Mapping diversity and relative density of cetaceans and other pelagic megafauna across the tropics: general design and progress of the REMMOA aerial surveys conducted in the French EEZ and adjacent waters

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REMMOA stands for ***RE****censement des* ***M****ammifères marins et autre* ***M****égafaune pélagique par* ***O****bservation* ***A****érienne* (Census of marine mammals and other pelagic megafauna by aerial survey)

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ABSTRACT

In order to establish a baseline map of cetaceans and other pelagic megafauna across the French EEZ (Figure 1), the French agency for marine protected areas (AAMP) decided to conduct a series of surveys allowing hotspots of abundance and diversity to be identified and a future monitoring scheme to be established. This paper describes the general design, progress and perspectives of the project. A dedicated aerial survey methodology, following standard protocols, was preferred to ship surveys. The general design corresponds to published protocols prepared for small cetaceans, but data for other marine mammals (large whales, sirenians), seabirds, sea-turtles, large teleosts and large elasmobranchs) are collected as well. Finally, human activities (fishing vessels, boating and merchant ships, marine debris > 0.5m size) are also recorded. Data collected include species, group size, angle to survey track for cetaceans located within 500m on both sides of survey track, allowing line transect data analyses. For seabirds all encounters located within 200m on both sides of survey track are recorded for strip-transect analysis. Covariates collected on board include sea-state, turbidity, glare and cloud coverage. The study areas will ultimately include all sectors of the French EEZ in the tropical Atlantic (French Caribbean and Guiana), Indian (Reunion Island, Mayotte and the Scattered Islands) and south Pacific oceans (French Polynesia, New Caledonia, Wallis and Futuna). Sampling is organised at three hierarchical spatial levels: regions (4 regions), areas (several areas per region) and gross bathymetric strata (shelf, slope, oceanic). The first surveys were conducted from February-March 2008 across the EEZ of Martinique and Guadeloupe (Caribbean; 123,000 km², 8,400 km or 71h of effort) and in October 2008 off Guiana (138,000 km², 7,800 km or 63h of effort). From December 2009 to April 2010, was conducted the southwest Indian Ocean survey, designed and implemented regionally under the framework provided by the Indian Ocean Commission (IOC), *i.e.* a study region of approximately 5,000,000 km² (90,000 km or 500h of effort). The spatial modeling is conducted in two steps. Firstly, the statistical relationships between sightings per unit effort and environmental covariates are established by using GAM (Generalized Additive Models) among three categories of covariates: covariates determining detection rates (cloud, glare, sea-state, turbidity, observers, tiredness,…), geographic covariates (depth, latitude, longitude, distance to coast, slope, …) and oceanographic covariates (Sea Surface Temperature, Chl*a*, distance to front, height anomaly, …). Secondly, the established relationships are used to predict densities of sightings across regions. Another objective is to derive minimal abundance estimates by using line-transect methodology for cetacean species and strip-transect methodology for birds. During the Caribbean survey, sea-state was suboptimal (Beaufort 3-4) in spite of the survey being planned after the trade wind season. A total of 55 sightings of cetaceans were collected, of 12 different taxa. In the Guiana survey, sea-state was excellent throughout (Beaufort 1-2) and 140 sightings of cetaceans were collected, of 10 different taxa. In the southwest Indian Ocean, detection conditions were excellent in all areas of the Mozambique Channel and the Seychelles Plateau, intermediate in the northeast of Madagascar and suboptimal in Reunion and Mauritius. 1,274 sightings of cetaceans were collected on effort, including 17 different taxa. In the Caribbean, the 'average' cetacean habitat appears to be mostly located over the slope, along the eastern side of the islands and limited overlap was found with human activities. Totals of 5,300 cetaceans and 15,400 seabirds were estimated in the surveyed area. In the Guiana survey area, minimal estimates of 38,280 *T. truncatus* and 1,942 *S. guianensis* were found. In the near future, the South Pacific regions are planned to be surveyed during the years 2010-11 (French Polynesia) and 2011-12 (southwest Pacific Ocean around New Caledonia and Wallis and Futuna). Finally, it is planned to conduct in 2012-13 the Atlantic survey regionally. Given the surface areas to be covered for these highly mobile pelagic organisms, a regional approach is highly recommended. Therefore regional co-operations, similar to the one conducted in the southwest Indian Ocean under the framework of the Indian Ocean Commission, would be highly beneficial. To build the conditions for such co-operations, contacts have to be established with these countries and regional agreements identified to act as frameworks for these collaborations.

INTRODUCTION

The French Agency for Marine Protected Areas (*Agences des aires marines protégées,* AAMP) was established by the Act of April 14th, 2006, with the following core missions: to support public policies for both creating and managing marine protected areas, to coordinate the network of MPA managers, and to manage human resources and funding provided for marine nature parks or other marine protected areas. To achieve this mission, the AAMP seeks *i.a.* to build up a knowledge base from existing data or, where appropriate, by organizing the production of new data. In this respect, the vast extent of the French EEZ (11million km², 97% of which lie around overseas territories, Fig. 1), its distribution in all three oceans at latitudes from *ca.* 50°N to 50°S and its fragmented nature make the identification of areas to be protected in priority particularly challenging, notably as of the pelagic ecosystems whose biodiversity and functioning are specially under-documented compared to coastal habitats.

The distribution of hotspots of diversity or abundance of cetaceans and other pelagic megafauna (birds, turtles, large teleosts and elasmobranchs) was considered as a key element of knowledge for the design and implementation of a marine biodiversity conservation strategy for three main reasons. Firstly, these species are intrinsically vulnerable because of their generally large size, high trophic level, low natural adult mortality and low fecundity; because of such characteristics most of these species are exposed to many anthropogenic pressures and have a limited capacity to recover from highly degraded situations; they are therefore listed in a number of national, regional or international agreements for marine conservation. Secondly, it is also considered that conservation strategies tailored for these highly mobile species would be beneficial to ecosystems and lower trophic levels over large areas or networks of areas, a consequence colloquially named the umbrella effect of top predators. Thirdly, these species form one of the few components of pelagic biodiversity that can be readily seen from the surface of the ocean and therefore be surveyed across large oceanic regions; it is therefore expected that their species assemblages would reveal some of the major properties of the underlying ecosystems, a characteristics referred to as the indicator value of cetaceans and other marine megafauna.

