Abundance of the Common Bottlenose Dolphin, *Tursiops truncatus* (Montagu, 1821) (Mammalia: Artiodactyla: Delphinidae) off the South and West Coasts of Puerto Rico[1]

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Abstract: The abundance of the common bottlenose dolphin, *Tursiops truncatus* (Montagu, 1821), was investigated by mark-recapture methods using photographic surveys on the south and west coasts of Puerto Rico from 2013 to 2015. The number of individuals having distinctive marks was 62, representing 46.5% of dolphins observed. Additionally, two dorsal fins were matched with photos taken during a study in 2000, making this the first report of long-term resightings in Puerto Rico. The abundance estimate for the south and west coast of Puerto Rico was of 127 dolphins. This represents a statistically significant, 60% decrease from the reported estimate back in 2001. It is unclear whether this decline is due to emigration, mortality, or a combination of the two. Management should prioritize further studies on the health of this population and the potential factors contributing to the decline, such as overfishing or excessive boat traffic.

Key Words: Common bottlenose dolphin, *Tursiops truncatus,* Puerto Rico, abundance

The common bottlenose dolphin, *Tursiops truncatus* (Montagu, 1821), is one of the most familiar and studied marine mammal species in the world (Figure 1, this paper; Jefferson et al. 2008). This species is found worldwide in tropical and temperate zones. The International Union for Conservation of Nature (IUCN) estimated a global population of 600,000 individuals (Hammond et al. 2012). In the Caribbean, bottlenose dolphins are considered the most common cetacean species (Ward et al. 2001). In Puerto Rico, bottlenose dolphin is the most abundant cetacean and the second most common marine mammal to strand on the Island (Mignucci-Giannoni et al. 1989, Mignucci-Giannoni et al. 1999).

For management purposes, dolphins in the US Caribbean are currently considered one stock separate from the Atlantic Ocean and Gulf of Mexico stocks, despite the lack of studies and data for such differentiation (Waring et al. 2011). True stock structure and population size of the bottlenose dolphin population of Puerto Rico are unknown both at large and small geographic scales. The current definition of stock structure is based on management need and not necessarily on available information.

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Figure 1. The common bottlenose dolphin, *Tursiops truncatus* (Montagu, 1821), one of the most familiar and studied marine mammal species in the world. Photo taken by Grisel Rodríguez-Ferrer on July 17, 2014 approximately 2 miles off Puerto Angelino, Cabo Rojo, Puerto Rico.

Two factors complicate our understanding of the local dolphin population. One is that there are two ecotypes of *Tursiops truncatus*. The distinction is based on morphology, but this is strongly supported by differences in DNA, hemoglobin, parasite loads, prey preferences, morphology, and distribution (Hersh and Duffield 1990, Mead and Potter 1995, Hoelzel et al. 1998, Segura et al. 2006). The coastal ecotype is found mainly in rivers, channels, waterways, estuaries, and on continental/insular shelfs and shelf breaks (Mead and Potter 1995), while the offshore or pelagic ecotype is found in zones close to oceanic islands, or offshore (Hersh and Duffield 1990). Despite the evidence supporting the existence of these two ecotypes, distinguishing them in the field is not straightforward, and this has hindered assessment efforts. In Puerto Rico, recent analysis of mitochondrial DNA from stranded bottlenose dolphins revealed the presence of both the inshore ecotype and a worldwide-distributed form comparable to the offshore or pelagic ecotype (Caballero et al. 2011). Yet, survey data to date indicate that within the platform–shelf edge environment only the inshore variety is present (Rodríguez-Ferrer 2001). The second factor is our understanding of the residency patterns of dolphins, as this directly affects the spatial scale of the population and thus, population size. A few long-term studies have noted site fidelity and small group size over the region (Grigg and Markowitz 1997 and Kerr et al. 2005 - Belize, Fearnbach et al. 2012 – Bahamas). Other short-term studies have also noted site fidelity and residency patterns (Whaley et al. 2006 - Dominican Republic; Rodríguez-Ferrer 2001 - Puerto Rico). Combined, these studies suggest that dolphins within Puerto Rico consist solely of the coastal ecotype and that they are limited in their movements, at least over the short-term relative to life span, such that populations are structured at a local scale relative to important ecological and population processes.

The purpose of this study is to assess the bottlenose dolphin population in the west and southwest coasts of Puerto Rico by using photo identification of dorsal fins as a tool for mark and recapture. Mark-recapture techniques allow not only for an estimate of population abundance, they also provide information on movements that can be used to determine if the bottlenose dolphins in this area are a subset of a larger, mobile population, or if there is local spatial structure and a smaller local population.

This distinction has important management implications. Understanding population size is one of the most crucial factors for assessing population health and vulnerability. A low population size can make a species vulnerable to threats affecting individuals directly or indirectly through impacts on its preferred environment (Bejder et al. 2006, Tezanos-Pinto et al. 2009). Anthropogenic effects such as pollution, fisheries, increased coastal development, habitat depletion, and human interactions could be detrimental on survival and population persistence. For this reason, one of the focal points of the US Marine Mammal Protection Act of 1972, which covers the US Caribbean, is to "prevent marine mammal species and population stocks from declining beyond the point where they ceased to be significant functioning elements of the ecosystems of which they are a part". This threat is real. Bottlenose dolphins are the second most frequently stranded marine mammal in Puerto Rico (Mignucci-Giannoni 1989, Mignucci-Giannoni et al. 1999), with human interactions directly implicated in some of these strandings. Additionally, the southwest area of Puerto Rico is the most important fisheries zone due to its extended insular shelf (Tonioli and Agar 2011), yet landings have steadily decreased from overfishing (Matos-Caraballo 2002). Such a decline in the fish supply could impact the bottlenose dolphin population and potentially increase dolphin-gear interactions. Other potential stressors of marine nearshore communities are coastal development and recreational activities, which have increased throughout Puerto Rico, especially on the west coast (Díaz and Hevia 2011). While there are no direct data on the effects of these activities (e.g., increased sedimentation, turbidity caused by terrestrial run-off, increased recreational boating) on the marine mammal species of Puerto Rico, the resulting decrease in resource availability could be having negative impacts.

