Designing a shipboard line transect survey to estimate cetacean abundance off the Azores Archipelago, Portugal

by

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ABSTRACT

Management schemes dedicated to the conservation of wildlife populations rely on the effective monitoring of population size, and this requires the accurate and precise estimation of abundance. The accuracy and precision of estimates are determined to a large extent by the survey design. Line transect surveys are commonly applied to wildlife population assessments in which the primary purpose of a survey design is to ensure that the critical distance sampling assumptions are met.

Little information is available regarding cetacean abundance in the Archipelago of the Azores (Portugal). This study aims to design a line transect shipboard survey that allows the collection of data required to provide abundance estimates for such species.

Several aspects must be taken into consideration when designing a survey to estimate cetacean abundance. This is an iterative process, and there is a constant trade off between the logistic constraints and the desired statistical robustness. Information on this process is provided to aid policy makers and environmental managers, such as the criteria used for the choices made when defining the elements of a survey design.

Three survey effort scenarios are provided to illustrate the range of possibilities between statistical robustness and logistic/ management restrictions. A survey is designed for the more economical scenario (L=5000Km), although the second scenario is the one recommended to be implemented (L=17,600Km) given it provides robust estimates of abundance (CV $\leq$0.2).

INTRODUCTION

ESTIMATING ANIMAL ABUNDANCE

Management schemes dedicated to the future conservation of wildlife populations rely on effective monitoring of the size of those populations. This requires that accurate and precise abundance estimates are obtained for the purposes of wildlife population assessment. The accuracy and precision of estimates are determined to a large extent by the survey design used to obtain population samples (Strindberg, 2001). Additionally, obtaining reliable results requires good field methods and data analysis (Thomas *et al*., 2007).

Line transect surveys are commonly applied to wildlife populations or natural resources, as they provide a cost efficient manner of dealing with mobile populations that may be sparse over a large region (Strindberg, 2001). The primary purpose of a survey design is to ensure that the critical distance sampling assumptions are met. The three assumptions essential for reliable estimation of abundance from line transect sampling (in order from most to less critical) are: objects directly on the line are always detected (i.e. they are detected with probability 1); objects are detected at their initial location; and, distances (and angles) are measured accurately (Buckland *et al.*, 2001).

Several constraints make it difficult to design shipboard surveys of cetaceans, the first of which is that the study area is often very large relative to the speed of the survey vessels, and ship time is relatively expensive. The second is that the study areas often have complex topography, containing features such as islands and inlets (Thomas *et al.*, 2007). Other species-specific issues may need to be taken into account during survey designing, one of them being the responsive movement of animals to the approaching observer (Buckland *et al.*, 2001).

Two essential requirements for a good design are randomisation and replication (Thomas *et al.*, 2007). Randomisation is achieved by using a random probability process to lay out the transects within the study area. Standard analysis methods assume that on average over many realisations, each point within the study area has the same probability of being sampled (i.e. uniform coverage probability). Replication (i.e. multiple lines) is required to provide a basis for an adequate variance of the encounter rate and a reasonable number of degrees of freedom for constructing confidence intervals. Additionally, it is important to address the concepts of stratification and sampling geometry (Strindberg *et al.*, 2004). The spatial stratification of the study area should be considered to improve precision. Another benefit of stratification is that the study area is divided into smaller areas, for which managers may want separate abundance estimates (e.g. presence of animal density gradients, say with the presence of costal populations), or in which may provide survey blocks of a more manageable size. The sampling geometry relates to the configuration and orientation of the set of lines. The best choice of sampling geometry will depend on the survey region, logistics and efficiency, knowledge of density gradients or patterns and their interplay with the other sampling concepts. One option is a series of connected line segments that form a continuous zigzag design, for which no time is lost traversing between lines. This design is particularly useful for aerial and ship surveys where travel time is costly, although time spent travelling can be beneficial for observer rest and rotation (Buckland *et al.*, 2001).

Three different classes of zigzag designs are described by Strindberg and Buckland (2004): equal angle, equal spacing and adjusted angle. Equal spacing zigzag is the most commonly used and it can be created, a set of equally spaced parallel lines is displayed perpendicular to, and randomly positioned along, the area axis and spanning its full length (i.e. waypoints are equally spaced along the design axis). Equal angle and spacing zigzags do not give even coverage probability (unless the survey region is rectangular), but this can be accounted for. Additionally, equal spacing zigzag yield much lower bias under the assumption of even coverage probability than the equal angle zigzag. (Strindberg *et al.*, 2004).

The recent development of automated survey design algorithms (Strindberg, 2001; Strindberg *et al.*, 2004) and their implementation in the free software program DISTANCE (Thomas *et al*., 2006) has considerably simplified the task of creating and comparing complex designs. Designs can be created on the computer, and many random realisations can be generated to assess properties such as average (or maximum) proportion of time off effort and uniformity of coverage. Once a design is chosen, a single random realisation of this design can be generated, exported from the software and used as the survey plan (e.g. by loading into the navigation system of a ship).

STUDY AREA

The Archipelago of the Azores is located between latitude 36°35' and 39°43' North, and longitude 24°45' and 31°17' West, extending to ca.600km oriented NW- SE (Fig.1). The Azorean Exclusive Economic Zone (EEZ) comprises 938,000km^2, ca. 30% of the European EEZ (Santos and Pinho, 2005).

Figure 1 – Location of the Archipelago of the Azores (Portugal) in the Atlantic Ocean.

The Azores are composed of nine volcanic islands divided into three groups; the Eastern group includes São Miguel and Santa Maria islands, Central group includes Graciosa, Terceira, São Jorge, Faial and Pico, and the Western group includes Corvo and Flores.
The islands are separated by deep waters (ca. 2000m) with scattered seamounts (Santos *et al*., 1995). The high bathymetric amplitude is known to influence the local and regional circulation patterns, which in turn influence the distribution of pelagic organisms. There is a high seasonal and inter-annual variability in the oceanographic processes, which in turn influence the overall circulation of the Azores (Seabra *et al*., 2006).

Despite sometimes denoted as poorly productive, the waters of the Azores present a high diversity of cetaceans with 23 species confirmed to occur in the area (Steiner *et al*., 2007). The most common cetaceans in the Azores are the Atlantic spotted dolphin (SFR - *Stenella frontalis*), short-beaked common dolphin (DDE - *Delphinus delphis*), bottlenose dolphin (TTR - *Tursiops truncatus*), Risso's dolphin (GGR - *Grampus griseus*), and the sperm whale (PMA - *Physeter macrocephalus*) (Silva *et al.*, 2003).

The IUCN Red List of Threatened Species for the Azores lists *S. frontalis*, *D. delphis*, and *T. truncatus* as Least Concern, *G. griseus* as Data Deficient and *P. macrocephalus* as Vulnerable (Cabral *et al.*, 2005). Additionally, all species are protected under the EU Habitats Directive and *T. truncatus* is listed in the Annex B-II, requiring the designation of special conservation areas (DL 49/2005).

AIMS

The aim of this study is to design a line transect shipboard survey. Such survey will allow the collection of data required to estimate the absolute abundance of the most common cetacean species off the Azores. This study aims also to provide information on alternative scenarios for policy makers and environmental managers.

In this thesis, I hope to provide clear information on the process of designing a survey. The criteria used for choices made along the iterative process of defining the elements of a survey design will be presented, as well as tables and figures with detailed information. Aspects of field methods and data analysis were considered, aiming to provide a good survey design. Further, three survey effort scenarios will be provided to illustrate the range of possibilities between statistical robustness and logistic/ management restrictions, and one survey design will be presented.

METHODS

INITIAL BRIEF

Various aspects must be taken into consideration when planning a survey and it is essential to gather information on these. In the present study, information was collected for the spatial and temporal frame of this survey, on methodology, biological and physical characteristics of the Azores, equipment available and logistic constraints.

The survey will use the mark recapture distance sampling method (Laake and Borchers, 2004), with a double platform configuration. The target species for data collection will be *S. frontalis*, *D. delphis*, *T. truncatus*, *G. griseus* and *P. macrocephalus*. In the Azores, *S. frontalis* and *D. delphis* dolphins are eager bow riders; *T. truncatus* may also be attracted to vessels whereas *G. griseus* and *P. macrocephalus* do not show attraction to vessels (Silva, *personal communication*). Data will be collected for all species encountered, providing this does not compromise data collection for the target species. The nautical survey will use visual counts for the delphinid species and use passive acoustics for sperm whales.

Regarding the vessel, the characteristics of the Research Vessel "Arquipélago" will be used; this vessel is 25.5m long with 2,500miles of autonomy, cruising speed of 9.5knots and maximum speed of 11knots, and able to accommodate six scientists. It will not be possible to perform a pilot survey and the time available at sea to perform the survey is 20 days; time at sea includes time off-effort, mainly driven by bad weather and transiting between waypoints. The study area will be defined to be as wide as possible, from a minimum range of 20-30km around all islands. The areas between the three groups of islands will be included if possible as well as the seamount complex located south to Pico island.

The Azores are known to have rough weather and sea conditions due to their position in the Atlantic Ocean and therefore the timing of the survey is crucial. The survey will be conducted some time between June and August, as these are the months with better and more stable sea-state conditions (Windguru, 2007). At this time, the day length is ca. 14 hours, allowing long days of work. In this period the percentage of days with sea-state above Beaufort 4 is about 20% (Silva, *personal communication*).

DEFINITION OF THE SURVEY AREA

A sequence of possible scenarios was plotted aiming to narrow the study area to a desirable and feasible survey area. The initial two survey areas considered were the Azorean EEZ (938,000km^2) and the geographic area defined by Seabra *et al.* (2005)

(258,228km^2 situated between 36°30' - 40°00' North and 24°30' - 31°45' West, that enclosed the effort and sightings recorded between 1999 and 2004 in two major projects developed in the Azores).

During the survey refinement, different shapes and width of survey areas were considered, using rectangular and circular regions. Also, the number of islands included in a survey sub-area varied from all islands, groups of islands to individual islands. Additionally, two buffer zones were tested around the islands, one of 10 nautical miles (nm) (suggested in previous studies) and another of 12nm (Territorial Sea). Aiming to account for possible biological gradients, three strata were considered with respect to distance from shore.

Several maps were created to assist the choices described above, using MANIFOLD (RELEASE 8). Parallel to this, the maps made along this study were improved as new mapping tools were introduced.

DEFINITION OF THE SURVEY PARAMETERS

Initially, the potential precision associated with choices of survey effort (i.e. line length, L) was investigated using input parameters from previous studies in the Azores. Previous findings dictated the choice of the values of encounter rate (ER), and a range of plausible coefficients of variation (CV) to achieve was used to define the estimates precision.

The total line length (L) required in a main survey was determined using the formula proposed by Buckland *et al.* (2001), based on a pilot study. Given a target CV, cv_t, where $\left[cv(\hat{D})\right] = \frac{s\hat{e}(\hat{D})}{\hat{D}}$; let n_0 be the animals (or clusters) counted from pilot survey, and L_0 the total line length from pilot survey, then

$$L = \frac{b}{\left[cv_t(\hat{D})\right]^2} x \frac{L_0}{n_0}$$

where $b \approx \frac{\text{var}(n)}{n} + \frac{n.\text{var}\left[\hat{f}(0)\right]}{\left[\hat{f}(0)\right]^2}$. For simplicity and lacking better information, b=3 will be considered following the suggestion of Buckland *et al.* (2001).

Three sets of encounter rates (ER) for each of the five target species were defined, based on information from previous comparable studies (Silva, *unpublished data*). Set 1 was defined to obtain the uncertainty in L needed to obtain a given CV; Set 2 aims to provide an upper and lower bound for estimates of L needed to obtain a given CV; and Set 3 aims to incorporate some environmental variability in the estimates. Survey effort scenarios were generated and illustrated using R (VERSION 2.5.1) (R Development Core Team, 2007).