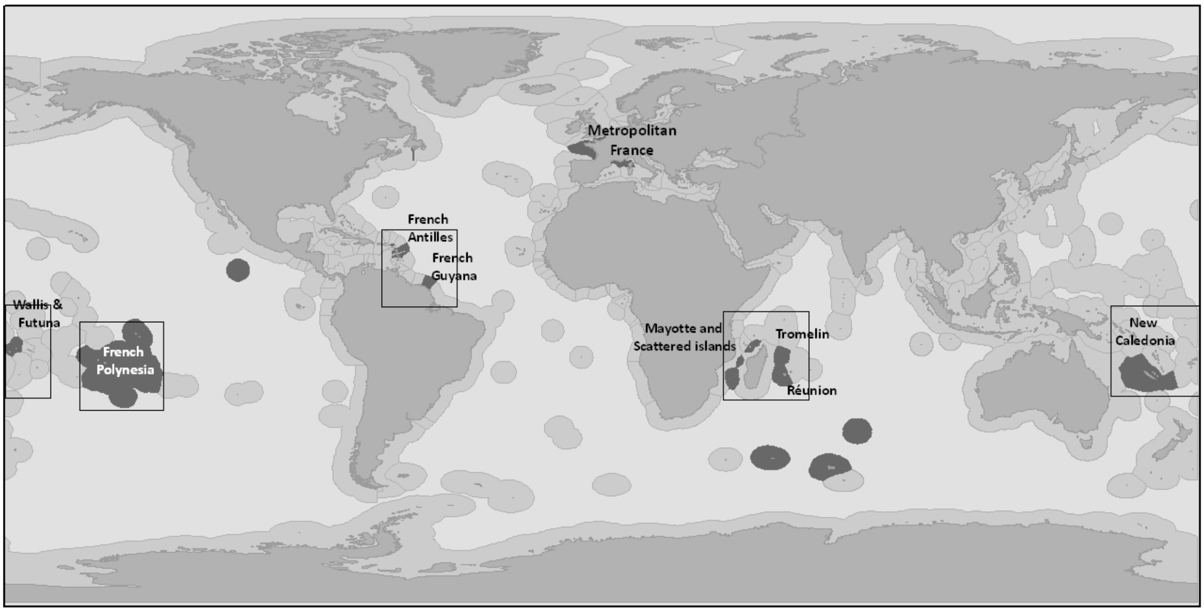

Figure 1: The French Economic Exclusive Zone (in dark grey) stretches across all three oceans from approximately 50°N to 50°S and is generally highly fragmented. Tropical regions of interest to the REMMOA surveys are the eastern Caribbean/Guiana Plateau regions, the southwest Indian Ocean, the western South Pacific Ocean, and the central South Pacific Ocean. These areas overlap with several Large Marine Ecosystems (LMEs; not shown).

In order to establish a baseline map of cetaceans and other pelagic megafauna across the French EEZ (Figure 1), it was decided to conduct a series of surveys from 2008 onwards following a standardized methodology that would allow comparisons within and between regions as well as temporally, for the sake of the identification of hotspots of abundance and diversity and the establishment of a future monitoring scheme (Table 1). These surveys are named the REMMOA surveys for ***RE****censement des* ***M****ammifères marins et autre* ***M****égafaune pélagique par* ***O****bservation* ***A****érienne* (Census of marine mammals and other pelagic megafauna by aerial survey). Additionally, considering the fragmented nature of the French EEZ, notably compared to the spatial scale that is relevant for the species of interest, the implementation of these surveys at regional scale by collaboration with neighboring countries is encouraged. The objective of the present paper is to report on the progress made so far in the Atlantic and the southwest Indian Ocean and the perspectives in the south Pacific. For the sake of developing regional co-operation where needed, this paper is intended to help exchange of information with scientists and stakeholders.

MATERIALS AND METHODS

General design, study areas and time line

A dedicated aerial survey methodology was preferred to ship surveys for its capacity to cover vast areas at a much lower cost than dedicated ship surveys and for its flexibility of implementation which allows a quick reaction to changing weather and sea conditions, hence resulting in a higher rate of platform usage in optimal detection conditions. These surveys follow the general SCANS methodology (Hiby and Lovell, 1998) adapted to aircrafts. A zigzag track layout is used and transects are sampled at a target altitude of 180 m and ground speed of 90 nm.h^{-1} (167 km.h^{-1}). Survey platforms are high-wing, double-engine aircrafts fitted with bubble windows; a Partenavia P68 was used in 2008 in the Atlantic and two Britten Norman BN-2 in 2009-10 in the southwest Indian Ocean.

Survey crew typically consists in two trained observers observing with naked eyes and a flight leader in charge of data collection. Observers rotate regularly to ensure that observation effort never exceeds 4 consecutive hours for any given observer, in an attempt to minimize the decrease of attention due to tiredness. The general design corresponds to published protocols prepared for small cetaceans. However in addition to this, presence and group size of other marine mammals (large whales, sirenians), seabirds, sea-turtles, large teleosts and large elasmobranchs are collected as well. Finally, human activities (fishing vessels, boating and merchant ships, marine debris > 0.5m size) were also recorded. Data collected include species, group size, angle to survey track measured with an inclinometer for cetaceans located within 500m on both sides of survey track, allowing line transect data analyses. For seabirds all encounters located within 200m on both sides of survey track are recorded but angles are not measured, in an attempt to minimize disrupting the attention of the observers from the target species (cetaceans) in areas of high seabird densities; consequently, seabird data are to be analysed using strip transect methodology under the assumption that all seabirds within the 2x200m sighting bands are seen; this latter assumption makes seabird data likely biased, particularly for the smaller and darker species. Identification is made to species level whenever possible, but groupings are inevitable for animals that cannot be told apart from the air. The *Stenella* dolphins and shelled turtles represent typical examples of such groupings. Covariates collected on board include sea-state, turbidity, glare and cloud coverage.

