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Progress report on the genetic and demographic assessment of dolphin taken in live-capture and traditional drive-hunt in the Solomon Islands

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SUMMARY
The Solomon Islands have a long history of exploiting dolphins through traditional drive-hunt. More, recently, the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*), a species not targeted by drive-hunters, has been subject of live-captured for the purpose of public display, with a current authorized quota of 50 dolphins exported per year. Since 2003, records show that 108 *T. aduncus* were exported overseas but the real number of dolphins effectively removed from the local populations is probably much larger given unaccounted deaths during capture and local captivity. A project was initiated in 2009, in collaboration with the Solomon Islands Government and the South Pacific Whale Research Consortium, to provide a biological assessment of the populations impacted by removals, in order to improve management and conservation of dolphins in the Solomon Islands. Here we report on the progress made on the investigation of *T. aduncus* population status and assessment of live-capture sustainability. From November 2009 to July 2011, we conducted three sets of boat surveys (n = 62) at four study sites in Solomon Islands, including the areas where all captures occurred so far, i.e. north Guadalcanal and, to a lesser extent, west Malaita. The other two sites were Florida Islands and south Santa Isabel. Nine species of marine mammals were encountered, including 45 groups of *T. aduncus*. The *T. aduncus* were always observed near shore (<2NM from coast) and in shallow waters (<100m deep). From 225 unique individuals identified using photo-identification, 46 were re-sighted between different years. All resightings but one were within one of the study sites, suggesting a high degree of site fidelity. Given the evidence for localised populations, abundance was estimated independently for each site using closed-population models. Total abundance estimates from closed-population capture recapture models suggest that each study site shelters a population in the low hundreds (about 100 to 300 individuals) but estimates were not precise for Malaita. Over the four sites, total abundance was about 700-1300 dolphins. Calculations of the Potential Biological Removal (PBR), used to set limits for anthropogenic removals under the US Marine Mammal Act, are low; one dolphin every five years for Guadalcanal and Florida Islands and one dolphin every two and a half years for Santa Isabel and Malaita. On the basis of the PBR, the authorized export quota of 50 dolphins/year is likely to be unsustainable and some populations (e.g., Guadalcanal) have likely been depleted since the beginning of live capture in 2003.

BACKGROUND AND INTRODUCTION

Despite a long history of traditional drive-hunting (Dawbin 1966, Takekawa 1996), little attention has been given to conservation or management of dolphins in the Solomon Islands until recently. The situation changed in 2003 with media coverage of the newly development of the live-capture dolphin trade focusing on Indo-Pacific bottlenose dolphins (*Tursiops aduncus*). Concern was expressed by major intergovernmental groups (CITES, CMS, IUCN, SPREP) about the potential conservation implications of dolphin removals in the Solomon Islands (Reeves & Brownell Jr. 2009) but to date, the only existing regulation is a quota of 50 dolphins exported overseas per year.

Indo-Pacific bottlenose dolphins are captured in the wild and held in captivity for the purpose of public display, most of the time after being sold and exported overseas. According to the Solomon Islands CITES Authorities, a total of 108 Indo-Pacific bottlenose dolphins were exported since 2003. However, the real number of dolphins removed is unclear and could be much larger when accounting for accidental deaths (during capture and captivity), deaths after release in the wild following a period of captivity and individuals currently held in Solomon Islands facilities (so not accounted by CITES). The Government of Solomon Islands currently permits up to 50 dolphins to be exported per year. However, based on the current state of knowledge of Indo-Pacific bottlenose dolphins throughout their range, international experts have suggested that this level of removal is unlikely to be sustainable (Reeves & Brownell Jr. 2009).

