and a less smooth estimate for the 50% UD (Supporting Information S3), which is expected since the FK method holds bandwidth constant for all locations and the AK method varies it with locations covered by kernels of different widths (Powell 2000). Estimates generated by both methods presented better results than the other methods tested for 13 individuals (KN #15, KN #19, KN #75, KN #154, KN #155, KN #179, KN #186, KN #197, KN #230, KN #244, KN #277, KN #285, and KN #304). Contours were more continuous and cores were well defined with AK compared to FK. Although if the external points were more dispersed from the majority registered, AK could still create disjunct, isolated areas. Kernels with LSCV did not generate good estimates for 12 other individuals (KN #51, KN #86, KN #88, KN #97, KN #98, KN #157, KN #160, KN #178, KN #198, KN #215, KN #231, and KN #236). In such cases, while disjunct UDs minimize the importance of areas only occasionally used by an individual, they may fail to indicate important corridors between used areas (Kie et al. 2010). Considering this, estimates generated by the MCP method could better illustrate the connection between areas, therefore, approaching more realistic home range estimations for several individuals. That seems to be the case for 7 individuals (KN #51, KN #86, KN #88, KN #97, KN #98, KN #157, and KN #231).

The effects of the chosen kernel (FK or AK) on the estimated home range of each surveyed individual were much more subtle when compared to the effects of the smoothing parameter (LSCV or HREF), which corroborates the conclusions presented by Worton (1995). This is why "choosing the appropriate smoothing parameter is considered the most important issue in a kernel analysis" (Wand and Jones 1995). There is not a single best method for choosing a bandwidth a priori (Worton 1989). For 20 individuals, home ranges estimated with HREF had boundaries encompassing an area larger than the study area itself (Supporting Information S3) and home range estimates were larger if they were based on geographic locations that occurred far from one another. However, when the geographic locations presented a more restricted and homogeneous distribution, the HREF estimates showed a more realistic distribution map and the boundaries were continuous, instead of the disjointed areas obtained with the LSCV.

Observations of large-scale movements of *S. guianensis* are still scarce because most studies are based on photo-identification and study areas are focused on relatively small bays and estuaries (e.g., Simão et al. 2000; Azevedo et al. 2004; Flores and Bazzalo 2004; Rossi-Santos et al. 2007; Santos and Rosso 2007; Hardt et al. 2010; Batista et al. 2014). Further, research teams do not regularly compare catalogs of collected sightings. In several mammal species, it is clear that individual movements are influenced not only by their current environment, but also by their past movement history (Powell 2000; Mitchell and Powell 2012; Moorcroft 2012; Spencer 2012). This makes exploring aspects of memory, behavior, and habitat preference of Guiana dolphins at different spatiotemporal scales important and will demand investments in new approaches to investigate their movement patterns. Advances in technology, with modern GPS tags and the recent use of drones (Koh and Wich 2012), allow scientists to collect location data for animals at increasing rates and greater accuracy (Kie et al. 2010; Tomkiewicz et al. 2010). Using these new tools is an attractive option to track movements in small delphinids, and it may render precise short-term information on distinct locations with less effort, when compared to photo-identification in a large habitat like the Cananéia Estuary, considering a population of hundreds of dolphins that use both the estuary and coastal waters.

Data on mean size of home range required by an individual are an important biological metric for a species that is still classified as data deficient by the IUCN (Secchi 2012). Individual Guiana dolphins' home ranges estimated in the present study should be considered for conservation planning especially because they indicate areas with higher intensity of use. It is known that cetaceans have special roles in the ecosystems in which they are found and play a key role in trophic relationships, from the detritivorous chain to vertical and horizontal vectors of nutrients (Roman et al. 2014). Therefore, cetacean health is usually linked to the health of the systems in which they are found (Moore 2008). This is especially important in our study site where a well-preserved area of the Atlantic Forest and mangroves still can be found surrounding the estuary, but in recent years this ecosystem has been facing threats provoked by the unplanned use of the land and sea by humans (Santos and Rosso 2007).

Drastic reductions in the abundance of Guiana dolphins have been detected at Guanabara Bay (Azevedo et al. 2009). The same threats described by those authors occur in other bays and estuaries where Guiana dolphin populations are found (Crespo et al. 2010). To avoid major impacts in the Cananéia Estuary, it is necessary to reinforce the regulations of the federal protected area (established in 1984) throughout the whole range where Guiana dolphins can be found in inner waters. Also, inspections are important to guarantee safety of this population in tourism activities and against the loss of habitat due to unplanned aquaculture activities, chemical, and noise pollution in the study area.

Home range sizes of individual Guiana dolphins varied in the Cananéia Estuary. Their spatial distribution was not homogeneous, and there was an extensive overlap among home ranges of different individuals. The 4 methods of home range estimation tested in this study resulted in significantly different home range areas in size and shape. While the MCP estimator was important to indicate the external limits of a home range and important corridors, the kernel estimator provided an analysis of the UD with core areas indicating placement of important resource areas. We found the results gathered by the methods tested to be complementary. These methods combined to provide a comprehensive data set and can be used more widely to compare and understand *S. guianensis*' habitat use in different bays and estuaries of Brazil.

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SUPPORTING INFORMATION

The Supporting Information documents are linked to this manuscript and are available at Journal of Mammalogy online (jmammal.oxfordjournals.org). The materials consist of data provided by the author that are published to benefit the reader. The posted materials are not copyedited. The contents of all supporting data are the sole responsibility of the authors. Questions or messages regarding errors should be addressed to the author.

Supporting Information S1.—Percentages of the original polygons (km^2) estimated for home range analysis of 31 Guiana dolphins (*Sotalia guianensis*) kept after the extraction of inhospitable habitats (terrestrial areas), evaluated from 2000 to 2010 in the Cananéia Estuary, southeastern Brazil. Four methods were tested for these estimates: minimum convex polygon (MCP), adaptive kernel with least-squares cross-validation (AKLSCV), fixed kernel with reference bandwidth (FKHREF), and fixed kernel with LSCV (FKLSCV).

Supporting Information S2.—Cumulative curves of home range sizes estimated with the minimum convex polygon (MCP) for Guiana dolphins with 20+ photo-identified sightings in the Cananéia Estuary between 2000 and 2010.

Supporting Information S3.—Guiana dolphins' home ranges estimated with 4 methods: minimum convex polygon (MCP), adaptive kernel with least-squares cross-validation (AKLSCV), fixed kernel with reference bandwidth (FKHREF), and fixed kernel with LSCV (FKLSCV). Data were collected in the Cananéia Estuary between 2000 and 2010.

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