The study areas include all sectors of the French EEZ in the tropical Atlantic (French Caribbean and Guiana), Indian (Reunion Island, Mayotte and the Scattered Islands) and south Pacific oceans (French Polynesia, New Caledonia, Wallis and Futuna). Sampling is organised at three hierarchical spatial levels: regions (4 regions; Figure 1), areas (several areas per region as exemplified here in the southwest Indian Ocean) and gross bathymetric strata (shelf, slope, oceanic).

The first surveys were conducted from February-March 2008 across the EEZ of Martinique and Guadeloupe (Caribbean; 123,000 km², 8,400 km or 71h of effort) and in October 2008 off Guiana (138,000 km², 7,800 km or 63h of effort) (Table 2; Figure 2; Van Canneyt *et al*., 2009, 2010). These surveys were restricted to the French EEZ as no attempt to implement them regionally was made because of time constraints. As described above, these surveys were stratified according to depth categories defining the main habitats in these areas.

From December 2009 to April 2010, was conducted the southwest Indian Ocean survey. This survey was designed and implemented regionally under the framework provided by the Indian Ocean Commission (IOC), which includes Comoros, Madagascar, Mauritius, Reunion Island (France) and the Seychelles, *i.e.* a study region of approximately 5,000,000 km². Sampling design was on several steps. Firstly we identified 7 areas accessible by aircraft and representing the variety of habitats and latitude-longitude across the region; each area was then stratified according to depth categories, as indicated above; finally sighting effort was allocated within each strata (90,000 km or 500h of effort; Table 2; Figure 3) in such a way that habitats expected to have low density of cetaceans (Chl*a*-depleted oceanic waters) would receive proportionately more effort than habitats with high expected cetacean densities (Chl*a*-rich oceanic waters, slope and shelf waters) so that sufficient data is collected for analyses irrespective of actual density. Finally, in one area of this survey (the Seychelles box) a high resolution digital camera was fitted under the aircraft as a feasibility experiment for further developments.

Table 1: Provisional time line of the REMMOA survey series (in grey: done).

Actions	Areas					
	Caribbean & Guiana (local)	Southwest Indian Ocean (regional)	French Polynesia (regional)	Southwest Pacific Ocean (regional)	Caribbean & Guiana (regional)	Monitoring scheme workshop
Planning	2007-8	2008-9	2009-10	2010-11	2011-12	2013
Survey	2008	2009-10	2010-11	2011-12	2012-13	
Analysis	2009	2010	2011	2012	2013	
Dissemination	2010	2011	2012	2013	2014	

The South Pacific regions are planned to be surveyed during the years 2010-11 (French Polynesia) and 2011-12 (southwest Pacific Ocean around New Caledonia and Wallis and Futuna). Finally, it is planned to conduct the Atlantic survey regionally in 2012-13. For each regional survey, the time line extents over 4 years, necessary for planning and conducting the survey, analysing the data and disseminating the results (Table 1).

Analytical procedure

The general aim of the analyses is to map regional diversity and relative abundance of cetaceans and other megafauna across oceanic regions and identify zones where hotspots of abundance or biodiversity overlap with hotspots of human activities. The analytical strategy is exemplified from the Caribbean survey (Figure 4), but must be considered as provisional since analytical effort will develop and diversify as new surveys become available.

The spatial modeling is conducted in two steps. Firstly, the statistical relationships between sightings per unit effort and environmental covariates are established by examining data at area and region levels. Significant covariates are selected by using GAM (Generalized Additive Models) among three categories of covariates: covariates determining detection rates (cloud, glare, sea-state, turbidity, observers, tiredness,…), geographic covariates (depth, latitude, longitude, distance to coast, slope, …) and oceanographic covariates (Sea Surface Temperature, Chl*a*, distance to front, height anomaly, …). A forward model selection procedure allows the most significant covariates to be selected (Wood & Augustin 2002); to date the covariate selection procedure was limited to indentifying the four most significant variables. For the Caribbean and Guiana surveys, all geographic and oceanographic covariates were obtained from http://las.pfeg.noaa.gov/oceanWatch/oceanwatch_safari.php). Secondly, the established relationships are used to predict densities of sightings across regions.

These results allow mapping of habitats of high importance for predator diversity by creating a multispecies index (Equation 1) that combines several representatives of different groups of pelagic top predators.

$$\text{Equation 1:} \quad H_s = \frac{1}{T}\sum_1^i \frac{N_{i,s}}{M_i}$$

with H_s : Habitat index at location *s*; *T* : total number of taxa; $N_{i,s}$: predicted relative abundance of the i^{th} taxa at the spatial location *s*; M_i : maximum predicted relative abundance of the i^{th} taxa within the study area.

This map can then be crossed with maps of anthropogenic activities to highlight areas of potential interactions. An index of human pressure on the habitat can be obtained in a much similar way than above (Equation 2)

$$\text{Equation 2:} \quad A_s = \sum_1^a N_{a,s} \times c_a$$

with A_s : index of human activity at location *s* ; $N_{a,s}$: predicted abundance of a^{th} human activity; and c_a: a weighting coefficient reflecting the potential impact of the a^{th} human activity on top predators, set to 1 in absence of information.

These two maps can then be crossed together in order to highlight areas of potential interactions (Equation 3).