Following the IUCN meeting to discuss these concerns in Samoa in 2008, the South Pacific Whale Research Consortium (SPWRC) offered to develop an independant research project intended to provide the Solomon Islands Government with basic scientific knowledge to inform management decisions involving the removal of dolphins from their wild populations. The specific aims were: 1) to gain an improved understanding of the population status of *T. aduncus* in the Solomon Islands; 2) to contribute to a robust science-based assessment of the sustainability of current authorised level of live-capture removal; and 3) to determine the species of dolphins taken by traditional drive-hunts in the Solomon Islands as well as investigating the population status of these species using molecular tools. In this progress report, we present preliminary results on abundance estimate of *T. aduncus* populations subject to live capture and level of community structure of *T. aduncus* around the primary islands of Guadalcanal, Florida Islands, Santa Isabel and Malaita. With this information, we then calculate a Potential Biological Removal (PBR) as a tool for management of any future anthropogenic removals.

The project was initiated in 2009, in direct collaboration with the Solomon Islands Government, which provided the main source of technical and financial support. Further funding was provided to the SPWRC by the Pew Environment Group, a Pew Marine Conservation Fellowship (to CSB) and the IWC Small Cetacean Fund. Here, we focus on the progress made in the investigation of *T. aduncus* population status and assessment of the live-capture sustainability. These results were recently presented at a workshop held in Honiara, Solomon Islands, May 2012, hosted by the Solomon Islands Government and facilitated by the SEMRICC-UNDP. This workshop was the starting point for the development of a National Management Plan for dolphins in the Solomon Islands, which should be finalised before the end of the year. Molecular analyses on *T. aduncus* and samples from drive-hunted species are in progress. A final report including all findings will be made available before the end of 2012.

MATERIALS AND METHODS

Species identification – It was reported that dolphins exported from the Solomon Islands belong to the species *T. aduncus* based on external morphological characteristics (Ross et al. 2003). However, the taxonomy of *Tursiops* sp. is rather complex and still not fully resolved, in particular in the Indo-Pacific Region. To clarify the taxonomic status of exported dolphins, we conducted phylogenetic analyses (Neighbour-joining, maximum parsimony and maximum likelihood) with the program MEGA (Kumar et al. 2004), comparing the sequences of the mtDNA control region obtained from dolphins in captivity in the Solomon Islands to sequences published in GenBank and elsewhere from the two currently accepted species (*T. aduncus* and *T. truncatus*) and from the South-East Australia *Tursiops* population recently proposed as a new distinct species, *T. australis* (Charlton-Robb et al. 2011).

Boat surveys and data collection - From November 2009 to July 2011, three series of small-boat surveys were conducted over one month each. In total, we conducted 62 surveys: 19 in November 2009, 20 in November 2010 and 23 in July 2011. The effort was focus on four islands or group of islands of the eastern part of Solomon Islands: Santa Isabel, Malaita, Guadalcanal and the Florida Islands (Figure 1). The choice for this area was made on the basis that most dolphin removals, past and present, happened around or near these islands. In particular, captures of *T. aduncus* were made on the North Coast of Guadalcanal and on the West coast of Malaita. Effort was primarily concentrated in 'coastal habitat' (stretch of water extending from the coastline to 1 nautical mile (NM) offshore) because it is the preferred habitat of *T. aduncus* throughout its range (Wang & Yang 2009). However, substantial search effort was also made offshore, including multiple crossing between islands. We recorded the geographic positions of each group of marine mammals encountered. For each encounter, group size was estimated by visual counts, recording the minimum, maximum and best estimates. Dorsal fin photographs were taken of as many individuals as possible, regardless of distinctive marks or vicinity to the boat, using digital SLR cameras equipped with telezoom lens. Attempt was made to collect small skin biopsy samples with the Paxarms system© and lightweight biopsy darts (Krützen et al. 2002). Biopsies were only collected on individuals presumed to be mature. Samples were preserved in 70% ethanol and stored at -20°C for subsequent analyses.

T. aduncus photographs processing – Dorsal fin photographs of *T. aduncus* were graded for quality and distinctiveness using standard protocols (e.g., Oremus et al. 2007). Every individual showing distinctive mark(s) were compared to each other, searching for re-sightings. A catalogue of unique individuals was created and re-sighting events were classified as "within" or "between" islands and "within" or "between" years.