Lastly, three survey effort scenarios were chosen to be presented to project managers. One illustrating the ideal scenario where the resulting abundance estimates are robust, another illustrating a more feasible scenario incorporating cost-benefit aspects, and a third illustrating a trade-off of statistical robustness and logistic/ management restrictions. The ER used for each target species was the respective overall mean for June to August, and the surveys will aim for CV≈0.2 and sample size (n) ≥60.

DEFINITION OF THE SURVEY STRATA

Given information on cetacean spatial distribution is scarce, the three strata initially created to account for possible gradients with respect to distance from shore were put aside. Alternatively, stratification was suggested to account for geographical gradients, given the underlying management interest. Strata were defined as: 1) Eastern group of islands; 2) Central group; 3) Western group; 4) Seamount complex SE Pico; and 5) corridors between island groups.

Within these, substrata were created, not to produce separate density estimates for each of these but to make the sub-areas more convex (and reduce off-effort time) and to maximize the number of transects per strata (Buckland *et al*. (2001) recommend 10-20 replicates as a minimum and Thomas *et al.*, 2007 reinforce the use of > 15). Several maps were created to assist the choices described above; each stratum was labelled and attributed a link ID number.

DEFINITION OF THE SURVEY DESIGN

An equal spaced line zigzag was chosen to create the survey design in the present study. A set of equally spaced parallel lines was displayed perpendicular to, and randomly positioned along, the area axis and spanning its full length (Strindberg *et al.*, 2004).

A survey design was generated using DISTANCE (VERSION 6) (Thomas *et al.*, 2006) for the more economical effort scenario, using a 2km strip width and a coverage grid with points 2km apart (9,817 points in total). The survey region was approximated by a convex hull. Effort was determined by line spacing, and proportional effort was allocated to each substratum. The angle of the line transects was determined to align the zigzag towards the strata boundaries. 5,000 simulations were run to examine the coverage probability (i.e., assess how even it is), and the number of line transects per stratum was checked to see if sufficient lines (≥15) were generated at the minimum. Additionally, on effort time needed to perform this survey was compared with the time allocated initially to perform the survey (20 days), to assess the feasibility of the survey design. Also, the off-effort line length within each stratum was determined to assess the extra time to be incorporated in the total survey days.

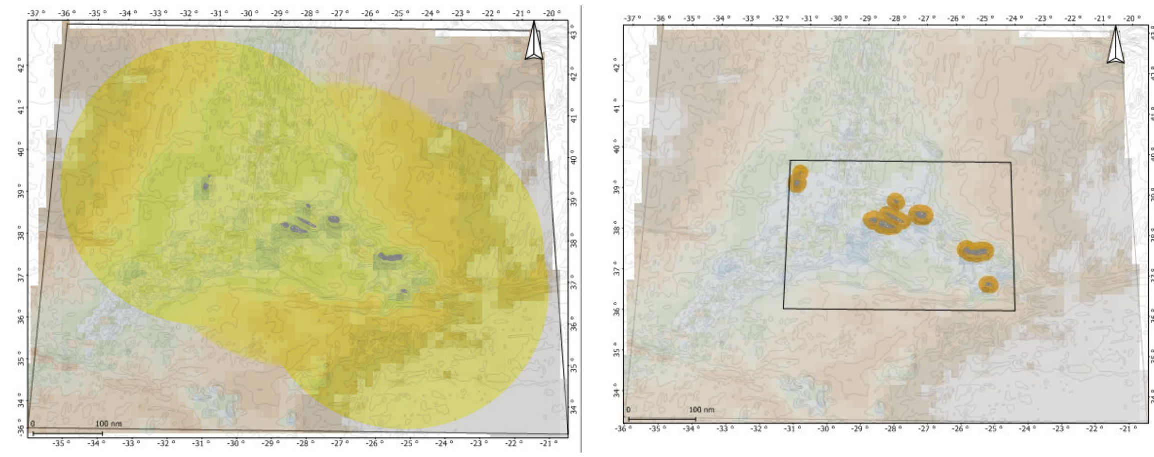
RESULTS

DEFINITION OF THE SURVEY AREA

The initial evaluation of the extension that the survey area could present showed that the 258, 228Km^2 (hereafter referred to as GIS area) were preferred over the total extension of the Azorean EEZ (Fig. 2-B).

Regarding the shape to be used within the GIS area, preference was given to oval regions (Fig. 3). Islands were chosen to be grouped per group (Eastern, Central, Western), having a12nm buffer (Fig 3-D).

Within the study area, sub-areas defined were: 1) sub-area within the 12nm buffer, for each of the island groups and seamount; 2) sub-area within circles that include the groups of islands but outside the 12nm buffer; and 3) sub-area within GIS rectangular area, but outside circles.



A **B**

Figure 2 – The two survey areas initially considered. **A** - Azorean EEZ (938,000km^2); **B -** GIS area. (258,228km^2).

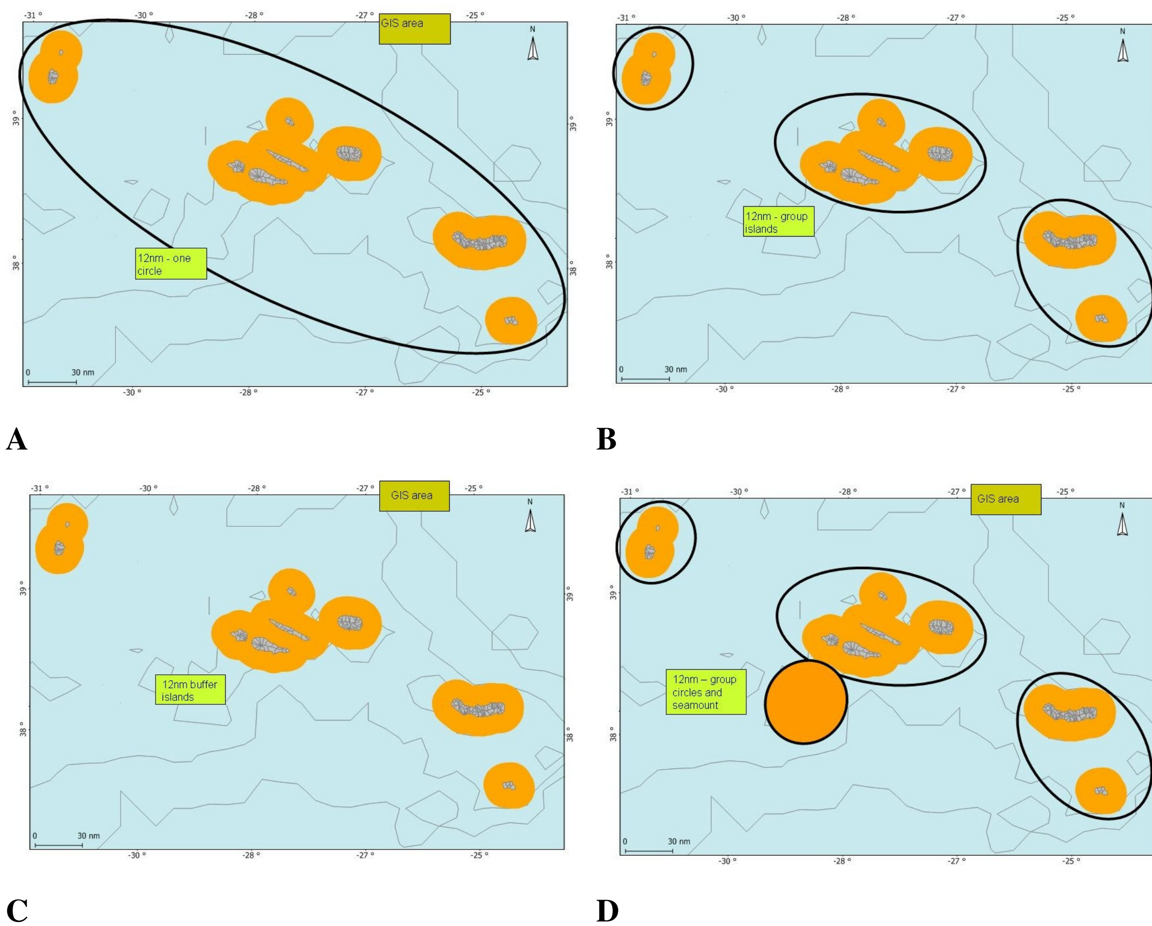


Figure 3 - Different shapes suggested for the survey areas, having chosen the GIS area; **A** –oval area enclosing all islands, **B** - oval r area enclosing groups of islands, **C** – 12nm buffer area around individual islands, **D** - oval area enclosing groups of islands and seamount complex.

DEFINITION OF THE SURVEY PARAMETERS

The values used for each species encounter rate (ER) are summarized on Table 1 (the baseline data is presented in Appendix 1). The ER chosen for *G. griseus* were always the lowest when comparing species, and ranged from 0.21 to 0.94 sightings/ 100km. *S. frontalis* showed the higher ER values, that ranged from 0 to 2.03 sightings/ 100km.

Table 1 – Summary of the three sets of encounter rate (ER, defined as sightings/ 100Km) used to generate scenarios of the variability attached to the survey parameters. Codes used for cetacean specie: DDE – *D. delphis*; GGR – *G. griseus*; PMA – *P. macrocephalus*; SFR – *S. frontalis*; TTR – *T. truncatus*.

			species				
Set	time frame	definition	DDE	GGR	PMA	SFR	TTR
1	Jun - Aug	-10% mean	0.88	0.42	0.74	1.00	0.63
	Jun - Aug	mean	0.98	0.47	0.82	1.11	0.71
	Jun - Aug	+10% mean	1.08	0.51	0.90	1.22	0.78
2	Jun - Aug	min	0.29	0.21	0.00	0.00	0.57
	Jul	mean	0.88	0.40	1.13	1.66	0.65
	Jun - Aug	max	1.65	0.94	3.27	2.03	1.01
3	Jun	mean	0.29	0.21	0.00	0.00	0.57
	Jul	mean	0.88	0.40	1.13	1.66	0.65
	Aug	mean	1.65	0.94	3.27	2.03	1.01
	Jun - Aug	mean	0.80	0.41	0.13	1.25	0.76

Survey effort scenarios were then created using the three sets of ER defined above. Expected coefficient of variation (CV) was calculated using a range of line length (L) values (500 to 35,000km) (Appendix 2-A). Overall, CV decreased dramatically up to L≈5,000km and decreased very slowly from then onwards.

L was then determined based on a range of CV values (0.025 to 0.5) (Appendix 2-B). L decreased steeply up to CV≈0.06 and decreased slowly from then on.

Thirdly, sample size (n) was determined using a range of L values (500 to 35,000km) (Appendix 2-C). As expected, n increased linearly with L.

Survey effort scenarios were then analysed in more detail (Fig. 6). The derived CV and L are consistently smaller for *S. frontalis*, then for *D delphis* closely followed by *T. truncatus*, and *G. griseus*; *P. macrocephalus* recorded the highest expected values for

these two parameters. Conversely, smallest sample size was expected for a fixed L for *P. macrocephalus*, up to *S. frontalis*.
8,250km were necessary to get CV≤0.3 for all species except *P. macrocephalus*, and 17,600km provided CV=0.36 for *P. macrocephalus*, and CV≤0.2 for the remaining species. In order to obtain CV=0.2, the amount of effort required for each species ranged from ca. 6,000km for *S. frontalis* and ca. 57,500km for *P. macrocephalus*. Regarding sample size, L needed to provide n=60 differed greatly, varying between 4,850km for *S. frontalis*, and ca. 46,500km for *P. macrocephalus*.

