Year-round presence of Northern and Southern Hemisphere blue whales (*Balaenoptera musculus*) at the Galapagos Archipelago

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ABSTRACT

Information about blue whales (*Balaenoptera musculus*) in the Eastern Tropical Pacific is scarce. Only a few whales have been seen in recent decades. Molecular research, photo ID and acoustic studies suggest a degree of connectivity between Chilean and Antarctic blue whales in potential breeding areas off the coast of Peru and the Galapagos, and also between blue whales of the Costa Rica Dome and Northern Hemisphere population feeding off the coast of California, though potential breeding areas are still unknown. With opportunistic sighting records in the Galapagos, group size and year-round distribution were documented during a 17-year period from 2001 to 2018. Sightings slightly increased during this period and 50% of the whales seen were singletons. Whales were seen year-round. Most sightings occurred during the austral winter (82%), while calf sightings occurred from June to September. With the remaining 18% of sightings in the austral summer, we propose there is geographical overlap between equatorial Galapagos and Northern Hemisphere blue whales. One blue whale was identified in the Galapagos during February 2009, resighted in the Costa Rica Dome during January 2014, and sighted again in the Galapagos during May 2016, when whales from the Southern Hemisphere could already be present. Our data strongly suggest there is a non-migratory blue whale population and a degree of overlap between the North and Southeast Pacific blue whale populations in the Galapagos.

KEYWORDS: BLUE WHALE; SOUTH AMERICA; PACIFIC; BREEDING GROUNDS; PHOTO-ID; MOVEMENTS; SITE-FIDELITY

INTRODUCTION

Blue whale populations were severely reduced due to whaling in the 20th Century before protective measures took effect in 1966 (Reilly *et al*., 2008). They are still rare throughout their range and listed as endangered in the IUCN Red List (Cooke *et al*., 2018). The best abundance estimate for the Northeast Pacific population is 1,647 whales (Calambokidis *et al*., 2013), while estimates for the South-eastern Pacific population are uncertain, with about 450 whales estimated off Chiloe Island based on photo ID data (Cooke *et al*., 2017), and an estimated recovery of 7.5%. Antarctic blue whales are still at a recovery rate of below 1% (Williams *et al*., 2017) with an estimated abundance of 2,280 whales in 1998 (Branch *et al.,* 2007).

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Blue whales tend to be found in deep offshore pelagic environments which can be hard to access. This means observations in the Eastern Tropical Pacific are rare, while abundance and distribution in the Southern Hemisphere are poorly understood (Branch *et al*., 2007). In the Eastern Pacific Ocean, blue whales from the Eastern North Pacific occur year-round off the Californian coast and Baja California, Mexico (Calambokidis *et al*., 2004), but mingle with whales off Alaska in the summer (Monnahan *et al*., 2014). Some may migrate to the Costa Rica Dome area in winter (Mate *et al*., 1999) and even further south off Peru (Le Duc *et al*., 2017).

Despite this year-round presence at the Costa Rica Dome, it is unclear whether these whales are residents or whether they are wintering from the Northeast or Southeast Pacific (Reilly *et al*., 1990). Blue whales move within high-latitude feeding areas in which euphausiids are abundant, and low latitude breeding areas where it is believed they mate and give birth (Lockyer *et al*., 1981; Mackintosh, 1965), though no breeding area has yet been reported. Their energetic costs are high, so they require the abundant food resources found along major upwelling areas, mostly found in cold productive oceans (Croll *et al*., 2005). When blue whales are present in low latitudes, they prefer the upwelling-modified waters of the Eastern Tropical Pacific (ETP), such as the Costa Rica Dome area, where blue whales concentrate year-round, or the Galapagos, where they are occasionally seen (Reilly *et al*., 1990). The documented blue whale distribution in the ETP therefore clusters around four productive upwelling areas: the coast of Baja, the Costa Rica Dome, the Galapagos and the coast of Peru (Palacios, 1999). At the Costa Rica Dome, a variety of cetaceans are supported by a standing stock of euphausiids and a maximum chlorophyll concentration which spans May to September (Fiedler, 2002). Equatorial upwelling in the Galapagos is most intense in the western region, where blue whales can find the euphausiid *Nictophanes simplex* (Palacios, 1999). In recent decades, blue whale sightings in the Galapagos have been infrequent, with only 23 sightings from 1978 to 1995 (Palacios, 1999). Overall, the blue whale population in the ETP is one of the least studied in the world (Hucke-Gaete *et al*., 2018). Therefore, the population's connectivity, movements and population dynamics in the Galapagos Archipelago are poorly understood.