In the only study to date in Puerto Rico, Rodríguez-Ferrer (2001) reported a population size of 314 individuals for the southwest insular shelf. That estimate was based on a line transect survey of the area, but included dorsal fin photographs for identification purposes. The resulting resighting rate in that study led Rodríguez-Ferrer (2001) to conclude that the dolphins could be moving over a broader distribution, such that true population size was larger. Using this previous study as a baseline, the present survey seeks to update the estimate of population size while revisiting the assumptions regarding movement and spatial distribution.

Methods

Study area

The study area covers the waters off the southwest coast of Puerto Rico from Aguada in the north to Punta Ballenas, Guánica in the south (Figure 2). The area is composed of broad and shallow insular shelf on the west coast that extends seawards up to 26 km and between 10 to 20 m deep (Schlee et al. 1999, Ballantine et al. 2008). The coast is characterized by low-wave energy conditions, and two major rivers, the Añasco and Guanajibo (Schlee et al. 1999), discharge in the area.

Also included is Bajo de Sico, an isolated seamount off the shelf about 25 km west of Puerto Rico (Armstrong and Singh 2012).

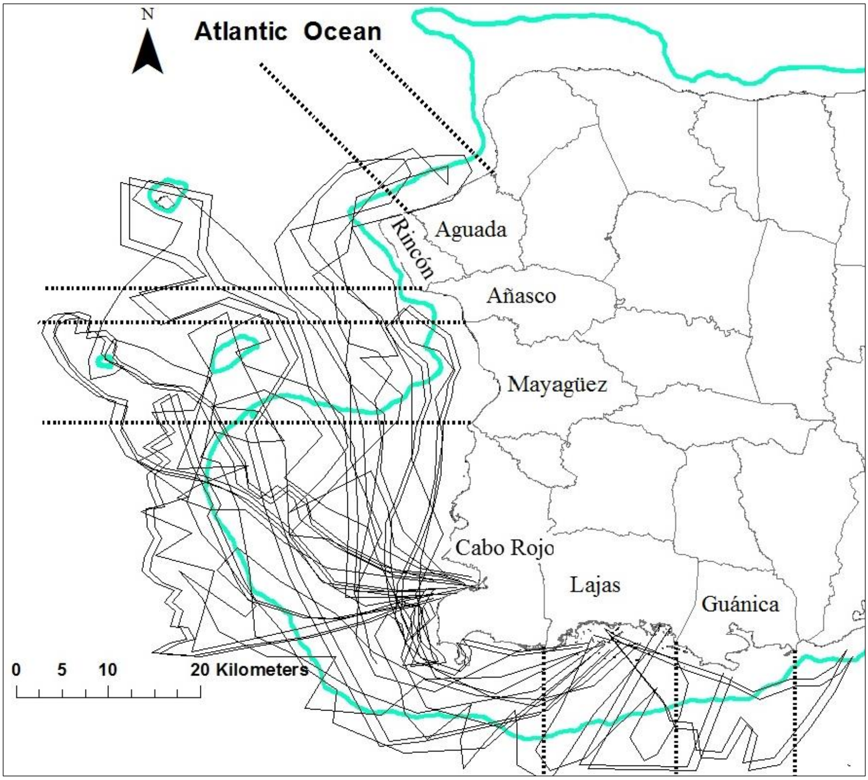

Figure 2. Survey areas off the west and south coasts of Puerto Rico. Black lines are the survey tracks for bottlenose dolphins sampled in 2013-2015. Blue (paler) line represents the 100-m isobath. Dotted lines represent the survey areas divided by municipality.

Along the south coast the area is characterized by a narrower insular shelf that tapers eastwardly. Off La Parguera, municipality of Lajas, the shelf extends from 6 to 10 km in width with an average depth of 18 to 20 m, but off Guánica it narrows to only 3 to 4 km width and an average depth of 12 m (Morelock et al. 1994). This zone is characterized by a series of small mangrove cays that extend over the south coast, interrupted by Guánica Bay.

Survey

Boat-based dolphin surveys were conducted in the study area from January 2013 to October 2015 in an open 7-m boat, offering a 360º field of view. Survey speed while searching was 10 knots (20 km/hr.) (Rosel et al. 2011). The survey team included the boat captain, a photographer, data recorder, and an additional observer or dolphin spotter. The area covered was recorded using the tracking mode of a handheld GPS (Global Positioning System). All surveys were conducted at a Beaufort Sea State scale of 3 or less, the equivalent of a wave height 0.9 m or less, to ensure that encounter rate was unaffected by poor visibility. On-going surveys were terminated if the sea state increased above Beaufort 3.

The following information was recorded for each dolphin sighting: 1) time of first sighting and position of the animal were recorded using a GPS unit, 2) weather conditions (i.e., cloud cover, sea state, approximate wind speed and direction) were recorded and depth determined with the boat's depth finder.

Group characteristics were also recorded: number of individuals, group composition (e.g., *all adults* = a group composed of individuals greater than about 250 cm in length, *all juveniles* = all individuals were less than 250 cm, *mixed group* = a group composed of several age classes including calves and neonates, *mom and calf pairs* = female and calf (Figure 3), *mixed species* = two distinct species clearly interacting (swimming together, social behavior) during the sighting. Also, the direction of travel was recorded when the group was first sighted.

Figure 3. A *Tursiops truncatus* mom and calf pair swimming by *Sargassum* sp. brown algae. The calf has a *Remora remora* (Linnaeus, 1758) on the right side anterior to dorsal fin. Photo taken by Grisel Rodríguez-Ferrer on June 19, 2015, Mayagüez Bay, Puerto Rico.