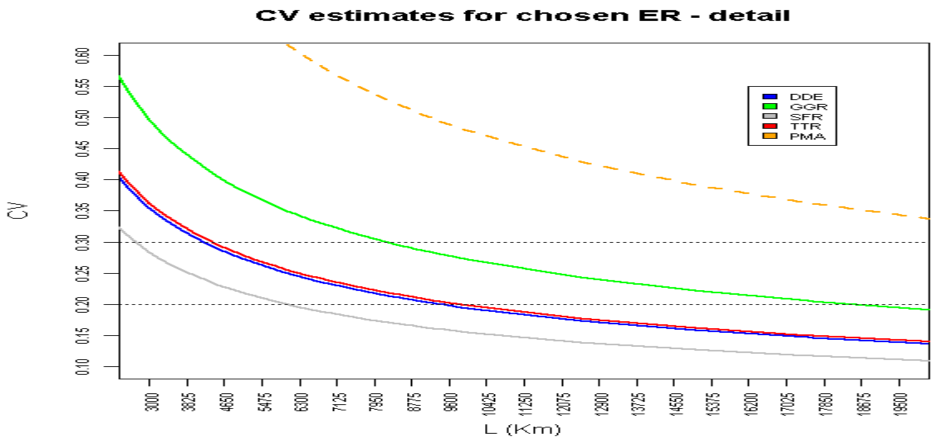
The ER values used for this study derived large differences in parameter values both within species and among species (Appendix 3). Focusing on important parameter values (L=5,000km, CV=0.2, n=60), it was possible to see PMA showed the higher range of CV for a given L and consequently showed also a higher range of L for a given CV; and GGR showed a very high range of L.
Following the interpretation of the scenarios described above, parameter values were narrowed down. Future work for the survey design will aim for CV≈0.2 and n≈60, and mean of ER for each target species, recorded from June to August were used. Further, *P. macrocephalus* will be left out from decision-making given its abundance estimates will not depend on visual sightings (and therefore on the available visual-based ER, but on an acoustic-based ER).

Lastly, three optional survey efforts were chosen to be presented to project managers. These are:

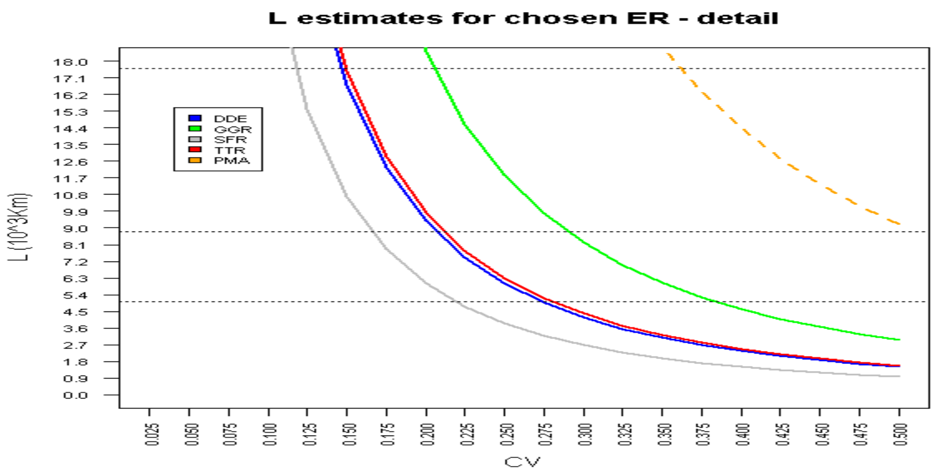
Option 1 – Economical, L=5,000km: incorporates cost-benefit aspects that result in the possible loss of robustness of one of the target species; it generates CV≈0.3 for all target species except for *G. griseus*;

Option 2 – Ideal, L=17,600km: defined as the minimum L that would provide CV at least equal to 0.2;

Option 3 – Intermediate, L=8,800km: defined as half the ideal, to illustrate a trade-off of statistical robustness and logistic/ management restrictions.



A



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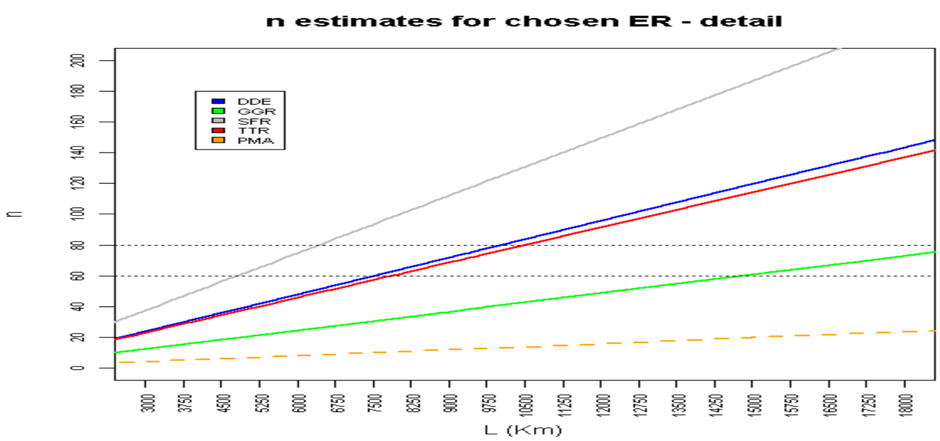

C

Figure 6 – Survey effort scenarios in detail. **A** - transect length (L) vs. expected coefficient of variation (CV); horizontal dashed lines show CV=0.2 and 0.3. **B** - coefficient of variation (CV) vs. transect length (L); horizontal dashed lines show L=5000, 8,800 and 17,600km. **C** – transect length (L) vs. sample size (n); horizontal dashed lines show n=60 and 80. Codes used for cetacean specie: DDE – *D. delphis*; GGR – *G. griseus*; PMA – *P. macrocephalus*; SFR – *S. frontalis*; TTR – *T. truncatus*.

Table 2 summarizes the values incorporated in the three survey effort options. Despite not being used for decision making, the corresponding values for PMA are also shown.

Table 2 – Summary of the three survey design options defined, showing CV and n. Codes used for cetacean specie: DDE – *D. delphis*; GGR – *G. griseus*; PMA – *P. macrocephalus*; SFR – *S. frontalis*; TTR – *T. truncatus*.

	mean ER for Jun - Aug	Option 1 - economical L=5000km		Option 2 - ideal L=17,600km		Option 3 - Intermediate L=8,800km	
species	ER (numb/ 100Km)	CV	n	CV	n	CV	n
DDE	0.80	0.27	39.90	0.15	140.45	0.21	70.22
GGR	0.41	0.38	20.28	0.20	71.39	0.29	35.70
SFR	1.25	0.22	62.31	0.12	219.33	0.17	109.66
TTR	0.76	0.28	38.12	0.15	134.18	0.21	67.09
PMA	*0.13*	*0.68*	6.52	*0.36*	22.95	0.51	11.47

DEFINITION OF THE SURVEY STRATA

Given the five strata initially defined to account for geographical gradients, a total of 16 substrata were created within those to make sub-areas more convex and reduce off-effort time.

Figure 7 shows the location of each stratum (identified in colour codes) and substratum.

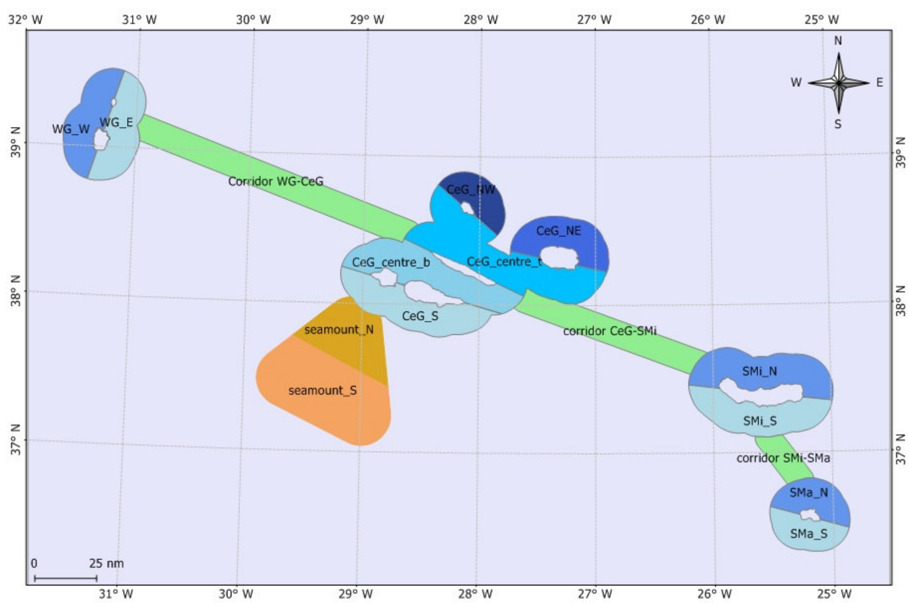

Figure 7 – Map of the survey area showing the 16 substrata with respective label. Blue tones represent the 3 islands strata, green the 3 corridor strata, and earth colours the seamount stratum.

The survey area, strata and substrata characteristics are summarized in Table 3. Total survey area is ca. 39,300km^2, and the proportion of the total area represented by substratum ranged from 2% (corridor SMi-SMa) to 12.7% (seamounts_S).

Table 3 – Characteristics of each stratum and substratum defined for the survey design.

Strata	Substrata	LinkID	Label		Area (Km^2)	% of total Area
seamount	Seamount complex North	1	seamounts_N		2,480.2	6.31
	Seamount complex South	2	seamounts_S		4,997.0	12.71
				sum	7,477.2	19.01
corridors	Corridor Western Group to Central Group	3	corridor WG-CeG		4,244.5	10.79
	Corridor Central Group to S. Miguel island	4	corridor CeG-SMi		2,656.8	6.76
	Corridor S. Miguel island to S. Maria island	5	corridor SMi-SMa		797.1	2.03
				sum	7,698.4	19.58
Western group	Western Group West	6	WG_W		1,878.6	4.78
	Western Group East	7	WG_E		1,854.9	4.72
				sum	3,733.5	9.49
Central group	Cental Group Northwest	8	CeG_ NW		1,207.4	3.07
	Cental Group Northeast	9	CeG_ NE		1,817.4	4.62
	Cental Group centre-top	10	CeG_centre_t		4,370.7	11.11
	Cental Group centre-bottom	11	CeG_centre_b		2,882.5	7.33
	Cental Group South	12	CeG_S		2,615.0	6.65
				sum	12,893.0	32.79
Eastern group	S. Miguel island North	13	SMi_N		2,624.9	6.68
	S. Miguel island South	14	SMi_S		2,355.2	5.99
	S. Maria island North	15	SMa_N		1,306.9	3.32
	S. Maria island South	16	SMa_S		1,234.9	3.14
				sum	7,522.0	19.13
survey area		1	survey area		39,316.9	

DEFINITION OF THE SURVEY DESIGN

A survey design was generated in DISTANCE, for the economic survey effort scenario described before (Option 1, L=5,000km). The angle of the zigzag lines was not the same per substratum, varying between 70^o and 175^o to the x-axis (Table 4). Proportion of effort per substratum (defined to be proportional to substratum area) was used to determine what line spacing would result in each substratum, and the mean of those line spacings was used as the design zigzag line space. Line spacing per stratum ranged between 7.96km (seamounts_S) and 8.72km (corridor SMi-SMa), and the resulting mean used in the survey design was 8.3km.

Table 4 – Strata properties used to generate the final equal spaced zigzag line transect survey design.

Strata	LinkID	Label	DA angle (°)	% of effort	spacing (km)
seamount	1	seamounts_N	160	6.31	8.07
	2	seamounts_S	160	12.71	7.96
corridors	3	corridor WG-CeG	160	10.79	8.55
	4	corridor CeG-SMi	160	6.76	8.70
	5	corridor SMi-SMa	120	2.03	8.72
Western group	6	WG_W	70	4.78	8.01
	7	WG_E	70	4.72	8.00
Central group	8	CeG_ NW	140	3.07	8.29
	9	CeG_ NE	165	4.62	8.28
	10	CeG_centre_t	150	11.11	8.16
	11	CeG_centre_b	160	7.33	8.46
	12	CeG_S	160	6.65	8.42
Eastern group	13	SMi_N	175	6.68	8.29
	14	SMi_S	175	5.99	8.41
	15	SMa_N	170	3.32	8.42
	16	SMa_S	170	3.14	8.48
				mean	8.33

5,000 simulations generated the coverage probability shown in Fig. 8; coverage probabilities (mean 0.49, range < 0.001 to 0.76, SE=0.05) seem quite even with only few grid points showing smaller/ higher coverage probability.