Equation 3: $C_s = H_s \times A_s$

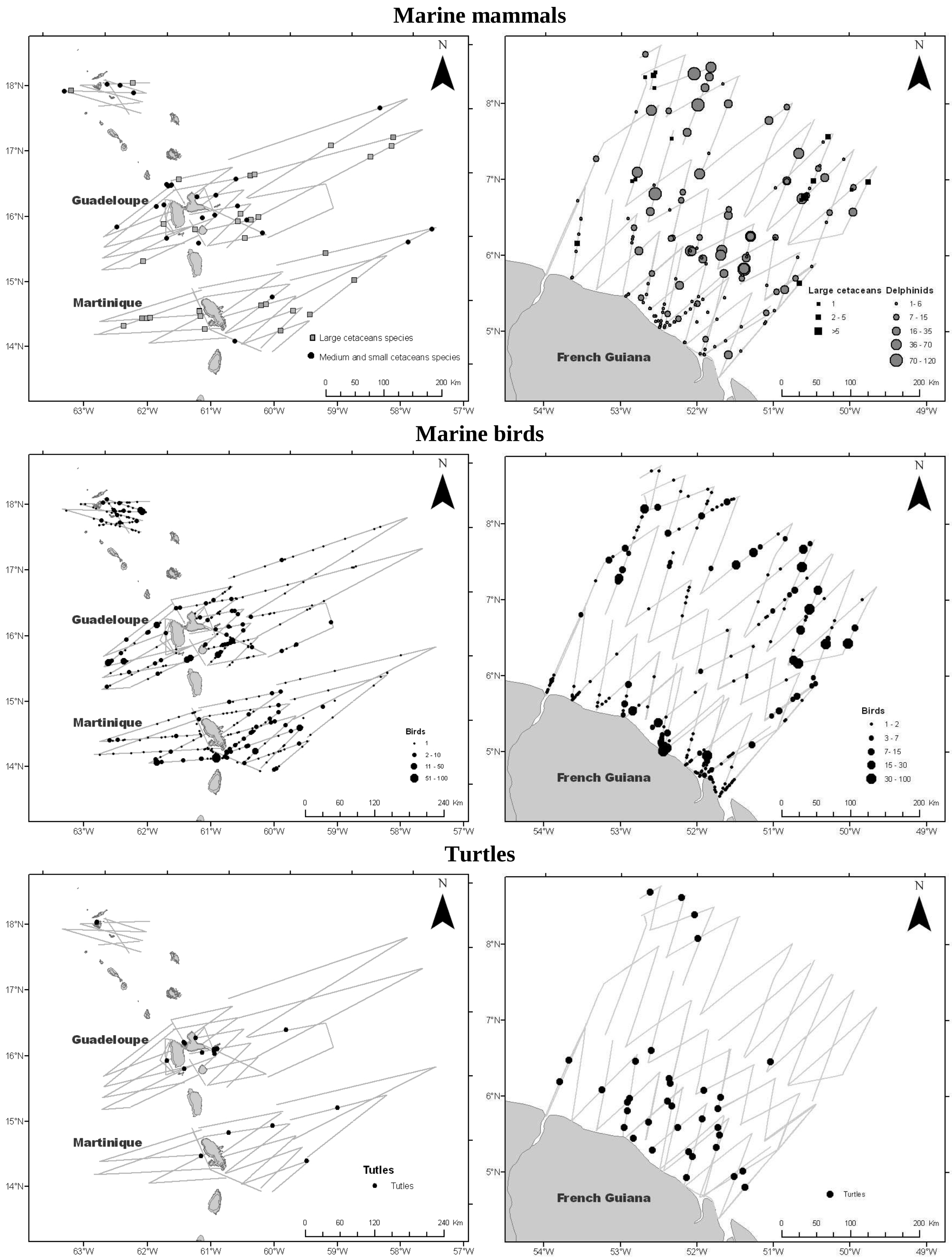

Figure 2: Maps of survey effort and sightings collected during the French Caribbean (left) and Guiana (right) surveys.