Individual movements and site fidelity - We used capture-recapture history based on photo-identification to investigate individual movements and site fidelity within the studied area. To provide a statistical assessment of site fidelity, inter-annual site fidelity was investigated using a maximum likelihood method assessing the probability, pt, that an individual observed in one particular area moves to another area between sampling periods, as implemented in the program SOCPROG (Whitehead 2009). These methods allow the number of identifications to be used as a measure of effort allowing the inclusion of all years with any individual identification (Whitehead 2001).

Population abundance estimates - Analyses of abundance estimates were performed for each study sites using four closed-population models from the program CAPTURE (as implemented in program MARK, White & Burnham 1999). These are: Mo, Mt Chao, Mh Chao and Mth. To obtain estimates of the total populations, CAPTURE's results were adjusted for the proportion of unmarked individuals estimated for each study site (Williams et al., 1993).

Assessment of sustainability - To evaluate sustainability or acceptability of removals, we choose to use the Potential Biological Removal (PBR) method, used to set limits for anthropogenic removals under the US Marine Mammal Act. This performance tested procedure explicitly takes into account uncertainty and potential biases in the available information (Wade 1998). For our calculations, maximum annual population growth rate (Rmax) was set of 0.04. For comparison, we used two values of recovery factor (Fr): 0.5, which is standard for unexploited populations, and 0.1, as recommended for very small or endangered populations (Wade 1998).

PRELIMINARY RESULTS

Species identity - A total of 15 sequences of the mtDNA control region were obtained from presumed Solomon Islands *T. aduncus* in captivity, revealing seven unique haplotypes. These haplotypes were aligned with haplotypes of *Tursiops* sp. from other regions of the Indo-Pacific (n = 145) after being truncated to a fragment of 290 base pairs available for all sequences. All phylogenetic reconstructions based on the consensus fragment show that sequences from captive dolphins in the Solomon Islands cluster with haplotypes of *T. aduncus* from the Indo-Pacific region, with ≥ 70% bootstrap support (Figure 3). *T. aduncus* from South Africa and *T. australis* form separate monophyletic clades while *T. truncatus* were paraphyletic.

Field effort and marine mammal encounters - Effort was broadly similar between the three series of boat surveys, for a total of 3848NM covered, including 2806NM of coastal effort and 1042NM of offshore effort (Figure 1). A total of 123 groups of marine mammals were encountered (Figure 2). These were represented by nine different species, including eight cetacean species and one sirenian (Table 1). Two species were encountered much more frequently than the others: spinner dolphin, *Stenella longirostris* (n = 55) and *T. aduncus* (n = 45), which were observed at each of the four study sites. *T. aduncus* were found in average group sizes of 10.6 dolphins (SD = 10.5), ranging from 1 to 60 individuals. They were often found in mixed aggregation with *S. longirostris* (n = 11). A total of 71 biopsy samples were collected from five species over the two years (32 in 2009, 32 in 2010 and 7 in 2011; Table 1). Most of these come from two species: *S. longirostris* (n = 39) and *S. attenuata* (n = 20). Unfortunately, we managed to collect only two biopsy samples of *T. aduncus* despite being the species with which we spent most time (38h 57min with *T. aduncus* compared to 24h 28min with *S. longirostris*).

Habitat use and seasonality – On average, *T. aduncus* groups were encountered at 0.39NM (SD = 0.26) from the coastline. In one occasion, out of 45 encounters, a group was observed more than 1NM offshore and it was only 1.5NM from coastline (Figure 2). The depth classes at which *T. aduncus* were encountered are distributed as follow: 5% at less than 10m; 26% between 10m and 20m; 53% between 20m and 50m; 16% between 50m and 100m; 0% at more than 100m.