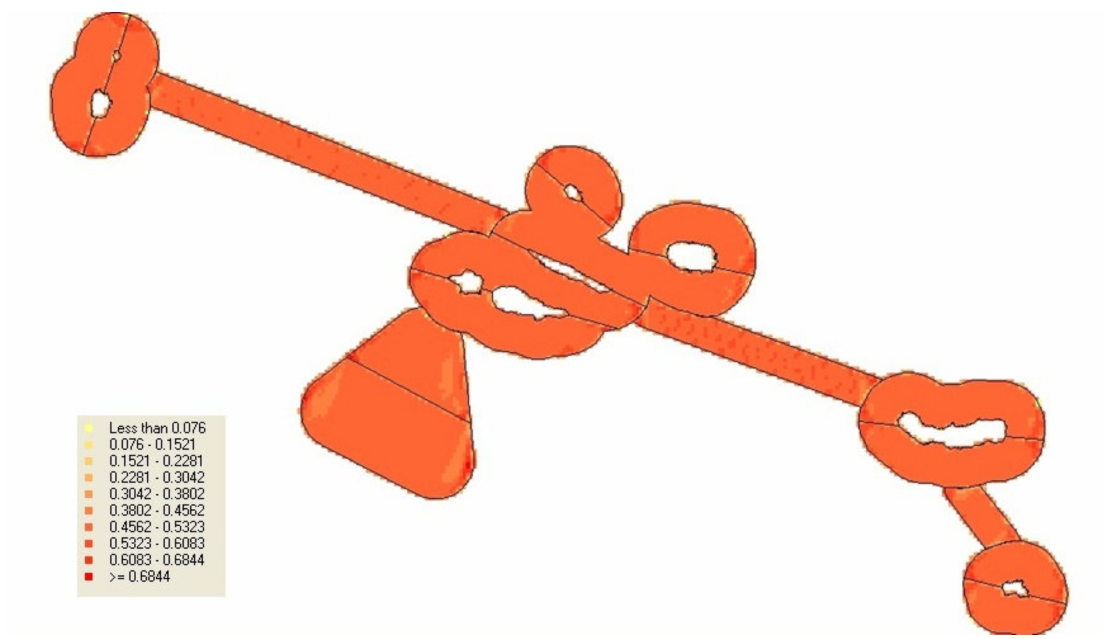

Figure 8 – Survey design coverage probabilities generated with 5,000 simulations along a grid of points 2km apart, for the smallest survey effort scenario (L=5,500km).

The mean total on effort line length generated for the survey design was 4,956.4km, having ranged between 4,729.6 and 5,151.5km (Table 5). The number of transect lines per substratum ranged from 5 (substratum 5) and 28 (substratum 3) and all strata had ≥20 lines minimum.

Table 5 – Survey design summary. Transect length and number of samples (i.e. transect lines) are means, followed by minimum and maximum in brackets. Numbers of survey days refer to proportion of a total 20 days available and the number of days required when traveling at 9 knots.

	Substrata		DESIGN		# survey days	
Strata	ID	Area (Km^2)	On effort trackline L (Km)	# samplers	from 20 days	at 9knots
seamount	1	2480.18	307.5 (288.2 - 313.9)	9.8 (8 -10)	1.3	1.5
	2	4997.02	611.6 (602.7 - 621.8)	13.4 (13 - 14)	2.5	3.1
	sum			23.2 (21 - 24)		
corridors	3	4244.54	554.0 (543.6 - 566.5)	27.1 (26 - 28)	2.2	2.8
	4	2656.80	346.4 (333.2 - 358.0)	18.1 (17 - 19)	1.4	1.7
	5	797.10	101.5 (87.8 - 115.7)	6.0 (5 - 7)	0.4	0.5
	sum			51.2 (48 - 54)		
Western group	6	1878.56	239.6 (223.4 - 250.2)	10.9 (10 - 12)	1.0	1.2
	7	1854.94	235.6 (215.7 - 248.9)	10.8 (10 - 12)	0.9	1.2
	sum			21.9 (20 - 24)		
Central group	8	1207.37	154.5 (141.9 - 165.2)	7.6 (7 - 8)	0.6	0.8
	9	1817.35	227.0 (207.5 - 249.3)	9.6 (9 - 10)	0.9	1.1
	10	4370.72	533.8 (511.9 - 547.3)	18.1 (17 - 19)	2.2	2.7
	11	2882.47	365.5 (355.5 - 371.5)	16.9 (16 - 17)	1.5	1.8
	12	2615.04	330.5 (316.8 - 341.8)	15.3 (14 - 16)	1.3	1.7
	sum			67.5 (63 - 70)		
Eastern group	13	2624.91	328.2 (313.8 - 348.1)	13.7 (13 - 14)	1.3	1.6
	14	2355.23	296.8 (282.1 - 305.9)	13.5 (12 - 14)	1.2	1.5
	15	1306.93	166.2 (157.3 - 180.5)	7.9 (7 - 8)	0.7	0.8
	16	1234.89	157.71 (148.2 - 166.9)	7.8 (7 - 8)	0.6	0.8
	sum			42.9 (39 - 44)		
		Total	4,956.41 (4,729.6 - 5,151.5)	206.7 (191 - 216)	20	24.8

Considering 12 hours of work per day, the time on effort needed to perform this survey, sailing at 9knots was 24.8 days of work. To fulfil the total transect in 20 days, the average survey speed would have to be 11knots.

A survey plan resulting from a single realization of the chosen survey design is shown in Figure 9. This presented a total line length of 4,968.2km. The number of transect lines per stratum ranged from 22 (Western group) to 66 (Central group). Further, the total off-effort line length was 156km, 3.14% of the total line length.

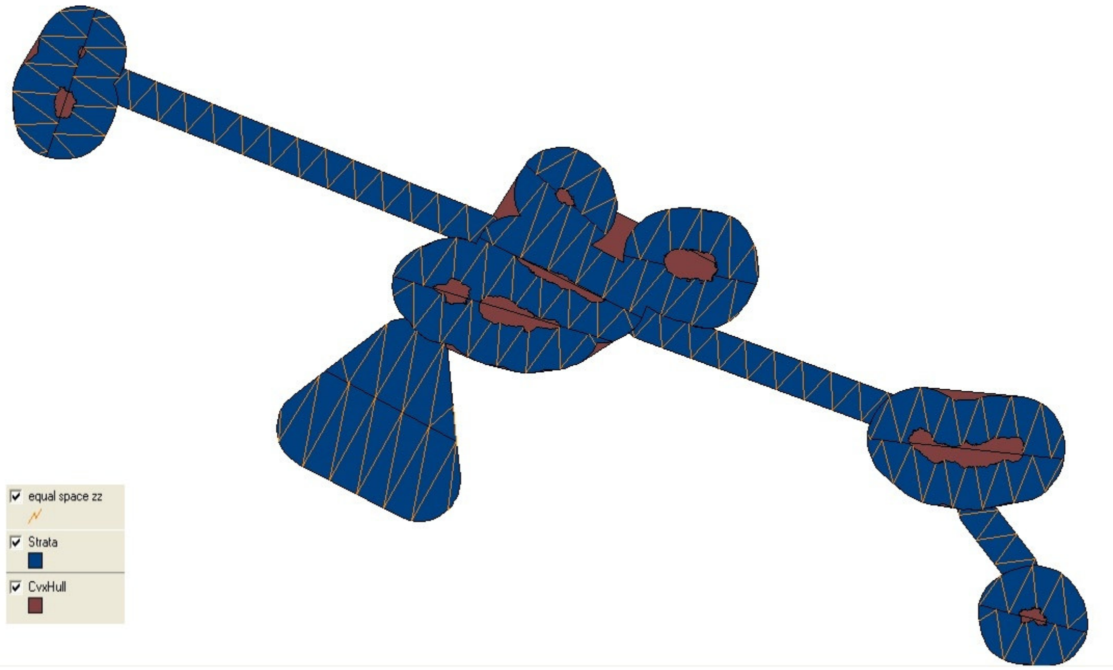

Figure 9 - Survey plan generated from a single realization of the survey design. Zigzag transect lines are in orange, substratum areas are in blue, convex-hull areas around each substratum are in brown.

Survey designs were not generated for the two other effort options presented in this study (Option 2, L=17,600km and Option 3, L=8,800km), given the minimum number (i.e. ≥15 lines) of line transects per stratum was achieved in Option 1.

DISCUSSION

ACHIEVING A GOOD SURVEY DESIGN

Several aspects must be taken into consideration when designing a shipboard line transect survey to estimate cetacean abundance. This is an iterative process, and there is a constant trade off between logistic constraints and the desired statistical robustness.

Consideration should be given to the field methods when designing a survey, since poor field methods may ruin an otherwise carefully designed survey. The primary purpose of a survey design is to ensure that the critical Distance Sampling assumptions are met:

g(0)=1, objects are detected at their initial location and accurate distance measurements (Buckland *et al.*, 2001).

The potential precision associated with choices of survey effort (i.e. line length, L) was investigated using input parameters from previous studies in the Azores. Values of encounter rate (ER) for each target species served as guidelines to determine the expected coefficient of variation (CV) and sample size (n) given L, and L was then determined to attain a given CV. This evidenced the high range of parameter values generated, both within and between species, when creating a scenario for survey effort. It was also shown that the expected survey effort strongly depends on ER, and that a minimum L can be chosen to present options for survey effort.

Three options for double platform survey effort were presented to guide project managers in the implementation of a shipboard survey design in the Azores. All these excluded *Physeter macrocephalus* from the target species, given its estimation will be based on acoustic detections, for which there are no previous ER data available in the Azores. Option 1 illustrated a more economical scenario, with the expected cost of loosing precision in the estimates and possibly not allowing adequate nor reliable estimates for one target species (*Grampus griseus*, the species with lowest ER). Option 2 illustrated the ideal scenario where the expected CV values are low and sample sizes are large. Despite the statistical excellence, however, this may be an excessive financial investment for a first survey. Thirdly, option 3 illustrated the trade-off between statistical robustness and logistic/management restrictions.

Given money is a severe and real constraint in the process of planning a design, and adding the fact this could be the first survey of this magnitude ever to be implemented in the Azores, Option 3 is the one recommended in this study.

The scenarios generated in the present study (double platform survey efforts), may nonetheless, be biased. ER values were derived from previous single-platform surveys, with a large proportion of sightings that were not identified to species level, and low height of the observation platform (Silva, *personal communication*). A double platform translates in practical terms as having more observers searching for cetaceans, and a (second) higher platform of observation, increasing the probability of detecting the animals. Consequently, ER values may be higher than those of single platform surveys and the survey effort scenarios presented in this study may be under-estimated. Additionally, the formula used to derive the survey effort scenarios refers to single-platform surveys leading to negatively-biased estimates.

An abundance estimate from data collected in a double-platform survey is expected to be higher than the previous estimates, given it can account for other sources of bias (e.g., undetected animals on the line, animal movement). Variability can be accounted for when collecting information on detectability of the animals (e.g. sea conditions, sighting cues) and employing Mark Recapture Distance Sampling to model the heterogeneity in the detection function (Marques and Buckland, 2003). Animal movement can be potentially accounted for using data on animal orientation (Palka and Hammond, 2001).

The use of Mark Recapture Distance Sampling will also provide the baseline of accurate information for future double-platform surveys in the Azores. It is important to point out to project managers that, in the absence of a dedicated pilot study, the outcome of implementing the survey proposed in this survey will be better seen as a very good pilot study for further surveys than a survey in itself.