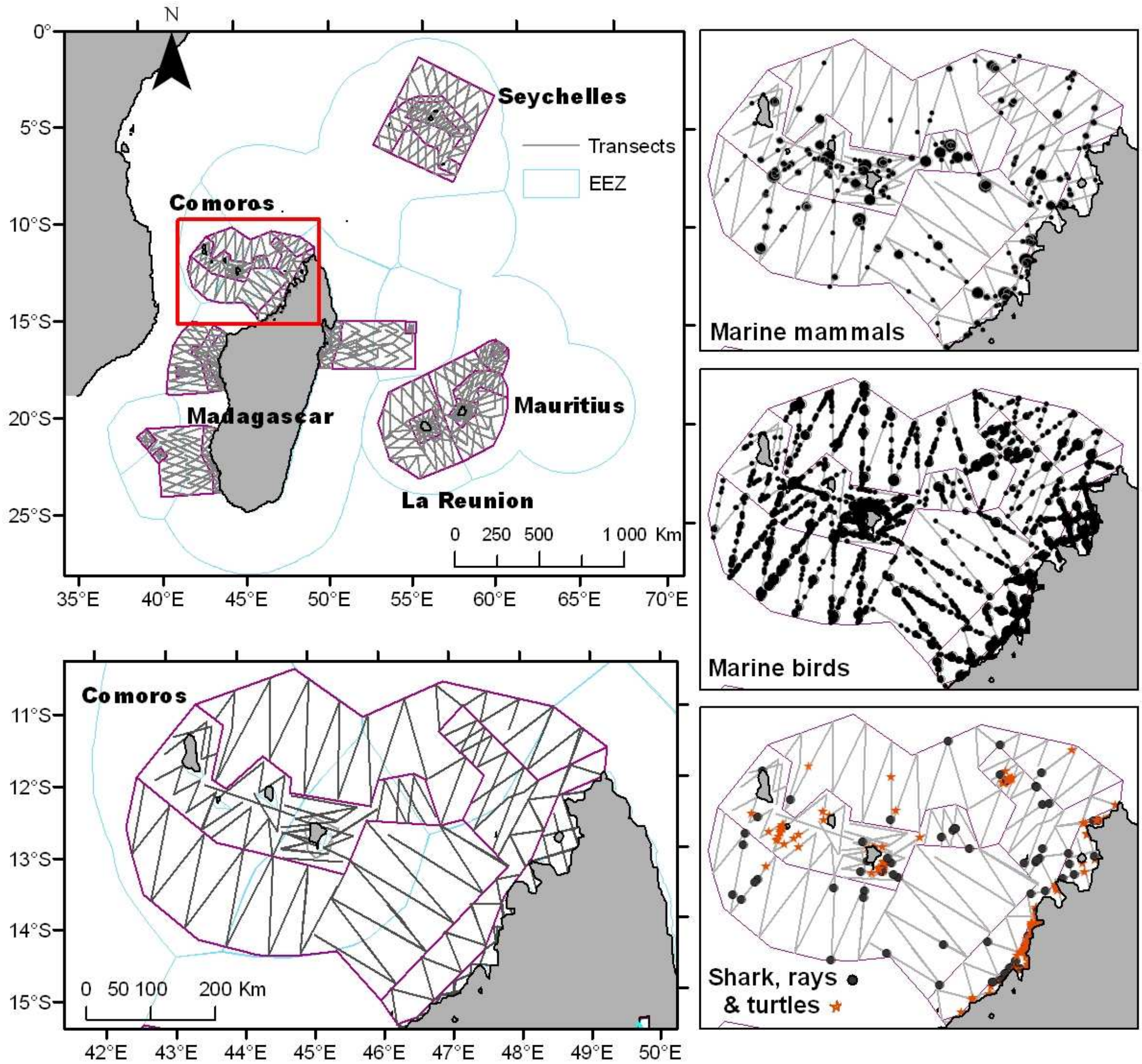

Figure 3. Maps of survey effort conducted in the Indian Ocean, with a focus on one of the seven areas (Comoros–Mayotte–Glorieuses-NW Madagascar) (left), and distribution of sightings for marine mammals, birds and sharks-rays and turtles collected in that same area (right).

Another objective is to derive minimal abundance estimates by using line-transect methodology for cetacean species (Buckland *et al*., 2001) and strip-transect methodology for birds (Certain and Bretagnolle, 2008). For cetaceans, this is only possible when sufficient data is available for fitting detection functions across a region; furthermore, the analyses are carried out under the assumption that detection probability on track line is 1 [g(0) = 1], which is an evident source of underestimation. Nonetheless, these figures would be first estimates for all areas in which they can be calculated, which will be a great interest to managers wherever interactions with fisheries or other anthropogenic pressures have to be assessed and mitigated.

RESULTS

To date, the Atlantic surveys of eastern Caribbean and Guiana were conducted in February and October 2008 respectively and the southwest Indian Ocean survey from mid-December 2009 to mid-April 2010. Only the Atlantic surveys have been submitted from a first series of analyses.

Description of available data

During the Caribbean survey, sea-state was suboptimal (Beaufort 3-4) in spite of the survey being planned after the trade wind season. A total of 55 sightings of cetaceans were collected on effort, including 12 different species or taxa (Tables 2 and 3; Figure 2 left): *Balaenoptera acutorostrata* (4 on-effort sightings), *Balaenoptera* spp. (1), *Megaptera novaeangliae* (9), *Physeter macrocephalus* (8), *Ziphius cavirostris* (2), unidentified Ziphiidae (4), *Orcinus orca* (2), *Globicephala macrorhynchus* (5), *Pseudorca crassidens* (2), *Kogia* spp (2), *Tursiops truncatus* (3), *Stenella spp.* (7), *Lagenodelphis hosei* (4) and undetermined cetaceans (2). A majority of sightings (cetaceans, birds, turtles) were made in slope habitats, notably off the eastern (Atlantic) side of the islands (Figure 2 left).

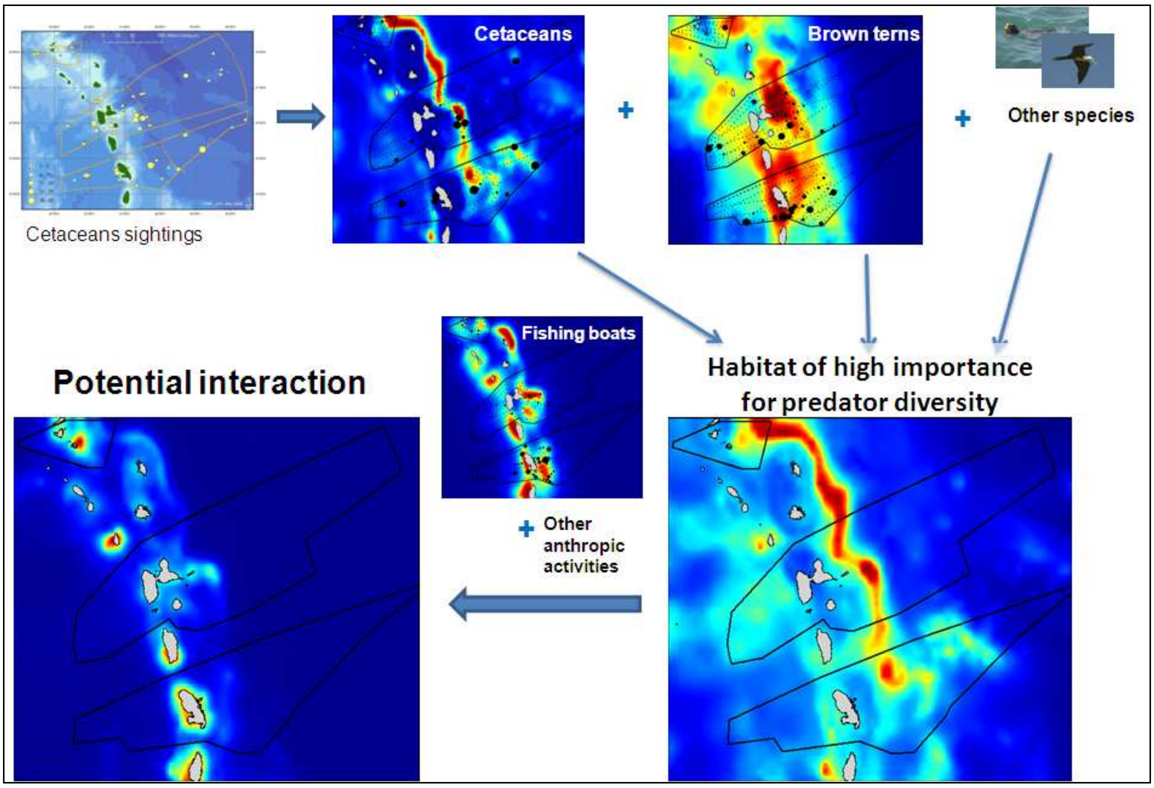

Figure 4: Representation of the spatial modeling procedure from the distribution of sightings to a map of preferential habitats for top predators and the identification of areas of potential interactions, as exemplified from the Caribbean survey.