To investigate a potential seasonal effect on the occurrence of *T. aduncus* in the Solomon Islands, we combined November 2009 and November 2010 data and ran comparative tests with data collected in July 2011. We found that there was no significant difference in the rates of group encounters (Kruskal-Wallis rank test $H = 0.259$, df = 1, p = 0.610) or the rates of individual encounters (Kruskal-Wallis rank test $H = 0.259$, df = 1, p = 0.610) between the two putative seasons.

Individual movements and site fidelity – A total of 293 individuals with distinctive marks on their dorsal fins were identified with good quality photographs. Matching of these 293 individuals revealed that 225 unique individuals are represented in the dataset and therefore, we found 68 re-sighting events. Twenty two re-sightings were found within years (Table 2); seven at Guadalcanal, two at Florida Islands, four at Santa Isabel and nine at Malaita. There is no within-year resighting between any of the different study sites. A total of 46 resightings events were found between years (Table 2). All of them are within the same study sites except one individual that was first observed in November 2009 around Florida Islands and was re-sighted in July 2011 on the North Coast of Guadalcanal. Likelihood analysis using SOCPROG shows high probabilities for individuals to be re-sighted at the same site each year for all our study locations ($pt > 0.7$). On the other hand, estimates of movement rates between study sites were all small ($pt < 0.05$). This is with the exception of a movement rate estimated at 0.14 from Guadalcanal to Florida Islands, a value that remains low in comparison to the probabilities of being re-sighted at the same site.

Population abundance estimates - Mh consistently provided the higher estimates of all models, while Mo and Mt resulted on the lowest estimates. Despite differences between models, we found that estimates for one site are largely consistent with one another, with the exception of Malaita (Table 3). Estimates for Malaita show very large CVs and wide CI in comparison to the other sites, indicating that estimates for that island are not precise.

After adjustment for the proportion of unmarked individuals (32% on average), we found that for Guadalcanal, Florida Islands and Santa Isabel, the total population sizes were in the low hundreds (~100 to 300), regardless of the model used (Table 3). In regards to Malaita, the Mt model suggest a population of similar size to that around Santa Isabel while the models Mo, Mh and Mth suggest that the population could be larger. However, as stated above, best estimates for that island should be interpreted cautiously. By summing the best estimates for each of the four study sites, it seems that the total population of *T. aduncus* in the study area probably numbers 700-1300 individuals.

Assessment of Potential Biological Removals - Values of PBR were calculated for each of the four study sites and overall using the abundance estimates and CVs obtained through the various models (Table 4). PBR values are very consistent for each of the study sites regardless of the model used to estimate population abundance. Using the conservative recovery value recommended for populations subjected to past exploitation or very small populations ($Fr = 0.1$), the PBR for Guadalcanal and Florida Islands was one dolphin every five years. For Santa Isabel and Malaita the PBR was one dolphin every two and a half years.