The information collected will be a single snapshot in time. Nevertheless, if repeated every four or five years, it could be possible to detect trends in the targeted species populations (e.g. Taylor and Gerrodette, 1993).

Reinforcing the underlying management purposes of the present study, the study area was created using a 12nm buffer around the strata of interest, as these comprise the Azorean Territorial Sea. Although there is insufficient data to define substrata by a biological gradient (e.g. insufficient data on costal populations), it is well known that there are differences between geographical regions. Silva *et al.* (2003) recorded cetaceans were not seen equally in all three groups of islands (Eastern, Central and Western), possibly due to differences in the abundance or diversity of food resources. Seamounts in the Azores may act as feeding stations for some visitor species as marine mammals, as they may localize pelagic prey (Morato *et al.*, 2008). Further, corridors between islands were considered to illustrate an off-shore habitat, but might nonetheless be different when compared to other off-shore areas not between islands.

Within each of the five strata considered, 16 substrata were created. This improved the survey design by allowing a better adjustment of the non-convex survey region, providing short transect length off-effort and thus maximizing time on-effort (Thomas *et al*., 2007).

The transect line width is very small compared to the transect length, so that overlap and other edge effects are likely negligible (Strindberg and Buckland, 2004; Thomas *et al.*, 2007). The equally spaced zigzag used generated even coverage probabilities along the study area, and one essential requirement for a good survey design, randomization, was fulfilled (Buckland *et al.,* 2001). Few points had low coverage probability, possibly derived by the survey algorithm itself. This unevenness may not affect the precision with which animal abundance is estimated (Rexstad, 2007).

Furthermore, a minimum of 20 transect lines were allocated to all strata, fulfilling a second essential requirement for a good survey design, replication (Buckland *et al.,* 2001).

Even though the survey design generated for an economical effort scenario has little off-effort time, the number of days at sea allocated initially for the survey (20 days) was not sufficient. To sail the total 5,000km transect in 20 days with 12 hours of work, the average survey speed would have to be 11knots and this may be an excessive survey speed. More days should therefore be attributed to implement the survey. The time on effort needed to perform this survey, sailing at 9knots was 24.8 days; 20% (i.e. 5 days) should be added to account for bad weather (Silva, *personal communication*) plus 1 or 2 days as a safety measure. Therefore, approximately 32 days should be allocated so the most economical scenario can be accurately conducted.

Survey designs were not generated for the two other effort options presented in this study (Ideal, L=17,600km and Intermediate, L=8,800km), given the achieved number of line transects per stratum was sufficient in the economical effort scenario. Because naturally this latter scenario requires the lowest L, any increase in line length will always result in more accurate and precise estimates.

Possible improvements to design

Some of the complications found when designing the survey presented here, were due to logistical constraints. It is therefore recommended that if logistic aspects persist and it is not possible to opt for the intermediate effort scenario proposed (8,800km), more days should be allocated (min 32 days) to allow a feasible implementation of the more economical scenario (5,000km).

If it is not possible to allocate more survey effort, *Grampus griseus* could be removed from the target species given this was the species levelling the minimum survey effort required to obtain a good precision level.

This study illustrated the amount of variability in the estimates of cetacean abundance due to various sources. Therefore, it is highly recommended to conduct a pilot survey which would provide information for the effort required to estimate cetacean abundance at a desired CV, i.e., values derived from similar conditions to that of the survey. A pilot study could also provide more detailed information that could be used to improve the definition of strata in the survey area, namely the existence of biological gradients in any of the strata (e.g., coastal populations or declining population density along a bathymetric gradient within the seamount complex).

The convex hull generated did not adjust properly to the centre-top substrata in the Central group. Therefore, it is recommended to design more substrata to adjust for this (a few more substrata would not be a problem regarding data analysis), and would minimize the off-effort time.

One more option to suggest would be the uses of alternative methods to estimate the abundance of cetaceans, such as broaden the use of passive acoustic methods or conduct aerial surveys (see Borchers *et al*., 2002, Evans and Hammond 2004 and Mellinger *et al.*, 2007 for reviews).

The inclusion of covariates in the detection function modelling might also help to improve precision. Additionally, estimates per year can be greatly improved by pooling data from several years to estimate a common detection function, provided one can assume that the detectability does not change with year.

Even though it was not possible to do a power analysis allowing the evaluation of population trends over time, that would be an interesting complement to this study.
The ultimate objective of these surveys would be to obtain estimates which can be used for the management of these cetacean populations, and being able to detect changes in abundance over time is a fundamental requirement for adequate management.

CONCLUSIONS

Knowledge of population size plays a crucial role in wildlife ecology and environmental biology. Complete censuses are not feasible for most populations, and abundance estimates are based on sampling methods.
The scenarios generated in this study based on encounter rates values from single platform surveys may be underestimating the minimum effort required to achieve a target coefficient of variation in a double platform survey. Even so, it is recommended that more than just the minimum effort is allocated to the survey to assure good data quality.
Careful consideration should also be given to the field methods when designing a survey, given poor field methods compromise an otherwise good survey. It is therefore highly recommended to conduct a pilot survey that could provide more detailed information that could be used to improve the definition the survey design (e.g. number of substrata in the survey area, existence of biological gradients in the strata, survey effort based on adequate ER).

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World map: APRS World, http://aprsworld.net/

APPENDIX 1

Baseline information used to define the 3 sets of values for encounter rates (as mean number of observations per 100Km), provided by previous studies conducted in the Azores (Silva, *personal communication*). The target species for each project are highlighted in bold.

Project A (2000-2004)

	June	July	August
DDE	1,65	1,60	0,78
GGR	0,26	0,49	0,41
PMA	0,26	2,96	3,27
SFR	0,00	1,15	1,08
TTR	0,93	0,67	0,60

Project B (2005-2006)

	June	July	August
DDE	1,32	0,29	0,77
GGR	0,94	0,50	0,38
PMA	0,00	0,33	0,14
SFR	0,38	1,79	1,85
TTR	0,57	0,62	0,66

Project C (1999-2000)

	June	July	August
DDE	1,01	0,75	0,64
GGR	0,72	0,21	0,28
PMA	0,00	0,11	0,28
SFR	0,29	2,03	1,42
TTR	1,01	0,64	0,64

APPENDIX 2

Scenario study based on ER, CV, L and n, using the formula defined to determine total line length required in the main survey based on a pilot study. Relevant (i.e. statistically important for the parameter in question) reference values were added to help the interpretation of each figure.

Codes used for cetacean species: DDE – *D. delphis*; GGR – *G. griseus*; PMA – *P. macrocephalus*; SFR – *S. frontalis*; TTR – *T. truncatus*.

A – Coefficient of variation; horizontal dashed lines show CV=0.2 and 0.3.

CV, using fixed ER (min-max range) and L

CV, using fixed ER (± 10% mean) and L

CV, using chosen ER and L

B –Line length (km); vertical dashed lines show CV=0.2 and 0.3; horizontal dashed lines show L=5000, 8,800 and 17,600km.

L, using fixed ER (min-max range) and CV

L, using fixed ER (± 10% mean) and CV

L, using chosen ER and CV

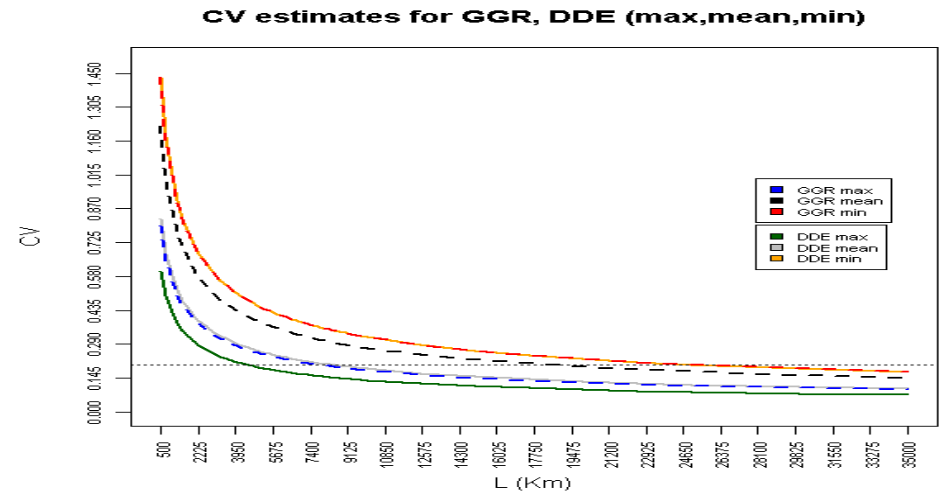
C – Sample size; horizontal dashed lines show n=60 and 80.