A group was defined as all dolphins sighted within a 100-m radius of its estimated center and that were engaged in similar activities (= school, Wells et al. 1987, Quintana-Risso and Wells 2001, Zoolman 2002). An "offshore" Tursiops was defined as an animal with dark gray coloration, adults approximately 290 cm, small flippers, and small beak, whereas a "nearshore/coastal" Tursiops was defined as an animal with light gray coloration, adults no larger than 260 cm, long beak and large flippers (Mead and Potter 1995, Wells and Scott 2002). Dolphin age categories were defined following guidelines established in Shane (1990) and Wells et al. (1987). A juvenile was defined as any individual approximately ≤ 2 m long that swam independent of the adult; calves were defined as individuals two-thirds or less the length of an adult and swimming alongside or slightly behind the adult, while a neonate was characterized by the presence of fetal folds (stripes on the sides of a new born dolphin that last a couple of weeks after birth) and a charcoal coloring with an uncoordinated surfacing pattern. Group behavior was recorded when first sighted, during the sighting and at the end of the sighting. Behaviors were classified according to Melancon et al.'s (2011) behavioral categories for bottlenose dolphins. The behavior categories used were *travel* = directional movement; *social behavior* = when animals have bodily contact including sexual interactions, chasing one another and fighting; *probable feeding* = some indications of feeding behavior (repeated dives, variable movement); *feeding* = fish in mouth is observed; *other* = any activity not described, such as interactions with the research boat, e.g., bow riding, boat avoidance, interactions with other boats, etc. These were then described on the sighting log.

In addition, photographs of the dolphin dorsal fins were taken using a Nikon D 7100 with a 300-mm lens. During the sightings, effort was focused on photographing all the individuals within the group. Four conditions were used to end a sighting: a) all the dolphins were photographed by a single, experienced dolphin photographer (GRF), b) the group was lost, c) sighting time surpassed 30 mins or d) dolphins were clearly avoiding the boat (Melancon et al. 2011). All research activities described in this manuscript are under the auspices of U.S. National Marine Fisheries Service Permit No. 14450-04, and Puerto Rico Department of Natural and Environmental Resources Permit number DRN-2015-I-C32.

Photoidentification of dolphins

The photographs were used to identify dolphins based on the location, size and patterns of notches on the dorsal fin (Wells and Scott 1990, Würsig and Jefferson 1990). Photographs of both sides of the fins, peduncle and tail, when possible, were taken to identify scars, notches and any other unique natural markings that helped identify individuals. Notches and or permanent scars were used as the primary distinctive elements for photoidentification (Figure 4, Gnone et al. 2011). These photographs were catalogued using the software application FinBase (Adams et al. 2006). Images were sorted and processed for photographic quality. This was based on the degree to which the fin was in focus (excellent, moderate or poor), contrast (ideal or excessive/minimal), angle of the dorsal fin relative to the camera (perpendicular, slight angle or oblique angle), if the whole fin was visible and the estimated distance of the camera to the dorsal fin (Melancon et al 2011). Each of the factors affecting the quality of the image was ranked from 1 (good) to 3 (poor) and a composite score was calculated by adding across all five factors. To be entered into the catalog, a dolphin had to have a photograph with a score of 12 or less. For each dolphin, the photograph with the lowest score was used.

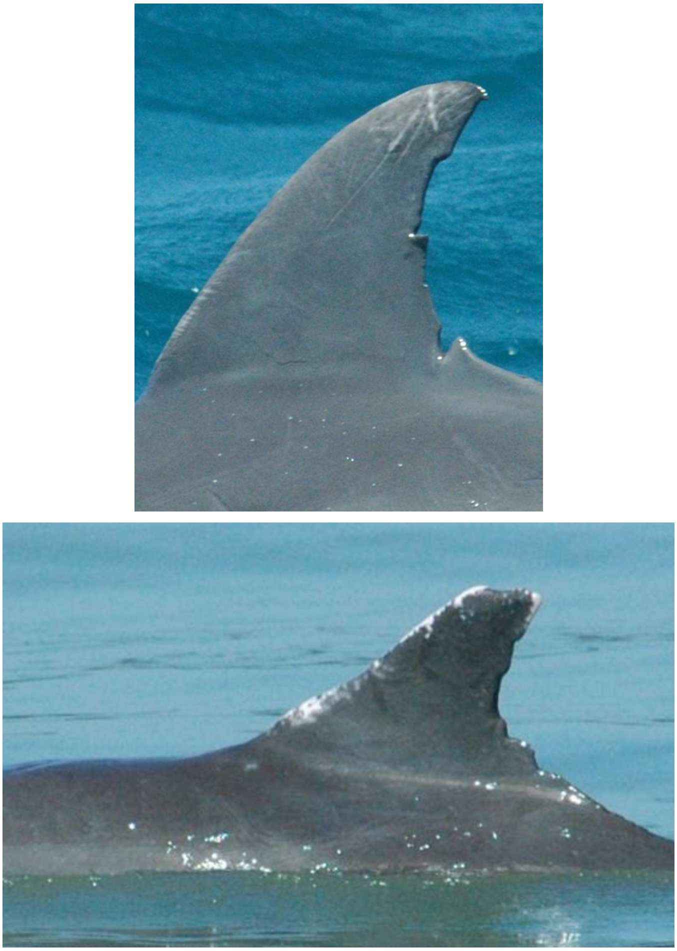

Figure 4. Dorsal fin of two *T. truncatus* showing diagnostic shape, color, and notches that enable researchers to identify individual dolphins. A. Specimen 7010, unknown sex. B. Specimen 1001, unknown sex. Images by Grisel Rodríguez-Ferrer on July 17, 2015 (7010), May 20, 2014 (1001).

The proportion of distinct individuals to all individuals was calculated separately for each sighting. These proportions were based on the catalogued photographs. The overall proportion for the entire population was taken as the mean across all sightings. This was then used as the proportion of marked dolphins in the population (see below).

Following the recommendations of Urian et al. (2015), only individuals with distinctive fin notches and or permanent scarring were considered for the estimation of population size. Dorsal fin photographs were also compared with those from the southwest coast taken in 1999-2001, available in the Puerto Rico Bottlenose Dolphin Catalog (Rodríguez-Ferrer 2001).

Population Estimation

The population size of dolphins in southwest Puerto Rico was estimated by the mark and recapture method (Würsig and Jefferson 1990, Gormely et al. 2005, Speakman 2010). In this project, a marked individual was defined as a dolphin photographed with an identifiable dorsal fin. Sampling was broken into periods to be able to meet Jolly-Seber assumptions. The sampling was characterized by short sampling periods (1-56 days) relative to longer periods between sampling periods (68-139 days) (Table 1).

The CloseTest program was used to test if the data were coming from a closed or open population. A closed population assumes no individuals were added to or lost from the population over the mark-recapture period (Stanley and Richards 2004). This program uses two closure tests; the Stanley and Burnham (1999), which allows time specific variations in capture probabilities, and the Otis et al. (1978), which allows for heterogeneity in capture probabilities.