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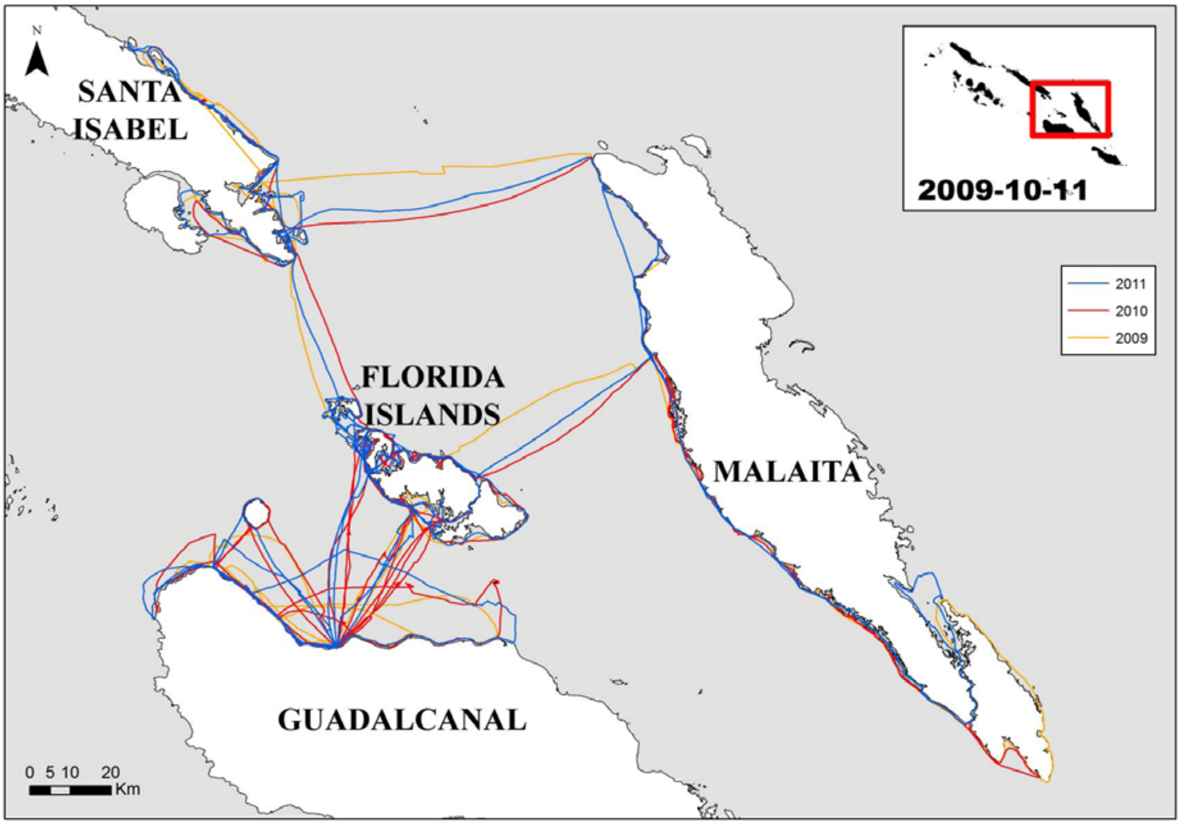