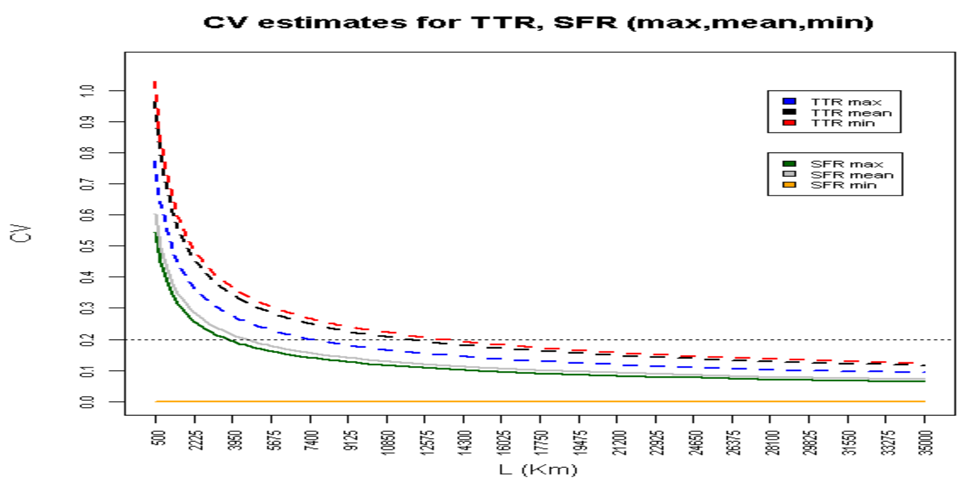
n, using fixed ER (min-max range) and L

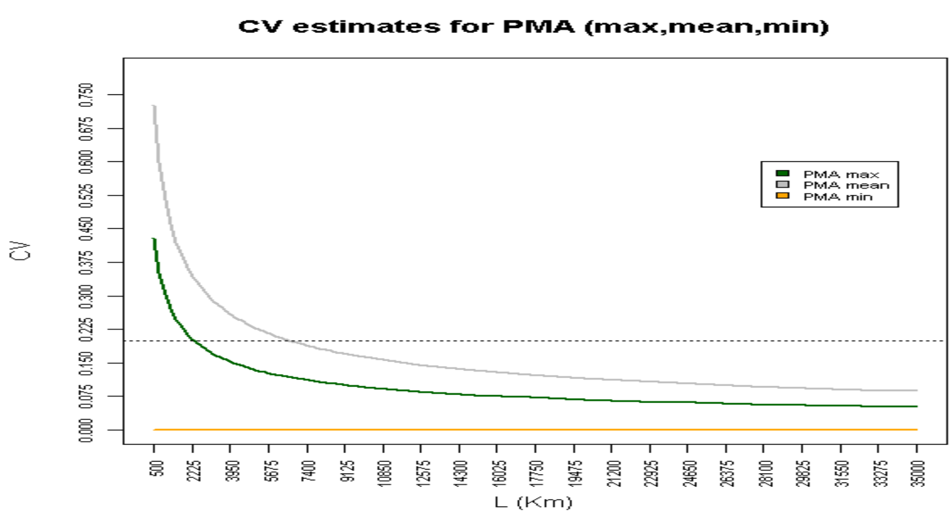
n, using fixed ER (± 10% mean) and L

n, using chosen ER and L

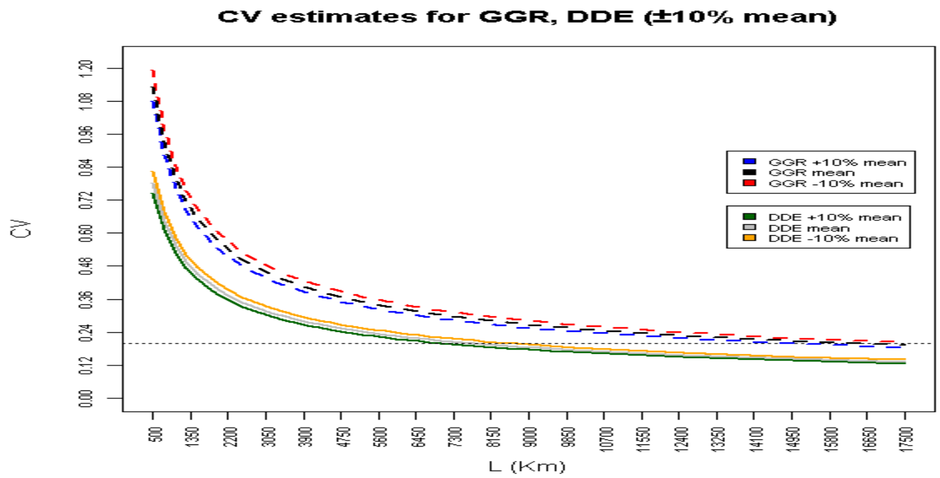
A

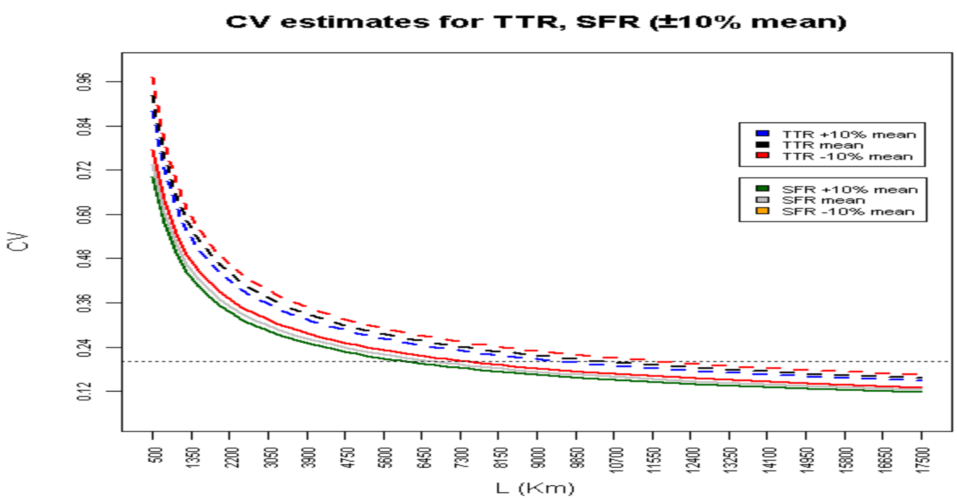

CV estimates for GGR, DDE (max,mean,min)
CV
L (Km)
GGR max
GGR mean
GGR min
DDE max
DDE mean
DDE min

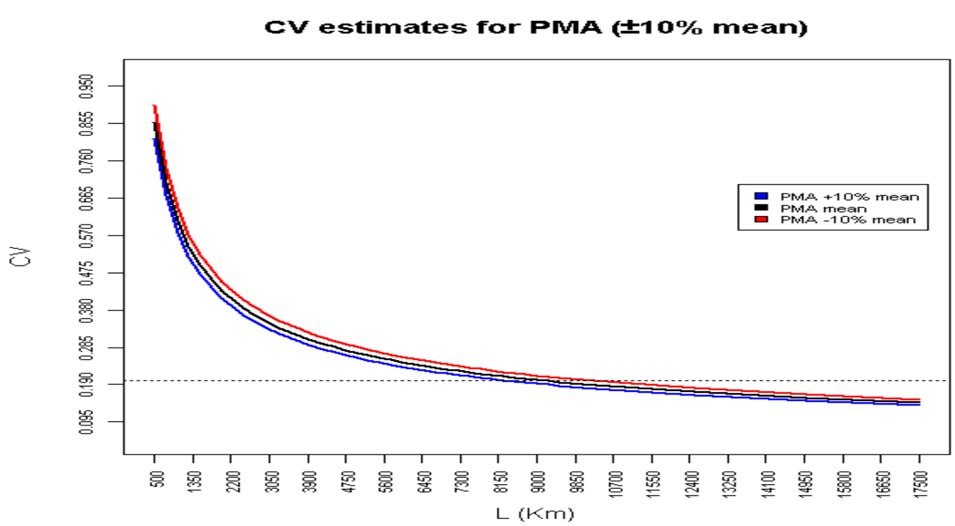

CV estimates for TTR, SFR (max,mean,min)
CV
L (Km)
TTR max
TTR mean
TTR min
SFR max
SFR mean
SFR min


CV estimates for PMA (max,mean,min)
CV
L (Km)
PMA max
PMA mean
PMA min

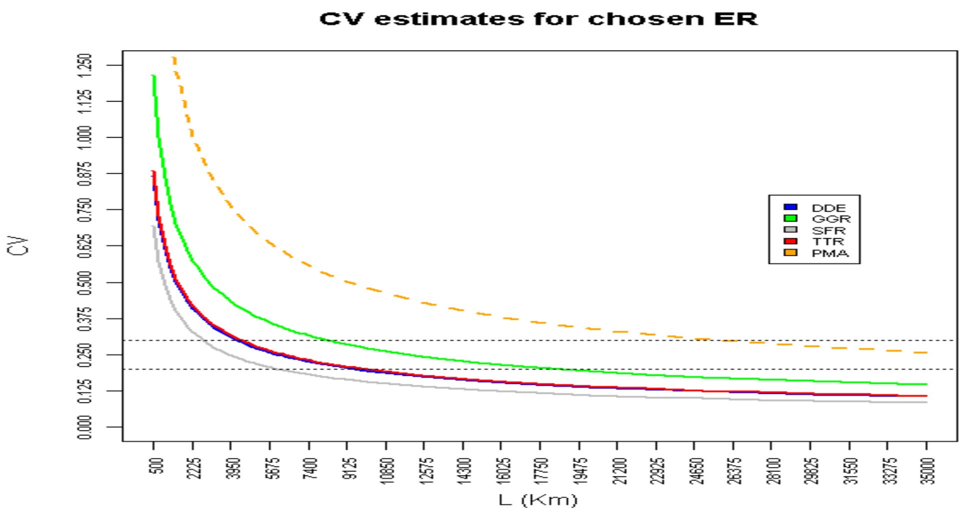
A – cont.


CV estimates for GGR, DDE (±10% mean)
GGR +10% mean
GGR mean
GGR -10% mean
DDE +10% mean
DDE mean
DDE -10% mean
CV
L (Km)

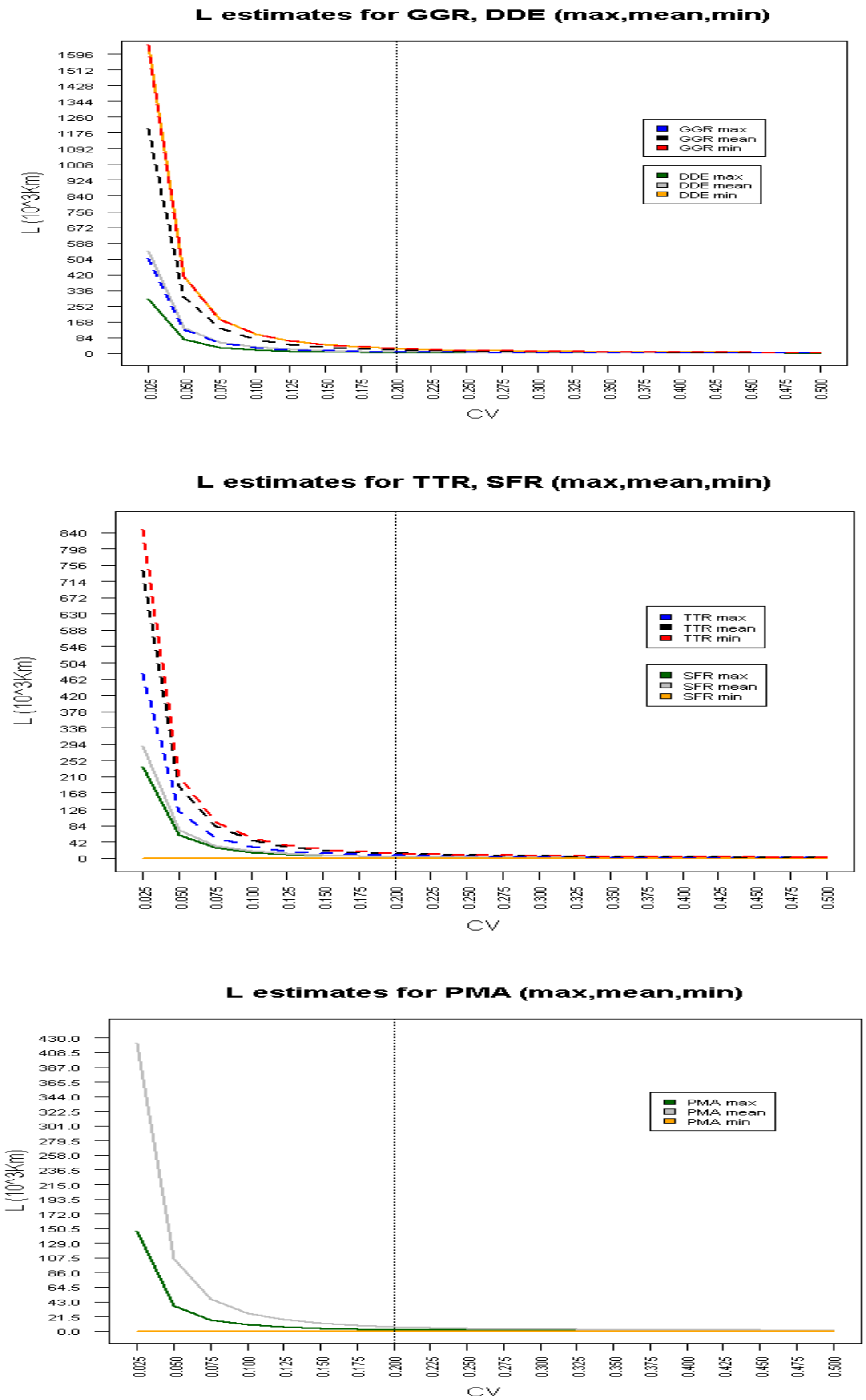

CV estimates for TTR, SFR (±10% mean)
TTR +10% mean
TTR mean
TTR -10% mean
SFR +10% mean
SFR mean
SFR -10% mean
CV
L (Km)


CV estimates for PMA (±10% mean)
PMA +10% mean
PMA mean
PMA -10% mean
CV
L (Km)

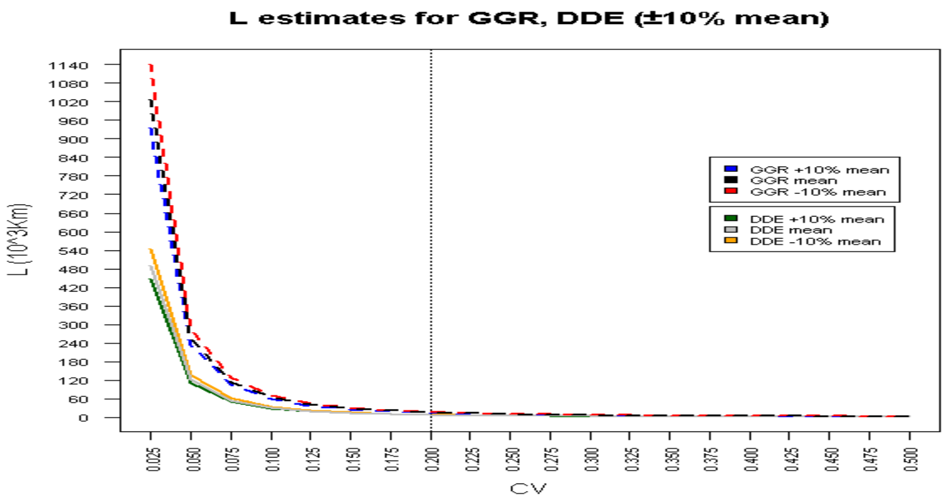
A – cont.