The program MARK (White and Burnham, 1999) was used to estimate population abundance, employing the POPAN module of the Jolly-Seber formulation (Schwarz and Arnason 2006) for open-populations. POPAN estimates the parameter N (super population), which is the total number of animals available for capture at any time in a study, i.e., the total number of animals ever in the sample area between the first and last sampling occasion (Nichols et al. 2000). Other parameters estimated are net births (B) = number of animals that enter the population between two sampling periods and survive to the next occasion, apparent survival rate (φ) between sampling periods, where permanent emigration is treated as mortality, probability of capture (P) within each sampling period, and the probability (b) that an animal from the super population enters the subpopulation, where subpopulation refers to the animals in the study area. Separate models were constructed making these parameters either vary with time ($_t$) (time dependence) or leaving the parameters constant. This estimate by POPAN gives a gross population size. The total population size (N) was obtained by dividing the gross population estimate obtained using POPAN (Ň) by the proportion of identifiable dolphins (Θ), that is N = Ň / Θ (Williams et. al. 1993).

Table 1. Summary of surveys, sightings, marks and recaptures and sampling periods for surveys of bottlenose dolphin, *Tursiops truncatus*, in Puerto Rico. A marked dolphin is a photographed dolphin that has a distinctive dorsal fin, and unmarked dolphin is a photographed dolphin that the fin is not distinctive and will be hard to recognize. Group size field estimates including presence of calves and or neonates are presented.

Date	Survey Area	Num. Sightings	Num. Dolphins	Num. Calves	Num. Neonates	Dolphins Marked	Dolphins Unmarked	Resights
1/23/2013	Guánica	0	0	0	0	0	0	0
2/7/2013	Guánica	1	2	1	0	1	1	0
2/8/2013	Cabo Rojo	1	2	1	0	0	0	0
2/15/2013	Guánica	0	0	0	0	0	0	0
2/28/2013	Cabo Rojo	1	2	0	0	0	0	0
3/1/2013	Lajas	1	0	0	0	0	0	0
3/14/2013	Lajas	1	0	0	0	0	0	0
11/21/2013	Guanica	1	8	2	2	2	1	0
1/3/2014	Bajo Sico	1	15	2	0	7	8	0
1/24/2014	Bajo Sico	1	3	0	0	0	0	0
5/22/2014	Cabo Rojo	1	8	0	0	5	3	0
5/23/2014	Mayagüez	1	2	0	0	0	2	0
6/13/2014	Guánica	3	33	4	0	18	4	0
6/18/2014	Cabo Rojo	0	0	0	0	0	0	0
6/19/2014	Cabo Rojo	0	0	0	0	0	0	0
7/8/2014	Guánica	0	0	0	0	0	0	0

Table 1. Summary of surveys, sightings, marks and recaptures and sampling periods for surveys of bottlenose dolphin, *Tursiops truncatus*, in Puerto Rico (continuation).

7/17/2014	Lajas	1	13	0	0	12	9	6
7/23/2014	Lajas	0	0	0	0	0	0	0
8/1/2014	Guanica	0	0	0	0	0	0	0
9/10/2014	Lajas	0	0	0	0	0	0	0
9/11/2014	Lajas	0	0	0	0	0	0	0
10/2/2014	Guánica	0	0	0	0	0	0	0
10/3/2014	Lajas	0	0	0	0	0	0	0
10/8/2014	Cabo Rojo	0	0	0	0	0	0	0
10/10/2014	Lajas	1	4	0	0	0	2	0
10/16/2014	Lajas	1	2	0	1	1	1	0
10/30/2014	Lajas	0	0	0	0	0	0	0
10/31/2014	Guayanilla	1	3	1	0	1	2	0
1/23/2015	Cabo Rojo	1	2	1	0	0	0	0
2/27/2015	Lajas	0	0	0	0	0	0	0
3/12/2015	Cabo Rojo	1	20	1	0	13	4	7
3/13/2015	Cabo Rojo	1	6	1	0	2	3	1
5/20/2015	Cabo Rojo	1	15	1	0	12	4	7
5/21/2015	Cabo Rojo	1	1	0	0	0	1	0

Table 1. Summary of surveys, sightings, marks and recaptures and sampling periods for surveys of bottlenose dolphin, *Tursiops truncatus*, in Puerto Rico (continuation).

5/27/2015	Lajas	0	0	0	0	0	0	0
5/28/2015	Lajas	0	0	0	0	0	0	0
5/29/2015	Cabo Rojo	1	7	1	0	7	4	7
6/2/2015	Guánica	0	0	0	0	0	0	0
6/3/2015	Cabo Rojo	1	3	1	0	1	0	0
6/19/2015	Rincón	1	3	1	0	0	0	0
6/24/2015	Guánica	1	4	0	0	0	3	0
7/10/2015	Mayagüez	0	0	0	0	0	0	0
7/23/2015	Mayagüez	0	0	0	0	0	0	0
8/6/2015	Mayagüez	0	0	0	0	0	0	0
9/16/2015	Rincón	0	0	0	0	0	0	0
9/17/2015	Mayagüez	2	30	3	0	7	5	2
9/18/2015	Guanica	0	0	0	0	0	0	0
9/25/2015	Cabo Rojo	0	0	0	0	0	0	0
9/24/2015	Cabo Rojo	0	0	0	0	0	0	0
10/2/2015	Lajas	0	0	0	0	0	0	0
10/14/2015	Aguada	1	10	1	0	4	6	0
Totals		**34**	**198**	**22**	**3**	**93**	**63**	**30**

The program MARK uses Maximum Likelihood models to estimate population parameters (Cooch and White 2006). The models were ranked using the Akaike Information Criterion (AIC) (Burnham and Anderson, 2002) as implemented within MARK (White and Burnham, 1999). We used the Goodness of Fit test (Test 2 and Test 3) run in the program U-Care (Choquet et al. 2005) to evaluate potential violations to the Jolly-Seber assumptions. TEST 2 evaluates heterogeneity in the data, with Test 2CT evaluating if animals were photo happy or photo shy, and Test 2CL examining if this potential effect lasts more than one interval. TEST 3 evaluates the probability of survival, with Test 3SR assessing if there is an effect of capture on resighting (transience), and Test 3SM examining if there is an effect of capture on survival.