Table 2: Total effort and associated number of sightings of cetaceans, seabirds, turtles and elasmobranchs.

Area	Effort km, hours	Cetaceans Sightings (taxa)	Birds Sightings (taxa)	Turtles Sightings	Sharks and Rays Sightings
French Antilles	8,400 km 71h	55 (11 taxa)	407 (15 taxa)	21	7
French Guiana	7,300 km 63h	140 (10 taxa)	291 (11 taxa)	36	149
SW Indian Ocean	89,000 km 502h	1,274 (17 taxa)	22,349 (14 taxa)	830	326

In the Guiana survey, sea-state was excellent throughout (Beaufort 1-2) and 140 sightings of cetaceans were collected on effort including 10 different species or taxa (Tables 2 and 3; Figure 2 right): *Balaenoptera* spp. (1 on-effort sighting), *Balaenoptera physalus* (2), *Physeter macrocephalus* (3), *Ziphius cavirostris* (3), *Ziphiidae* spp. (2), *Mesoplodon* spp. (2), *Globicephala macrorhynchus* (8), *Globicephala or Pseudorca* (1), *Peponocephala or Feresa* (3), *Grampus griseus* (1), *Tursiops truncatus* (70), *Sotalia guianensis* (22), *Stenella* or

Delphinus spp. (8), delphinids undetermined (12). Cetacean sightings were fairly equally distributed across the shelf, slope and oceanic strata (Figure 2, right).

In the southwest Indian Ocean, detection conditions were excellent in all areas of the Mozambique Channel and the Seychelles Plateau, intermediate off Antongil Bay and Sainte Marie in the northeast of Madagascar and suboptimal in Reunion and Mauritius. Over the seven different study areas of the SW Indian Ocean, 1,274 sightings of cetaceans were collected on effort including 17 different species or higher level taxa (Tables 2 and 3): *Balaenoptera acutorostrata/bonaerensis* (4 on-effort sightings), *Balaenoptera* spp. (17), *Physeter macrocephalus* (46), *Ziphius cavirostris* (33), *Mesoplodon densirostris* (4), *Indopacetus pacificus*. (3), unidentified Ziphiidae (25), *Globicephala macrorhynchus* (27), *Pseudorca crassidens* (54), *Globicephala* or *Pseudorca* (22), *Peponocephala electra* (75), *Feresa attenuata* (1), *Peponocephala or Feresa* (33), *Kogia* spp. (30), *Grampus griseus* (62), *Tursiops truncatus* (259), *Sousa chinensis* (9), *Tursiops* spp. or *Sousa* (213), *Lagenodelphis hosei* (1), *Stenella attenuata* (2), *Stenella longirostris* (16), *Stenella or Delphinus* spp. (205), unidentified delphinids (54), unidentified cetaceans (30). In addition to this, 8 sightings of the sirenian *Dugong dugon* were collected, as well as over 22,000 seabird and 830 turtle sightings (Table 2). Examination of raw data from one of the seven area plotted on a map suggest that in this case highest densities of cetacean sightings per unit effort would be in slope habitats (Figure 3, top right).

Table 3: Marine mammal species encountered during the surveys
(X: present; ?: unconfirmed)

Species	French Caribbean	French Guiana	SW Indian Ocean
Balaenoptera spp.	X	X	X
Balaenoptera musculus			?
Balaenoptera physalus		X	
Balaenoptera acutorostrata	X		?
Balaenoptera bonaerensis			?
Balaenoptera edeni			?
Megaptera novaeangliae	X		
Physeter macrocephalus	X	X	X
Orcinus orca	X		?
Ziphidae spp.		X	X
Mesoplodon densirostris			X
Indopacetus pacificus			X
Ziphius cavirostris	X	X	X
Kogia spp.	X		X
Globicephala macrorhynchus	X	X	X
Pseudorca crassidens	X	?	X
Peponocephala electra		?	X
Feresa attenuata		?	X
Grampus griseus		X	X
Tusiops truncatus	X	X	X
Sotalia guianensis		X	
Sousa chinensis			X
Steno bredanensis			?
Lagenodelphis hosei	X		X
Stenella attenuata			X
Stenella longirostris			X
Stenella spp./ Delphinus sp	X	X	X
Dugong dugon			X

Modeling top predator preferential habitats and areas of potential risks
This section briefly describes the first analyses carried out from the Caribbean data set (Figure 4) and is by no means the only and definitive analytical procedure to be applied uniformly to all regions in the project. As new data sets become available the effort in spatial analysis will develop and diversify.

Because no cetacean species was reported more than 9 times in this particular survey area, it was decided to conduct the spatial analysis for all cetacean pooled together as a first approach. This model represents a kind of 'average' cetacean habitat biased in favour of the few most frequently seen taxa (here: sperm whale, humpback whale, *Stenella spp.* and *Tursiops truncatus*) and will inevitably mask species specific habitat preferences. The most significant covariates explaining this 'average' cetacean distribution were 'distance to coast', 'slope', 'Chl *a* gradient', and 'distance to front' among all covariates available for this area; the resulting model explained 24% of total variance. The 'average' cetacean habitat appears to be mostly located over the slope, along the eastern side of the Caribbean archipelago (Figure 4, middle of top row). A similar exercise was done for other top predators (three seabird species) for which sufficient data were obtained, and these spatial models were combined into a single composite top predator model in which cetaceans and seabirds had equal weights. In this top predator model, the Atlantic slope remains an important habitats and waters closer to the islands reach fairly high values on the color scale as a result of incorporating seabird habitat preferences (Figure 4, bottom right corner). A similar approach allowed a activity model for human to be established with fishing boats and fishing gears (mainly net buoys); finally a model predicting areas of possible interactions was obtained (Figure 4: middle and left of bottom row respectively). The areas of higher risk appear to be located mostly in the immediate vicinity of the islands, suggesting a lower pressure on cetaceans in their core habitats, located further offshore on the Atlantic side.