Recent molecular studies of East Pacific blue whales suggest they comprise distinct subspecies in the Northern and Southern Hemispheres. The Northern and Southern Pacific blue whales both use the ETP, but while the Northern subspecies has a greater affinity for Central America and the Costa Rica Dome area, the Southern subspecies breeds off the coast of Peru and Ecuador, including the Galapagos Islands (LeDuc *et al*., 2017). Several lines of evidence support these findings: namely, the same acoustic songs from Southeast Pacific blue whales between the coast of Chiloe in Chile, the northern Peruvian coast, and southern Ecuador (Buchan *et al*., 2015); satellite tags (Hucke-Gaete *et al*., 2018); photo-identifications (Torres-Flores *et al*., 2015); and their seasonal appearance in the Galapagos during austral winter, from June to November (Palacios, 1999; Branch *et al*., 2007; Denkinger *et al*., 2013). In the Costa Rica Dome area, blue whale migrations have been linked to southern California using satellite tags (Mate *et al*., 1999) and acoustic recordings (Stafford *et al*., 1999; Bailey *et al*., 2009), where blue whales arrive between the end of July to mid-September (Sears *et al*., 2013). But little is known if or how this population connects to the Galapagos. Northern Hemisphere blue whales appear to breed offshore, but use Baja California as a feeding area where they are present in the first half of the year and are sighted from late January to April, peaking in late February to mid-March (Sears, 1990). Reilly *et al*. (1990) report a peak of blue whale sightings from April to June and suggest blue whales are observed year-round at the Costa Rica Dome. Here we investigate whether there is overlap between breeding populations of the Northern and Southern Hemisphere by comparing photographs of blue whales seen in the Galapagos with photographs from Costa Rica and Chile.

The diverse migration patterns of the endangered blue whales are poorly understood (Reilly *et al*., 2008). To improve knowledge about blue whales in the ETP, namely the Galapagos and Costa Rica Dome, we document the presence of blue whales in Galapagos using opportunistic sighting data from 2001 to 2018, and the results of one photo-identified blue whale seen at the Costa Rica Dome and Galapagos.

MATERIALS AND METHODS

Study site

The Galapagos Archipelago extends from 3°N to 4°S and 87°W to 94°W (Fig. 1). It is characterised as one of the primary equatorial upwelling systems (Palacios, 2002). The influence of the equatorial front in the north, with