Results

Field Effort

Fifty photographic surveys were completed during January 2013 to October 2015 for a total effort of 217 hours (time searching for dolphins). Consistency of mid-morning/afternoon trade winds made surveys possible only early in the morning. Surveys covered the whole of the shelf totaling a distance traveled of 4,417 km across all surveys. The average distance per survey day was 88.34 km. (Figure 1). The distribution by area is given in Table 1. Survey areas were assigned to adjacent municipalities (Figure 1). The Cabo Rojo area, which contained most of the southwest insular platform, was the zone most visited, with 15 trips; these surveys included an inshore or coastal portion and an offshore portion. Sightings were obtained on 20 (39%) of the 51 surveys. During these 20 surveys, a total of 26 sightings were recorded (mean = 0.12 sightings/hr). Sightings per day ranged from 1-3 (1.13 ± 0.68). A total of 186 dolphins was observed during the 26 sightings.

Abundance Capture/Recapture

Sixty-two dolphins with distinct dorsal fins were observed and catalogued during the survey period between 2013 and 2015. The estimated number of dolphins with non-distinct dorsal fins (i.e., unidentified) was 65. Thus, the proportion of marked individuals was 0.465 (SD = 0.315).

Of those 62 dolphins with distinctive fins, the overall recapture rate was 50%, including multiple recaptures of individuals within and across time periods. For the Jolly-Seber analysis, the respective recaptures were as follows: 66.1 % (n = 41) were only sighted once (i.e., the initial capture event), while 22.6% (n = 14) were resighted once, 6.5% resighted twice (n = 4), and 4.8% three times (n = 3). Additionally, there were two dolphin fins that matched with the 1999-2000 Bottlenose Dolphin Photo Identification Catalog (Rodríguez-Ferrer 2001). Including these, the number of days between first and last sighting ranged from 5 to 5,935 days (mean = 900.3 ±1,248.7). Table 2 shows the marked dolphins and the years they were sighted.

Table 2. Marked and recapture history of individual bottlenose dolphins off of southwest Puerto Rico. Data prior to 2013 are from the Puerto Rico Dolphin Survey 1999-2000 Photo Identification Catalog and from opportunistic surveys from 2003-2010.

ID	Number of sightings	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2013	2014	2015
1000***	3							2							1	
1001	3	1						1		1						
1002	2	1							1							
2002	1								1							
2003	1												1			
2004	1														1	
2005	4														3	1
2006	6														3	3
2007	4														3	1
2009***	2	1														1
3002	1												1			
3003	4													1	1	2
3005	3														1	2
3006	4															4
5000	2						1								1	
5003	1	1														
6000	2						1	1								
6001	1							1								
6002	1							1								
6005	1												1			

Table 2. Marked and recapture history of individual bottlenose dolphins off of southwest Puerto Rico (continuation).

6006	1				1	
6008	6				3	3
6009	1				1	
7003	3	1		1	1	
7004	1	1				
7005	2	1	1			
7008	1				1	
7009	1				1	
7010*	8				4	4
7011	2				1	1
7012	1				1	
7013*	8				4	4
7014	3				3	
7015	1				1	
7016	6				3	3
7017**	10				6	4
7018	3				2	1
7019	2				1	1
7021	1				1	
7022	1				1	
7023	1				1	
7024	1				1	

* = dolphins always sighted together, ** = dolphins with the most sightings, *** = dolphins with the longest time betwee first and last sightings.

Dolphin No. 2009, sighted July 30, 1999 and resighted after 16.3 years on October 14, 2015, represents the longest period between sightings. The second longest period between sightings was 8.9 years (dolphin 1000, sighted March 3, 2005; resighted January 3, 2014.

The CloseTest analysis determined that the population was opened (z-value = -0.99817, p-value = 0.159, $p < 0.05$, $\alpha = 0.05$). The POPAN model of Jolly-Seber for open populations successfully fit the data, with survival (phi) and population size (N) varying through time and with probabilities of capture and entrance constant [phi (t), p (.), pent (.), N (t)] being selected using the AIC evaluation (Table 3).

For analysis purposes, sampling periods were divided into approximate three-month intervals, except for 2013 (Table 1, Appendixes 1-2). This was the year with the least field work, and all samplings for that year then were combined in a single four-month period. A sampling day is considered a day wherein dolphins were sighted and positively marked (new or resighting) by photographs. Jolly-Seber analysis showed that the influx of new individuals with distinctive, identifiable fins was essentially zero. Thus, the study effectively monitored a fixed initial population of marked individuals over the study period. That no new individuals entered the identifiable dolphin population, despite evidence of juveniles and neonates (Table 1), raises the question as to whether the ratio of identifiable to non-identifiable dolphins within the population changed during the study. Consequently, the population size reported here is restricted to that of the initial population estimate. The estimate of N (super population) is 58.8 (SE = 6.42, 95% confidence interval, or CI = 51.4-79.0 dolphins). The corresponding estimate for the distinctive individuals was 59 (SE = 6.42, 95% CI = 47.5-72.8). Taking the 46.5% photographed individuals with distinctive fins into account, the best estimate of population size (N) for the bottlenose dolphin in the study area is 127 individuals.

The Global test result for the Goodness of Fit statistic (Program U-Care) indicated that there is no significant overdispersion in the data. The test for transience (Test 3 SR) was not significant [N (0, 1) z = 0.76, *p*-value (two-sided) = 0.445], indicating that there is no difference in the probability of the animals being reencounter. Test 2 CT indicates that the animals are neither camera shy nor camera happy [N (0, 1) z = 0.85, *p*-value (two-sided) = 0.393]. The test 2CL was also not significant ($X^2 = 2.3427^{-30}$, df = 1 *p*-value = 1), an expected result given there was no initial photo effect detected.

Table 3. Open population models for abundance for marked bottlenose dolphins, *Tursiops truncates*, on the Southwest coast of Puerto Rico: N (super population) = the total number of animals available for capture at any time in a study, or as the total number of animals ever in the sample area between the first and last sampling occasion, pent= probability of entrance, phi = apparent survival rate, p = probability of capture, (.) = constant parameter, (t) = time varying parameter. AIC = Akaine Information Criterion.