Figure 1: Map of the study area and boat tracks over the 3 years project

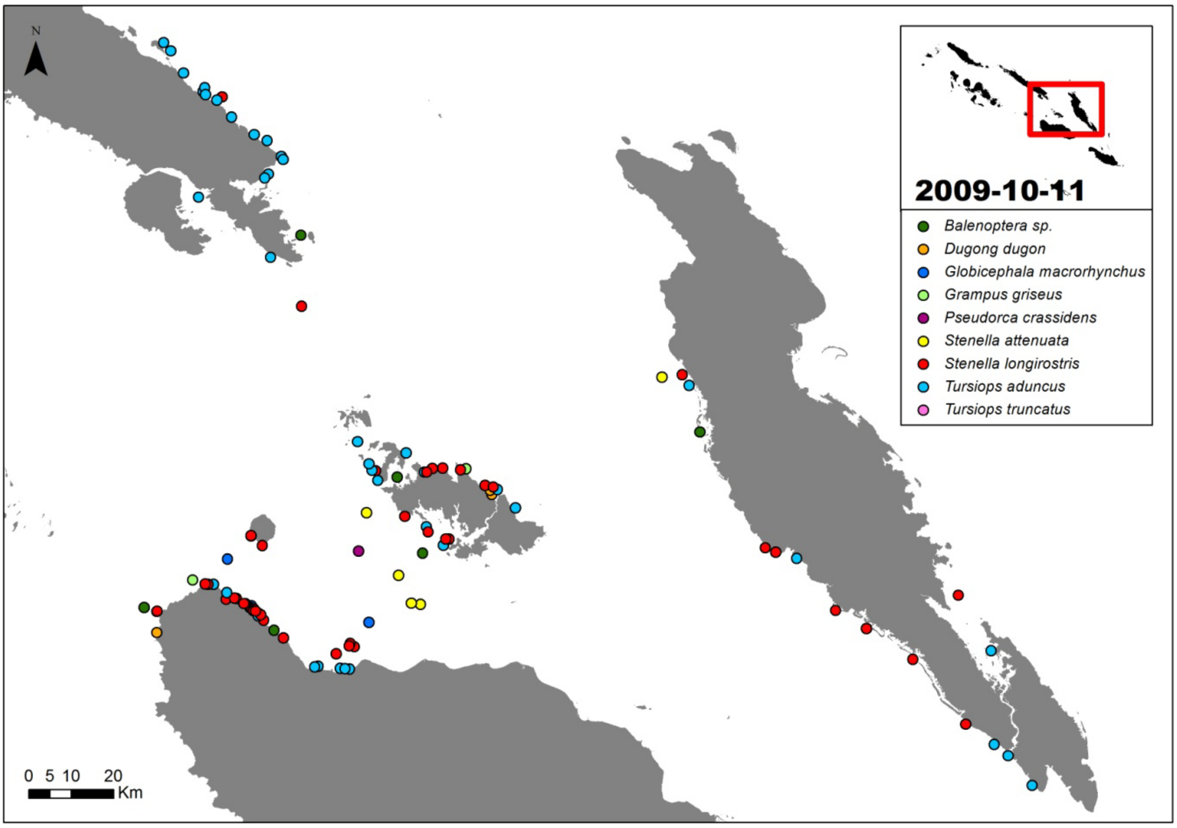

Figure 2: Geographic positions of marine mammal encounters

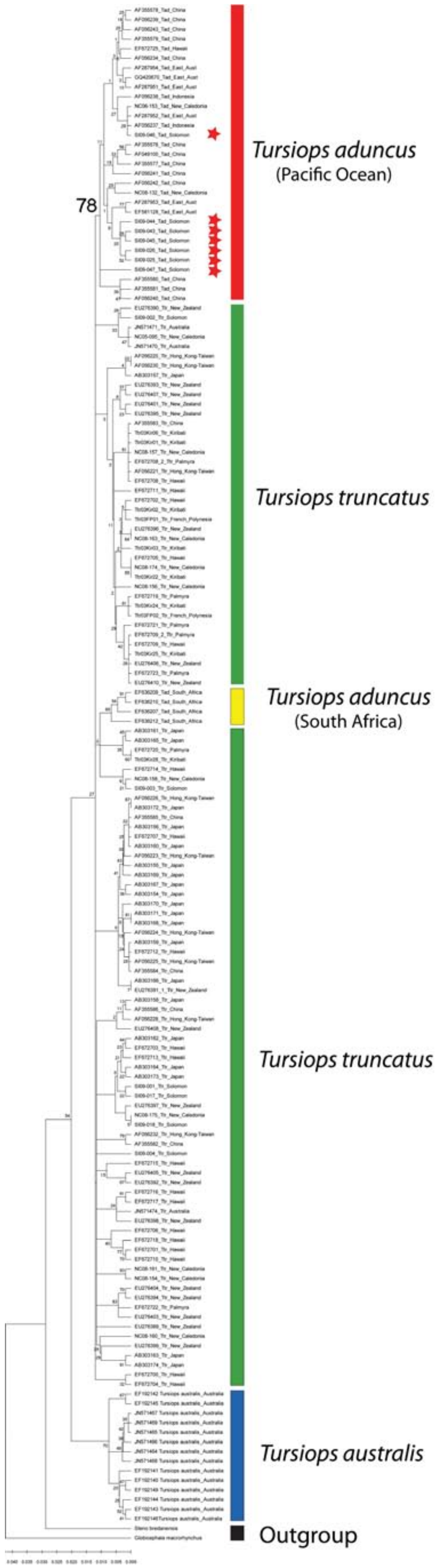

Figure 3: Phylogenetic relationships (neighbor-joining) among mtDNA haplotypes from captive dolphins in Solomon Islands (stars) and haplotypes from all species of *Tursiops* currently recognized.

Table 1: List of marine mammals encountered in the Solomon Islands across the study, including number of groups, number of biopsies and average group size.