Minimal abundance estimates
Different abundance estimates were made from the Caribbean and the Guiana data set (Table 4). In the French Caribbean, no one cetacean species provided sufficient data for using the Distance sampling methodology. Consequently, we attempted a strip transect estimate for all cetacean combined in order to produce a minimal order of magnitude of cetacean number in the area. We made no correction for availability or detection biases and as a consequence the estimate is negatively biased. Similarly, we made strip transect abundance estimates for 4 seabird taxa (brown terns, brown sulidae, tropic-birds and frigate-birds). Totals of 5,300 cetaceans and 15,400 seabirds were estimated in the surveyed area (Table 4).

In the Guiana survey area, sufficient data for Distance sampling methodology were obtained for the common bottlenose dolphin and the Guiana dolphin. Minimal estimates of 38,280 *T. truncatus* and 1,942 *S. guianensis* were found under the assumption of g(0)=1 (Table 4). Various strip-transect abundance estimates were also calculated for other taxa with large number of sightings (frigate-birds, terns, manta rays, shelled turtles).

Table 4: Abundance estimates for main species or groups. Figures are not corrected for availability and detection biases. On the basis of available knowledge on surface behavior of the different taxa, underestimation biases are likely to be the strongest for manta rays and turtles, intermediate for dolphins and the lowest for birds.

Region	Taxa		Density (ind.km^{-2})	Abundance	95% CI
French Caribbean	Cetaceans		0.043	5,300	2,600 – 8,200
	Marine birds		0.125	15,400	11,300 – 20,200
French Guiana	Cetaceans	*Tursiops truncatus*	0.2791 (CV=0.24)	38,280	22,914 – 63,952
		Sotalia guianensis	0.0439 (CV=0.37)	1,942	928 – 4,063
		Others	0.1116	7,025	3,220 – 15,515
	Marine birds	Frigate-bird	0.039	5,450	1,960 – 10,700
		"Grey" terns	0.199	27,500	13,700 – 44,750
		"Brown" terns	0.137	18,980	9,500 – 32,900
	Others	Manta rays	0.017	2,400	1,300 – 3,700
		Sea turtles	0.004	600	400 – 800

DISCUSSION AND PERSPECTIVES

General

The implementation of the REMMOA aerial surveys is still at its beginning with two spatially restricted surveys fully done and only partially analyzed in the tropical Atlantic (French Caribbean and Guiana) and one regional scale survey recently completed in the southwest Indian Ocean and still to be analyzed. Two regional scale surveys are still to be conducted in the south central and southwest Pacific Ocean in 2010-11 and 2011-12 respectively (Figure 5) and the eastern Caribbean/Guiana plateau region is planned to be surveyed regionally in 2012-13. Lessons drawn from the first steps are extremely useful for the continuation of the project.

Regarding the choice of the platform, aircrafts *versus* ships, the advantages and limitations of both types are well known. Vessels allow a higher proportion of sightings to be identified at species level; thank to their higher passenger capacity, they allow double platform methodology to be implemented and therefore the detection probability on track line to be estimated; finally, because of their much longer autonomy, logistic constraints on survey design are lower. Their drawbacks include the limited flexibility of utilization during survey period which generally precludes quick reaction to changing weather and sea conditions, hence resulting in a lower rate of platform usage in optimal detection conditions; ships generate positive and negative interaction biases with the survey target species (either cetaceans or birds) which imply species-specific analyses; because of limited steaming speed, several ships are needed to cover extended survey areas if sufficient spatial resolution is needed for modelling; finally cost and carbon print per unit effort (km surveyed in effort) are higher. For aircrafts, the higher flexibility of utilization allows an optimal rate of platform usage under good detection conditions; there is no evidence of survey target species reaction to survey platform (this may be different with a helicopter); extended areas can be surveyed in a limited amount of time; costs and carbon print are lower per unit effort flown (km surveyed in effort). Several limitations to surveying from the air are well known and include the heavier logistic constraints placed on survey design (aircrafts are ‘central-place’ survey platforms); higher number of sightings that cannot be identified to species; difficulty to implement the double platform methodology and hence to estimate detection probability on survey track.

In the case of the REMMOA survey series, cost related issues were key elements of the decision because of the vast geographical span of the project, which made a ship survey too expensive. Some of the aircraft-specific limitations can be mitigated. In particular, the proportion of sightings identified to species could be improved by using digital cameras fitted under the aircraft; the experimental deployment made in the Seychelles box will be analyzed in this perspective. Specific methodologies are available to estimate g(0) from an aircraft; they include special arrangement in the cabin for implementing the double platform methodology, tandem flights and the circle-back procedure. The next two surveys should incorporate dedicated experiments allowing detection probability to be estimated. Logistic constraints on survey design can be alleviated by technical responses such as the use of additional gas tanks allowing longer operational ranges. In this respect, observer tiredness is another aspect to be considered and the capacity to have one extra observer onboard is an advantage as it allows rotation of observers to be done within a flight and observation bouts not to exceed a given duration for any one observer.

Next steps

As mentioned earlier (Table 1), the South Pacific regions are planned to be surveyed during the years 2010-11 (French Polynesia; top of Figure 5) and 2011-12 (southwest Pacific Ocean around New Caledonia and Wallis and Futuna; bottom of Figure 5). The Polynesia survey alone (5,030,000 km²) would be of the same spatial extent as the southwest Indian Ocean survey. Since it is a massive single oceanic area belonging to the same eco-region, with a well defined latitudinal gradient of productivity from the Chl *a*. rich waters of Marquesas Islands in the North to the depleted waters of the Australes Islands in the South, extending this survey to adjacent waters is not a priority as the area in itself can be seen as a region. Nevertheless, if nearby countries (UK, NZ, Kiribati) would consider developing similar initiatives in their EEZs, combining effort, data sets and analyses would be recommended. The identification of areas within the region is underway and the definition of bathymetric strata and survey effort remain to be completed in consistency with the Atlantic and southwest Indian Ocean surveys.