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par	Deviance
{Phi(t) p(t) pent(.) N(.)	170.3957	170.3957	0	0	10	-62.5847
{Phi(.) p(.) pent(.) N(.)	227.5423	227.5423	0	0	4	9.3831
{Phi(t) p(.) pent(.) N(t)	46855.76	46855.76	0	0	7	46630.517
{Phi(t) p(.) pent(t) N(t)	46859.489	46859.489	0	0	10	46626.508
{Phi(t) p(t) pent(t) N(.)	46863.396	46863.396	0	0	13	46621.929
{Phi(.) p(.) pent(t) N(.)	46866.695	46866.695	0	0	7	46641.452

Discussion

We took several steps to validate Jolly-Seber assumptions. The Jolly-Seber assumption of equal capture probabilities (complete mixing) was addressed by having a high sampling effort spread out over the whole study area. In addition, complete mixing was supported by movements documented by the mark-recapture histories of individual dolphins (e.g., Table 1, Figure 2); during the study dolphins were found to move over broad areas multiple times (e.g., Figure 2, dolphin 7011 is an example moving from Rincon into one of the more heavily surveyed areas south). To validate mark recognition, only superior quality images were used, and only of animals with long lasting marks; any fins not distinctive enough were counted as unmarked. Sampling was done on a regular basis over the three-year period to be able to detect any dramatic changes on fin shape or new scarring. We used two experienced persons to catalogue and validate fins, thus controlling for observer error and providing consistency to the analysis. Photo identification is a non-invasive method that reduces the probability of an adverse behavioral response to sampling; therefore, there is no behavioral response to "marking" that would violate the assumptions of equal behavior and probability of capture, and this was supported by the results of Tests 2CT, 2CL and 3SR. The resulting capture probability was relatively high for mark-recapture studies of open populations. A high probability of capture suggests that the population is resident or semi-resident on the scale of the area surveyed.

Having surveys and sightings in all months of the year over the study period helps confirm that bottlenose dolphins are resident in Puerto Rico. Furthermore, the observed sighting rate (39% of the surveys with sightings) is like that reported by Rodríguez-Ferrer: 39.8% of surveys with sightings (41 of 103 surveys). Of the marked individuals, the majority (61%) were sighted only once, with 22% of the animals resighted within only one sampling period and 11% on two or more sampling periods. This supports Rodríguez-Ferrer's (2001) conclusion that the dolphins of south and west coasts of Puerto Rico constitute a semi-resident population, where most of the individuals surveyed are staying within the study area most of the time. Nevertheless, dolphins are capable of long distance movement, potentially covering a larger area over multiyear time periods (see below). If so, residency might more properly be viewed in the context of animals using the areas on the west and south coasts as important habitats over multiple years. Further study is clearly needed on dolphin home range boundaries.

One noticeable difference in this study was the fact that dolphins on the south coast were not sighted in offshore waters during our surveys, but on the west coast they were sighted over deep waters. Figure 2 illustrates the observed movements for two such dolphins. One potential explanation is that dolphins would have no incentive or navigational cues that would direct them into the deep waters off the south coast, while off the west coast there could be multiple geomorphic and acoustical cues that would lead them to navigate across the Mona Channel to connect to the island of Hispaniola. Dolphins are capable of long movements, and it has been noted that they have different movement patters depending on habitat (Würsig et al. 1991) and/or fish abundance (Würsig and Würsig 1979).

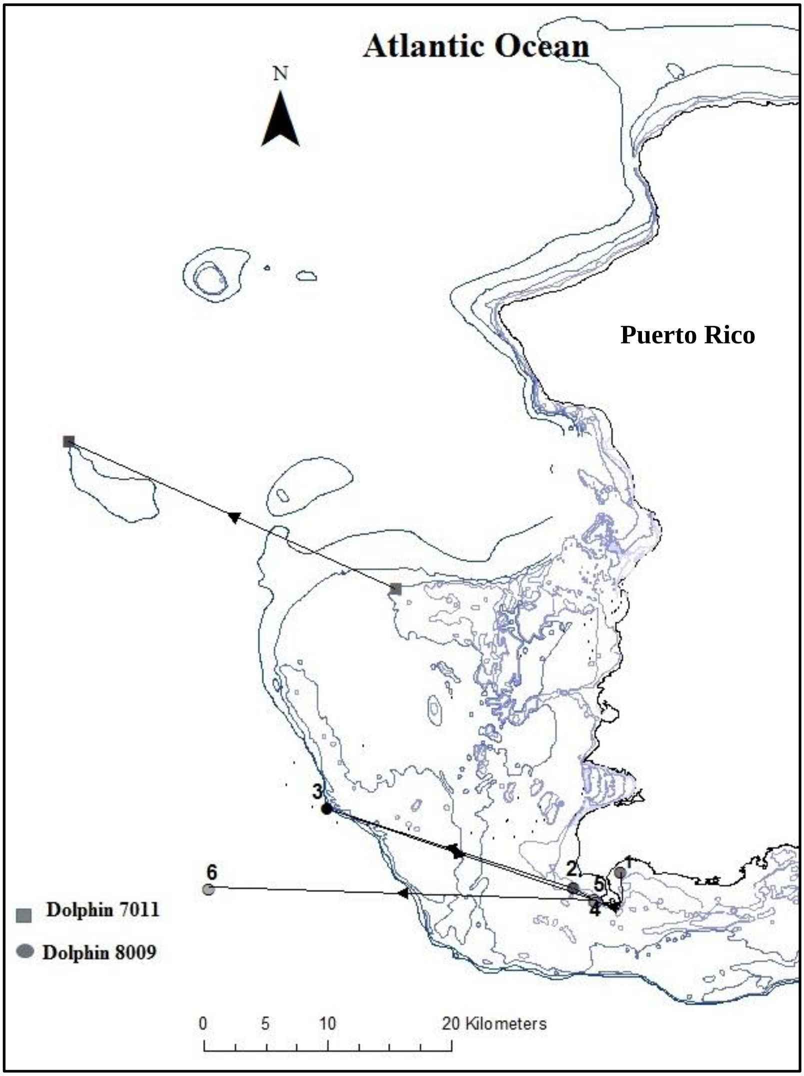

Figure 5. Example of movement patterns of bottlenose dolphins (7011 and 8009) in the waters off the southwest platform of Puerto Rico. Sighting days ranged from November 21, 2013 to September 17, 2015. Numbers for dolphin 8009 indicate the sighting sequence. Arrows connect the observation locations in sequence but do not reflect actual paths of movement. Outer two depth isobaths are for 30 m and 50 m depth, representing the top and slope of the insular platform, respectively.