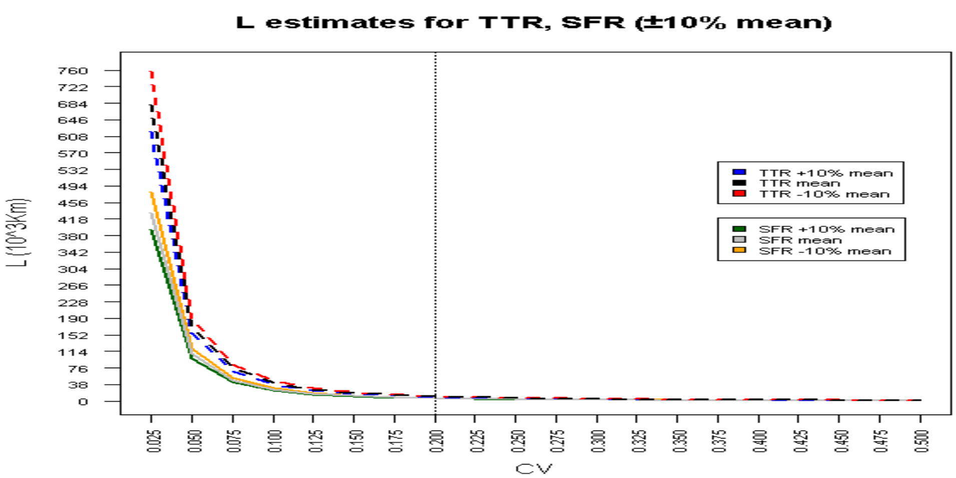

CV estimates for chosen ER
CV
L (Km)
DDE
GGR
SFR
TTR
PMA
0.000
0.125
0.250
0.375
0.500
0.625
0.750
0.875
1.000
1.125
1.250
500
2225
3950
5675
7400
9125
10850
12575
14300
16025
17750
19475
21200
22925
24650
26375
28100
29825
31550
33275
35000

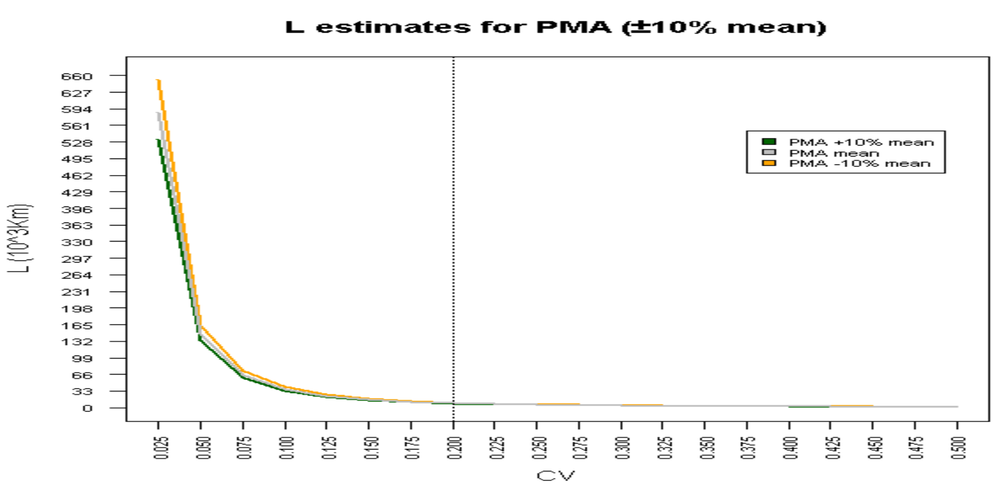
B


L estimates for GGR, DDE (max,mean,min)
GGR max
GGR mean
GGR min
DDE max
DDE mean
DDE min
L (10^3Km)
CV
L estimates for TTR, SFR (max,mean,min)
TTR max
TTR mean
TTR min
SFR max
SFR mean
SFR min
L (10^3Km)
CV
L estimates for PMA (max,mean,min)
PMA max
PMA mean
PMA min
L (10^3Km)
CV

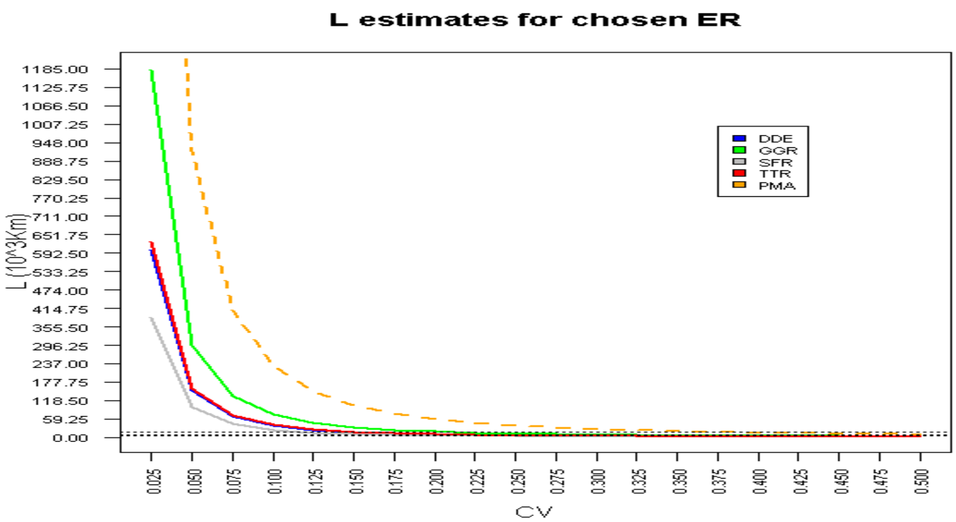
B – cont.


L estimates for GGR, DDE (±10% mean)
L (10^3Km)
CV
GGR +10% mean
GGR mean
GGR -10% mean
DDE +10% mean
DDE mean
DDE -10% mean


L estimates for TTR, SFR (±10% mean)
L (10^3Km)
CV
TTR +10% mean
TTR mean
TTR -10% mean
SFR +10% mean
SFR mean
SFR -10% mean

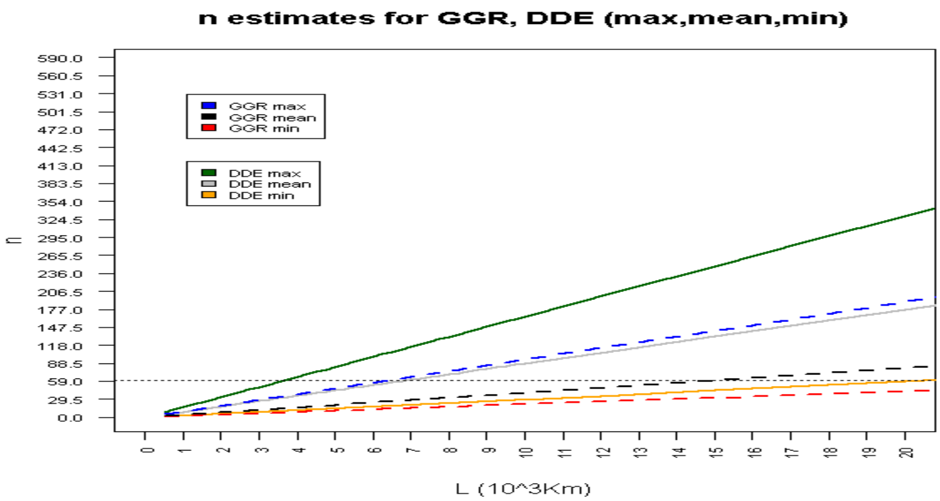

L estimates for PMA (±10% mean)
L (10^3Km)
CV
PMA +10% mean
PMA mean
PMA -10% mean

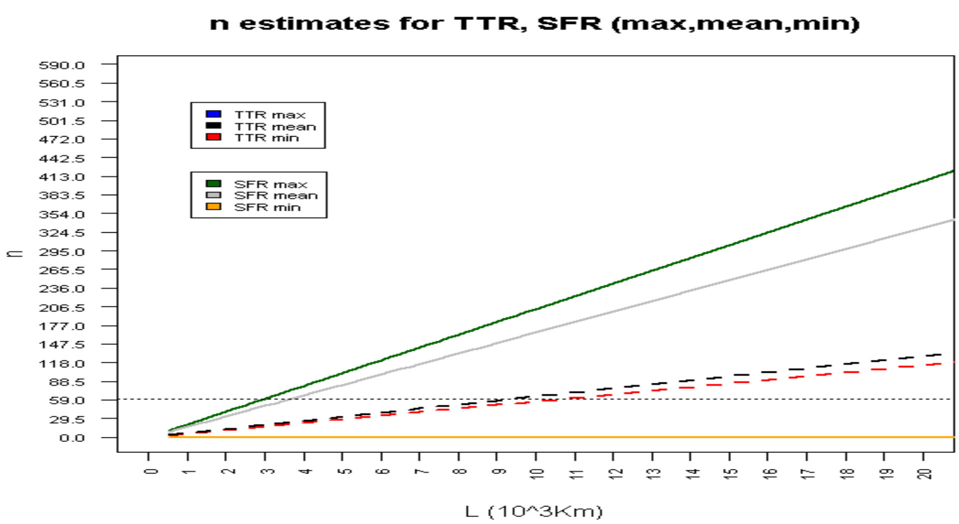
B – cont.

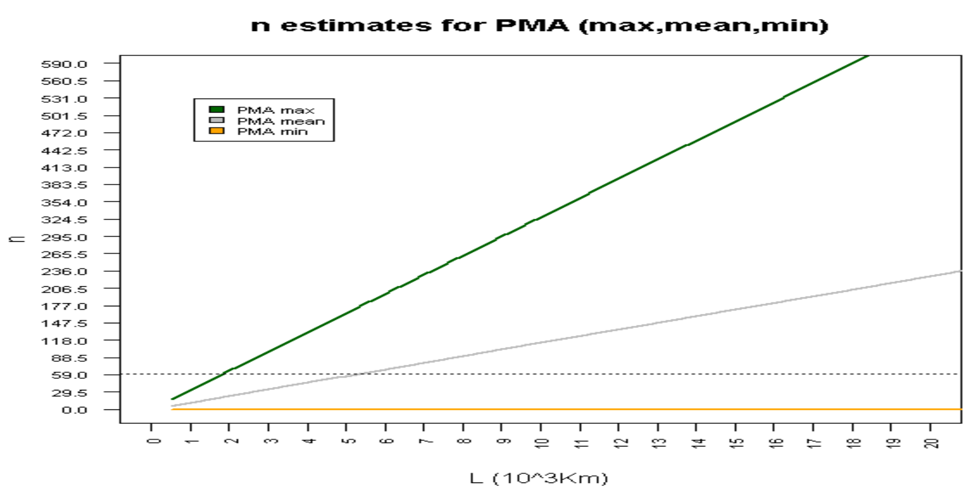


L estimates for chosen ER
DDE
GGR
SFR
TTR
PMA
L (10^3Km)
1185.00
1125.75
1066.50
1007.25
948.00
888.75
829.50
770.25
711.00
651.75
592.50
533.25
474.00
414.75
355.50
296.25
237.00
177.75
118.50
59.25
0.00
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
0.225
0.250
0.275
0.300
0.325
0.350
0.375
0.400
0.425
0.450
0.475
0.500
CV