Common name	**Latin name**	**# of groups encountered**			**# biopsies**	**Average group size**
		2009	**2010**	**2011**		
Indo-Pacific bottlenose dolphin	*Tursiops aduncus*	13	16	16	1	10.6 (SD = 10.5)
Spinner dolphin	*Stenella longirostris*	17	18	20	34	57.6 (SD = 58.7)
Baleen whale	*Balenoptera sp.*	1	2	3	0	1.2 (SD = 0.4)
Pantropical spotted dolphin	*Stenella attenuata*	1	3	1	19	87.5 (SD = 58.9)
Short-finned pilot whale	*Globicephala macrorhynchus*	2	1	0	3	36.7 (SD = 17.6)
Dugong	*Dugong dugon*	0	3	0	0	1.0 (SD = 0)
Common bottlenose dolphin	*Tursiops truncatus*	2	0	0	7	60.0 (SD = 14.1)
Risso's dolphin	*Grampus griseus*	1	1	0	0	4.0 (SD = 2.8)
False killer whale	*Pseudorca crassidens*	0	1	0	0	9
Unidentified sp.		0	0	2	-	-

Table 2: Summary of overall re-sighting history for *Tursiops aduncus* between November 2009, November 2010 and July 2011 (within year/between years)

	Guadalcanal	Florida Islands	Santa Isabel	Malaita	All
Guadalcanal	**7/6**	-	-	-	-
Florida Islands	0/1	**3/15**	-	-	-
Santa Isabel	0/0	0/0	**3/22**	-	-
Malaita	0/0	0/0	0/0	**8/3**	-
All	-	-	-	-	**22/46**

Table 3: Summary of total abundance estimates of *Tursiops aduncus*, after adjustments for the proportion of un-marked individuals, at the different study sites and overall using four closed-population models, including coefficient of variation (CV) and confidence interval (CI).

	Mo				Mt (Chao)				Mh (Chao)				Mth (Chao)			
	N	CV	95% CI low	95% CI high	**N**	CV	95% CI low	95% CI high	**N**	CV	95% CI low	95% CI high	**N**	CV	95% CI low	95% CI high
Guadalcanal	132	0,33	84	264	**98**	0.28	69	182	**162**	0.39	93	359	**126**	0.43	75	175
Florida Islands	131	0,20	102	198	**120**	0.18	95	177	**158**	0.25	111	271	**137**	0.35	92	309
Santa Isabel	252	0,16	197	352	**249**	0.18	191	361	**327**	0.22	232	510	**287**	0.31	187	567
Malaita	459	0,53	200	1263	**283**	0.44	148	685	**644**	0.58	256	1888	**570**	0.60	223	1751
SUM of ALL	973		582	2078	750	-	503	1405	1291	-	691	3027	1120	-	577	2802

Table 4: Summary of values for Potential Biological Removals (PBR) for *Tursiops aduncus* calculated for the different study sites and overall, depending on the model of population abundance and on two values of recovery factor (Fr= 0.1 or 0.5)

	Mo		Mt		Mh		Mth	
	PBR (Fr=0.1)	PBR (Fr=0.5)	**PBR (Fr=0.1)**	PBR (Fr=0.5)	**PBR (Fr=0.1)**	PBR (Fr=0.5)	**PBR (Fr=0.1)**	PBR (Fr=0.5)
Guadalcanal	**0.2**	1.0	**0.2**	0.8	**0.2**	1.2	**0.2**	0.9
Florida Islands	**0.2**	1.1	**0.2**	1.0	**0.3**	1.3	**0.2**	1.0
Santa Isabel	**0.4**	2.2	**0.4**	2.1	**0.5**	2.7	**0.4**	2.2
Malaita	**0.6**	3.0	**0.4**	2.0	**0.8**	4.1	**0.7**	3.6
SUM of ALL	**1.5**	7.3	**1.2**	5.9	**1.9**	9.3	**1.5**	7.7