The distance between Puerto Rico and Hispaniola is about 120 km (64 Nmiles); however, the extended insular platforms of the two islands reduce this distance to 95 km. Furthermore, there is a ridge of several sea mounts and banks connecting the two, where depths can be less than 360 m (e.g., see dolphin 7011 in Figure 3), while the islands of Mona and Monito in the middle of the channel are additional features that could facilitate inter-island movement. Dolphins of the coastal ecotype have been routinely observed around these islands. The depths within the Mona Passage, especially along the submerged ridge running off the northwest portion of the western platform, are within known dolphin diving limits. Klasky et al. (2007) reported dives that were from 50 to 450m deep for satellite tracked individuals off Bermuda.

The above distances are small relative to known movement patterns elsewhere. For example, long-distance movements of satellite tracked offshore *Tursiops truncatus* have been reported of up to 4,200 km in depths that ranged from 10-5,000 m (Wells et al. 1999), while Würsig (1978) reported a round trip of 600 km for a group or bottlenose dolphins in Argentina, thus making interisland movements plausible. However, most studies of dolphin movements do not sufficiently report information (ecotype, distance, depth and driving mechanism, e.g., following migratory fish stocks) necessary to assess the likelihood of inter-island movement between Puerto Rico and Hispaniola. One exception is Tobeña et al. (2014), who report that coastal dolphins inhabiting the Canary Islands exhibit regular inter-island movements, which would involve distances of 60-80km over waters of 2000+m depth. If there is any connectivity between dolphins off the west coast of Puerto Rico and eastern Hispaniola, this implies either a migratory stock or a larger population boundary. This would have a potentially profound impact on population size estimates, genetic structure, ecological resilience and therefore conservation and management, and as such would warrant confirmation studies based on genetic analysis and on individual movements.

The abundance estimated for the studied population was 127 dolphins. Given the 95% confidence limits of this estimate, this is a statistically significant 60% decrease from the 2001 estimate of 314 individuals (Rodríguez-Ferrer 2001). The 2001 study targeted the west coast insular platform and used a line transect survey analysis. The present study covered not only the area studied previously, but also added the south coast from Guánica Bay. The difference between survey methods is that mark and recapture provides an estimate of the abundance of all dolphins (present or not present) using the area during the study (Daura-Jorge and Lopez 2016), while line transect only estimates the abundances of the animals present now of the survey in each area (Calambokidis and Barlow 2004). For coastal dolphin populations found in small groups, mark and recapture methods have proven to be more precise in abundance estimates than line transect methods (Lukoschek and Chilvers 2008, Daura-Jorge and Lopez 2016). Thus, based on both area surveyed and methodology, if the dolphin population was stable, a higher population estimate would have been expected for the recent survey, and this was not the case. As a check on the current estimate, a separate calculation based on the proportion of the shelf surveyed was made using the following parameters: Transect width = 1km, Mean distance/trip = 67.8km, Surveys during first sampling period = 9, Shelf area to 50m contour = 980km^2. Using these parameters, the total area surveyed was 611km^2, or 62.3% of the shelf. The 69 dolphins observed during the first sampling period would then represent the same percentage, for a total population estimate of 110 individuals. Given that the area surveyed went outside the 50-m contour demarcating the insular platform, this calculation would slightly underestimate population size, but the result is consistent with that obtained using the mark-recapture approach.

A 60% decline in the dolphin population off southwest Puerto Rico in 15 years is substantial but represents only a 4.06% annual loss. Daura-Jorge and Simões-Lopes (2016) used power analysis in their mark-recapture study of a bottlenose dolphin population in Brazil to estimate that it would take 11 years of continued sampling to determine a 5% decrease per year with a 95% level of confidence. They further point out that, given their small population size, the resulting 40% decline would already have devastating effects long before such significance was achieved. This is on a scale with that observed in Puerto Rico. Given the magnitude of the change already observed, and the difficulty in detecting slight changes, more frequent and intense sampling is recommended.

The observed population decline represents a high degree of either mortality or emigration, or some combination of the two. Given that dolphin home ranges and movements are not well known, it could be that the population has shifted its location to other areas. One possible factor related to either mortality or emigration could be the decrease on prey abundance. Puerto Rico fish stocks were declared by Matos-Caraballo in 2001 as overfished, which was supported by a more quantitative analysis by Ault et al. (2008); it has not shown signs of recuperation since, although there has been a shift in fishing pressure toward recreational and coastal migrating species (Appeldoorn et al. 2015). Declines in habitat quality due to land-based anthropogenic inputs could also contribute to a decline in food resources (Appeldoorn et al. 2009, Hernandez-Delgado et al. 2010). A significant decline in food availability could either force dolphins to seek new feeding areas or lead to increased mortality through starvation or increased stress. The Puerto Rico Marine Mammal Rescue Program reported an average of 1-3 bottlenose dolphin strandings per year in the last 10 years (unpublished), a rate that has not changed over that period. Therefore, there has not been an increase in reported deaths or a massive die-off that could explain such a decline. Yet, some of these strandings show unambiguous evidence of human, particularly fisheries interactions indicating potential competition for scarce resources.

Another factor that could contribute to permanent emigration and increased stress is the high boat traffic associated with recreational activities and fishing that characterizes the southwest coast of Puerto Rico. High boat traffic has proven to negatively impact dolphin behavior (Nowacek et al. 2001, Hastie et al. 2003). It can affect habitat selection for foraging by changing preferred areas, either directly to avoid boat traffic or indirectly because of the prey response to high boat traffic (Allen and Read 2000), which can result in changed residency patterns (Lusseau 2005). The noise created by high boat traffic has been categorized as a source of acoustic harassment for the species (Haviland-Howell et al. 2007). Small dolphin populations, such as the one presented here, have been shown to be negatively affected by dolphin watching operations. In several areas where dolphin-based tourism is practiced the population has declined (Constantine 2002, Bejder et al. 2006, Lusseau et al. 2006, Currey et al. 2009).