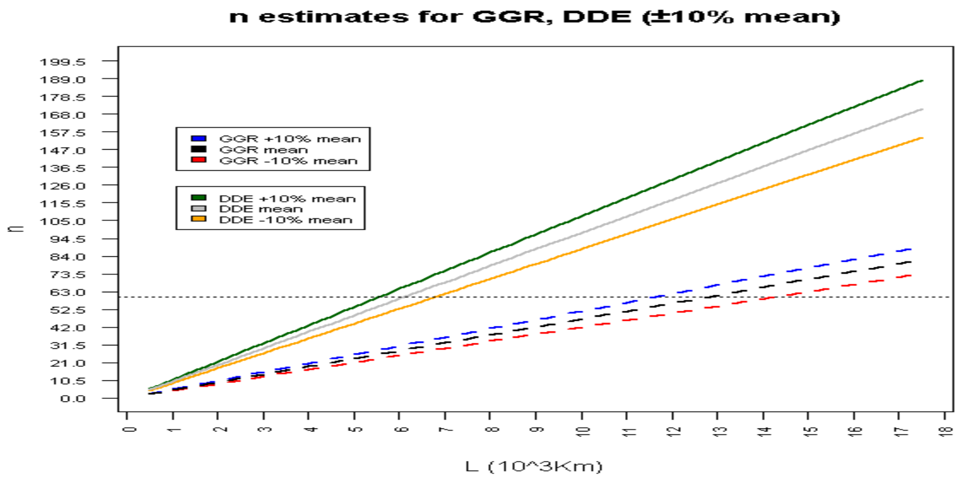
C

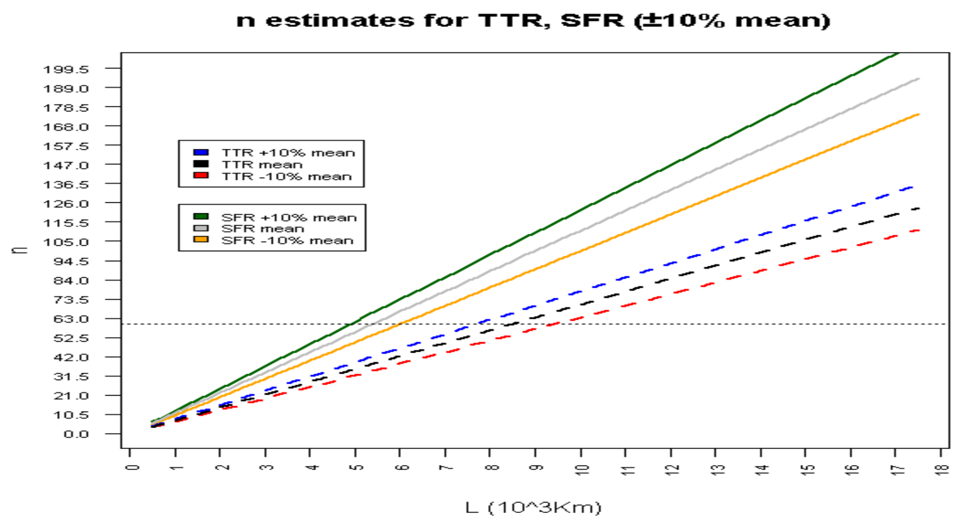

n estimates for GGR, DDE (max,mean,min)
GGR max
GGR mean
GGR min
DDE max
DDE mean
DDE min
n
L (10^3Km)

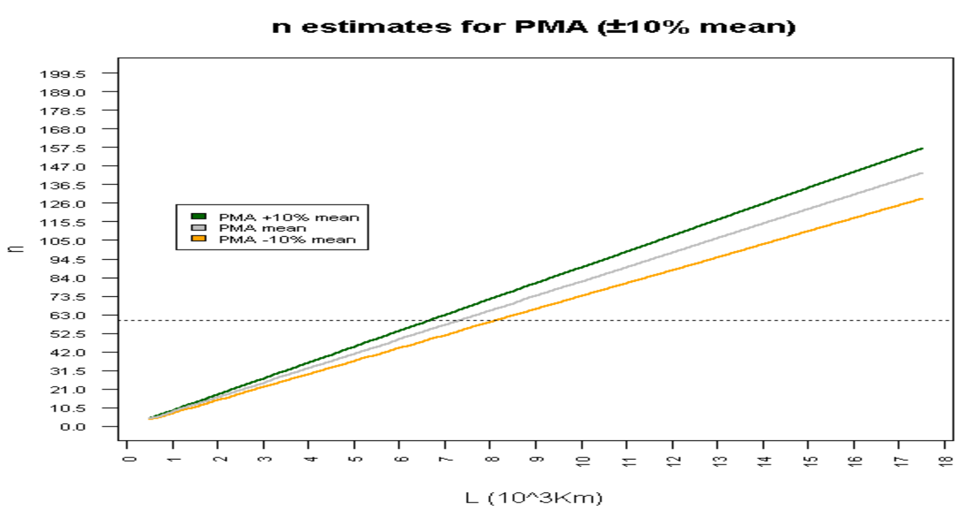

n estimates for TTR, SFR (max,mean,min)
TTR max
TTR mean
TTR min
SFR max
SFR mean
SFR min
n
L (10^3Km)


n estimates for PMA (max,mean,min)
PMA max
PMA mean
PMA min
n
L (10^3Km)

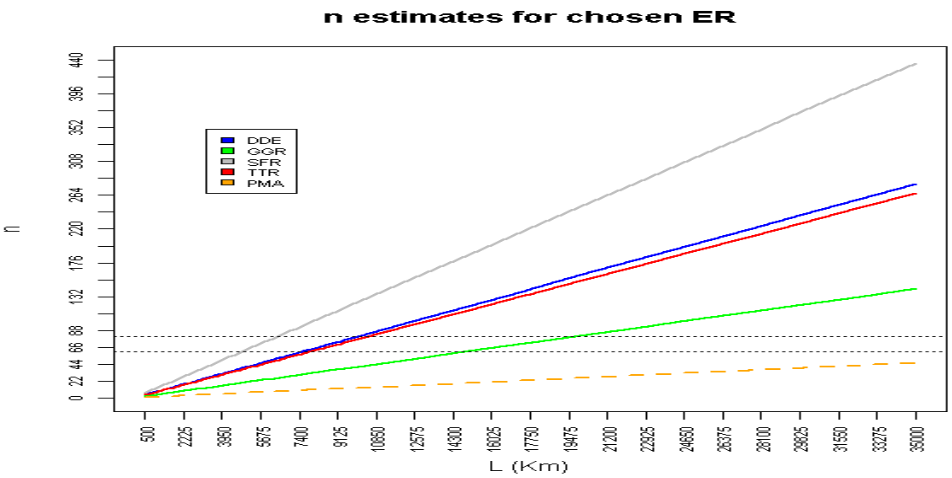
C – cont.


n estimates for GGR, DDE (±10% mean)
GGR +10% mean
GGR mean
GGR -10% mean
DDE +10% mean
DDE mean
DDE -10% mean
n
L (10^3Km)


n estimates for TTR, SFR (±10% mean)
TTR +10% mean
TTR mean
TTR -10% mean
SFR +10% mean
SFR mean
SFR -10% mean
n
L (10^3Km)


n estimates for PMA (±10% mean)
PMA +10% mean
PMA mean
PMA -10% mean
n
L (10^3Km)

C – cont.



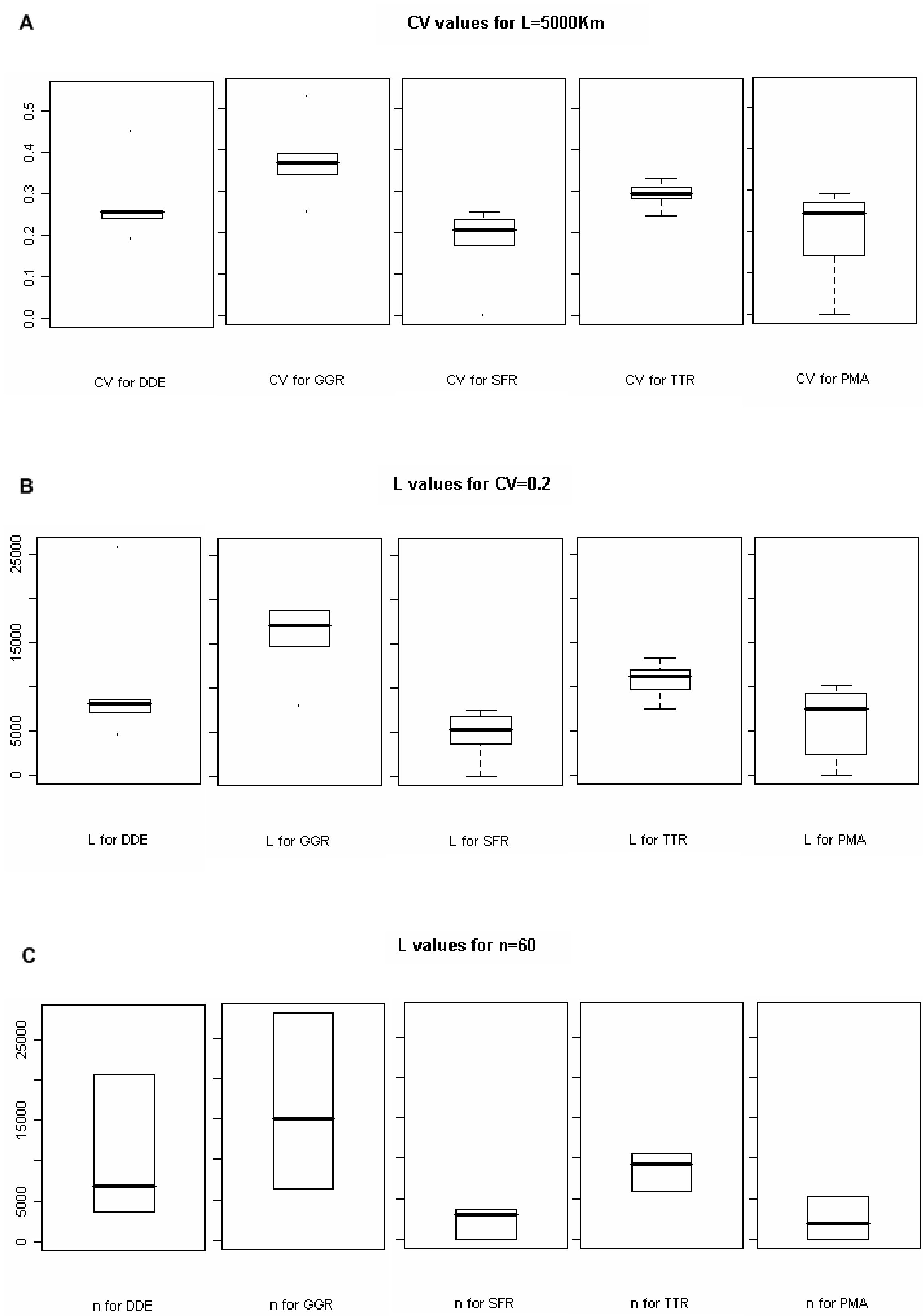
APPENDIX 3

Box plots summarizing the range in parameter values obtained using all the tested ER for each species, emphasizing important parameter values. ER values were derived from previous data collected in the Azores. Codes used for cetacean specie: DDE – *D. delphis*; GGR – *G. griseus*; PMA – *P. macrocephalus*; SFR – *S. frontalis*; TTR – *T. truncatus*.

A – CV values for L=5000Km

B – L values for CV = 20%

C - L values for n=60



A
CV values for L=5000Km
0.0
0.1
0.2
0.3
0.4
0.5
CV for DDE
CV for GGR
CV for SFR
CV for TTR
CV for PMA
B
L values for CV=0.2
0
5000
15000
25000
L for DDE
L for GGR
L for SFR
L for TTR
L for PMA
C
L values for n=60
0
5000
15000
25000
n for DDE
n for GGR
n for SFR
n for TTR
n for PMA