In the southwest Pacific survey, the French EEZ (2,040,000 km²) is split into two sub-units: the large New Caledonia and Chesterfield bank area and the smaller Wallis and Futuna area that are located some 15° longitude apart. The two areas are surrounded by many other countries’ EEZs, with which they share some well identified eco-region, like the Coral Sea and the southeast Melanesia region. In this context, implementing this southwest Pacific survey regionally in collaboration with neighbouring countries would be highly relevant. Provisional areas to be surveyed are proposed (bottom of Figure 5), but are likely to be modified when the context of regional cooperation is set. Bathymetric strata are still to be defined in consistency with previous surveys.

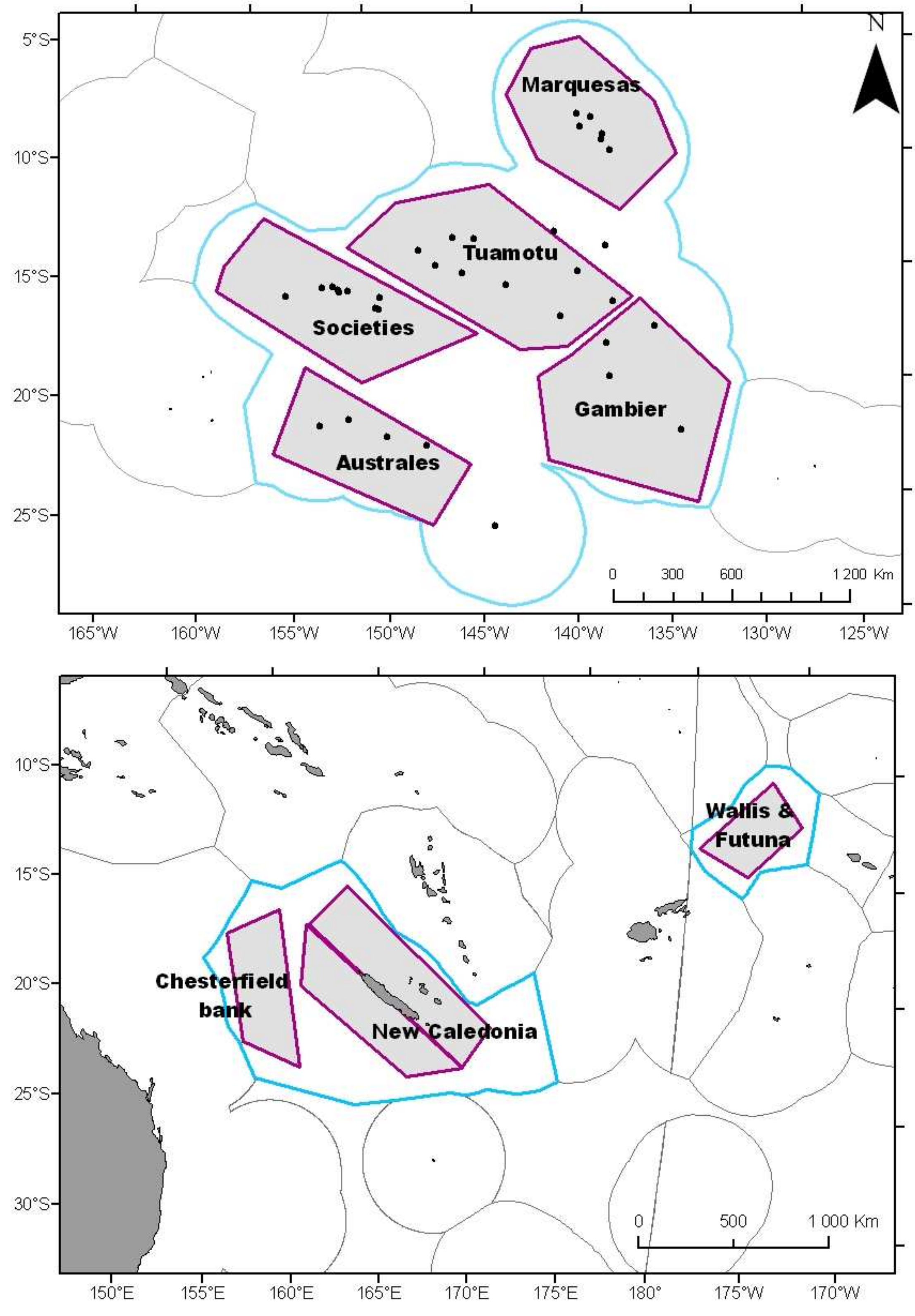

Figure 5: Provisional survey blocks planed for the French Polynesia EEZ (top) and New Caledonia and Wallis-Futuna EEZ (down).

Finally, it is planned to conduct in 2012-13 the Atlantic survey regionally for the same reasons as those prevailing in the southwest Indian and southwest Pacific oceans. This would provide a second snapshot view of the EEZs off Martinique, Guadeloupe and Guiana and the opportunity to better understand their relationships within their eco-regions, the Eastern Caribbean and the Guiana plateau/Amazon river plume respectively. Areas and bathymetric strata remain to be defined.

Perspectives

In the near future the immediate priority is to complete the first series of REMMOA surveys. Given the surface areas to be covered for these highly mobile pelagic organisms, a regional approach is highly recommended. Because of its large EEZ, French Polynesia can be considered as a region in itself; nonetheless exchange of information and possible synchronization of similar existing initiatives should be encouraged. In the southwest Pacific Ocean and the western tropical Atlantic, the French EEZ is fragmented and overlaps with several eco-regions that extend across many other countries' waters. Therefore a regional co-operation, similar to the one conducted in the southwest Indian Ocean under the framework of the Indian Ocean Commission, would be highly beneficial. To build the conditions for such co-operations, contacts have to be established with these countries and regional agreements identified to act as frameworks for these collaborations.

The long term objectives of the REMMOA surveys is to establish an initial situation of cetacean and other pelagic megafauna diversity and relative abundance and to build up a monitoring strategy to be implemented from this point onwards. When the series of surveys is completed in 2013, it is planned to hold a workshop that would examine the statistical properties of the complete data set and infer recommendations for monitoring strategies. In this exercise, expertise from the marine mammal, seabird and fish scientific communities would be most welcome and the outcomes of this work extremely useful for all stakeholders and managers in charge of monitoring cetaceans across the tropics.

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