While there are no data on reproductive success or related life history parameters for the bottlenose dolphin population in Puerto Rico, long-term studies elsewhere have reported an estimated age at first birth from 5-12 years (Wells and Scott 1987, Mann et al. 2000,) and a calving interval of 3-6 years for Australia (Connor et al. 1996, Mann et al. 2000), 2-10 years for Florida (Scott et al. 1996), and 3 years of North Carolina (Thayer 2008). This lengthy time to reach age of reproduction, coupled with low fecundity and long time between births limits the ability of dolphins to respond to either a sudden population decrease, by mass die offs or slow sustained declines resulting from anthropogenic impacts. Yet, the majority (38%) of the dolphin sightings during this study were composed of mixed groups of adults, juveniles and calves, with most the sightings having 1 calf and 1-2 juveniles per group (Table 4); but only 3 neonates were observed. This suggests that there is at least some active level of reproduction occurring, but there is insufficient information to interpret if this is adequate to sustain the population.

Table 4. Description of the group compositions for bottlenose sightings, *Tursiops truncatus*, encountered in Puerto Rico on surveys between 2013 and 2015.

Solitary	Mom and calf pairs	Adults only	Mixed (adults ar calves in group	Pair of adults
2 (12%)	4 (15%)	7 (27%)	10 (38%)	3 (12%)

A minimum effective breeding population size is estimated to be 500 individuals (Franklin 1980, Lande and Barrowclough 1987), and small populations generally show greater variability in population size. Even if the change reported here represents such natural variation, given the low reproductive potential for dolphins it would represent a serious threat to local population persistence. This significant decline in population abundance means that the conservation and management of bottlenose dolphins in Puerto Rico needs to be more aggressive. However, further efforts should focus on determining the causes of this decline so that management actions can be targeted to reduce overall societal impact, especially, for example, if overall reductions in fishing or boating activities are warranted. There is a need for research on the effect of anthropogenic factors on bottlenose dolphins in Puerto Rico. Factors such as overfishing, coastal development, boat traffic, human interactions and pollution should be studied in relation to the species' distribution, behavior and population dynamics, and further mark-recapture on studies are needed to assess if there is in fact a decreasing abundance trend in this population.

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Appendix 1. Summary of the field information by day for the survey on bottlenose dolphin, *Tursiops truncatus*, off the south and west coast of Puerto Rico. Photographs by day, number of individuals present as well as number of animals marked is presented.

Date	SubArea	Number of sightings	Number of pictures	Number of photographed dolphins	Cataloged	Marked dolphins	Unmarked
07-Feb-13	Parguera	1	43	2	2	1	1
28-Feb-13	Combate	1	5	2	0	0	0
21-Nov-13	Parguera	2	87	2	2	2	0
03-Jan-14	Puerto Real	1	140	15	15	7	8
24-Jan-14	Joyuda	1	0	0	0	0	0
22-May-14	Combate	1	72	8	8	5	3
23-May-14	Bouy 8	1	23	2	2	0	2
13-Jun-14	Combate	3	436	36	21	18	3
17-Jul-14	Combate	1	285	22	21	12	9

Appendix 1. Summary of the field information by day for the survey on bottlenose dolphin, *Tursiops truncatus*, off the south and west coast of Puerto Rico (continuation).

10-Oct-14	Parguera	1	38	3	2	0	2
16-Oct-14	Parguera	1	66	2	2	1	1
31-Oct-14	Guanica	1	138	4	3	1	2
23-Jan-15	Combate	1	0	0	0	0	0
12-Mar-15	Combate	1	0	0	0	0	0
13-Mar-15	Bouy 4	1	147	6	5	2	3
20-May-15	Combate	1	114	15	15	11	4
21-May-15	Bouy 8	1	82	1	1	0	1
29-May-15	Combate	1	510	10	10	6	4
03-Jun-15	Boquerón	1	63	2	1	1	0
19-Jun-15	Mayagüez Bay	1	125	5	5	1	4
24-Jun-15	Guánica	1	64	5	3	0	3
17-Sep-15	Boquerón	1	0	0	0	0	0
17-Sep-15	Combate	2	193	20	12	7	5
14-Oct-15	Aguada	1	49	10	10	4	6

Appendix 2. Summary of the data used for the mark recapture analysis. For mark-recapture analysis, survey days were compiled into six sampling periods starting 11/21/2013 as indicated by horizontal lines. A marked dolphin is a photographed dolphin that has a distinctive dorsal fin, and unmarked dolphin is a photographed dolphin that the fin is not distinctive and will be hard to recognize. Group size field estimates including presence of calves and or neonates are presented.

Date	Survey Area	Number of Sightings	Number of Dolphins	Number of Calves	Number of Neonates	Dolphins Marked	Dolphins Unmarked	Resights
11/21/2013	Guánica	1	8	2	2	2	1	0
1/3/2014	Bajo Sico	1	15	2	0	7	8	0
1/24/2014	Bajo Sico	1	3	0	0	1	2	0
5/22/2014	Cabo Rojo	1	8	0	0	5	3	0
5/23/2014	Mayagüez	1	2	0	0	0	2	0
6/13/2014	Guánica	3	33	4	0	18	3	0

Appendix 2. Summary of the data used for the mark recapture analysis (continuation).

7/17/2014	Lajas	1	13	0	0	12	9	6
10/10/2014	Lajas	1	4	0	0	0	2	0
10/16/2014	Lajas	1	2	0	1	1	1	0
10/31/2014	Guayanilla	1	3	1	0	1	2	0
1/23/2015	Cabo Rojo	1	2	1	0	0	0	0
3/12/2015	Cabo Rojo	1	20	1	0	13	4	7
3/13/2015	Cabo Rojo	1	6	1	0	2	3	1
5/20/2015	Cabo Rojo	2	15	1	0	12	4	7
5/21/2015	Cabo Rojo	1	1	0	0	0	1	0
5/29/2015	Cabo Rojo	1	7	1	0	7	4	7
6/3/2015	Cabo Rojo	1	3	1	0	1	0	0
6/19/2015	Rincón	1	3	1	0	0	0	0
6/24/2015	Guánica	1	4	0	0	0	3	0
9/17/2015	Mayagüez	2	30	3	0	7	5	2