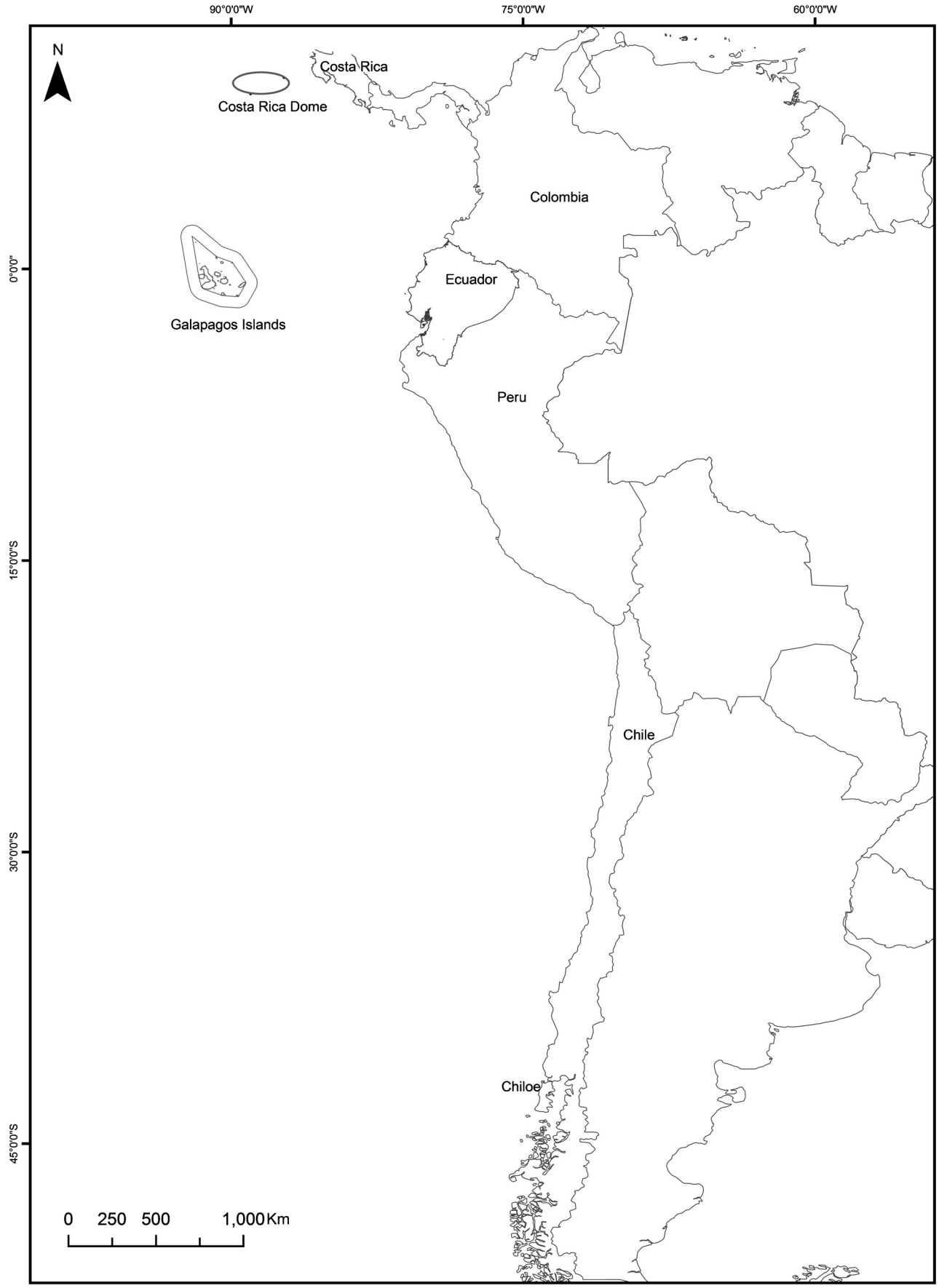

Fig. 1. Study area and distribution range of blue whales linked to the Galapagos Marine Reserve in the South-Eastern Pacific and Costa Rica Dome.

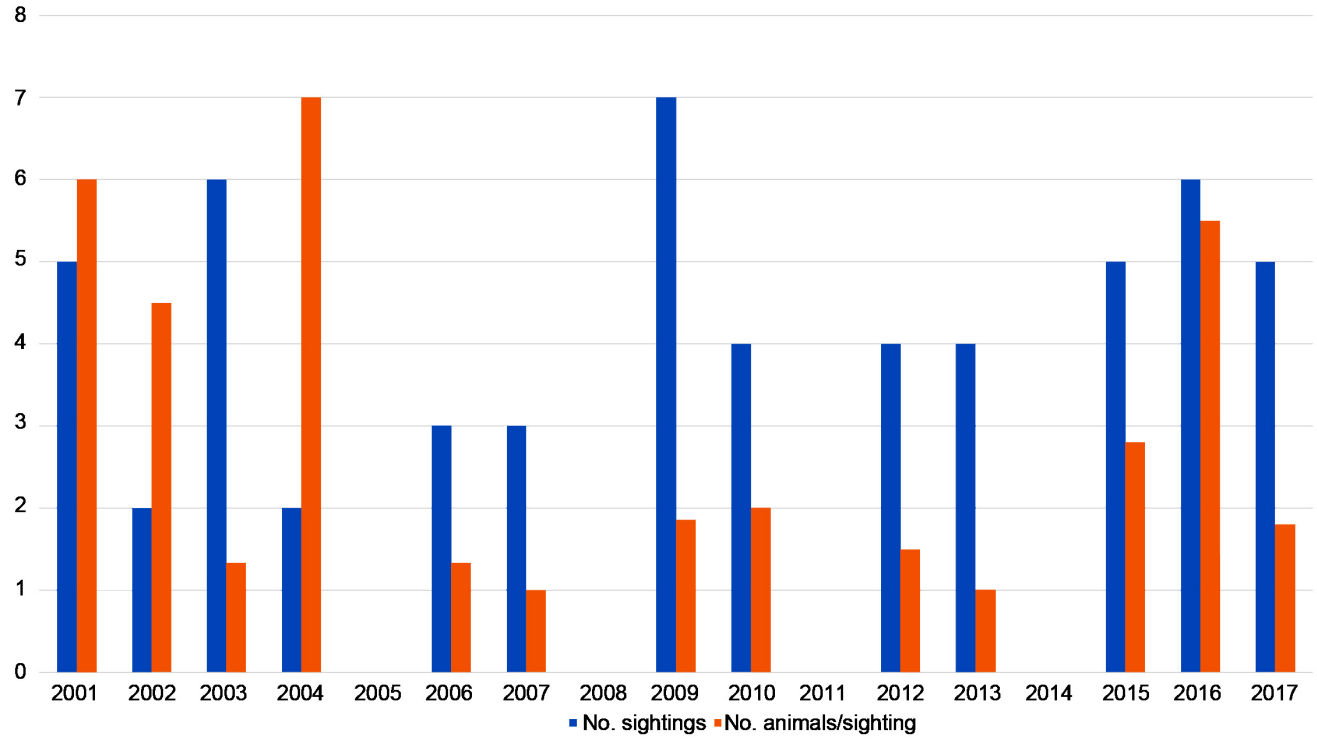

Fig. 2. Yearly blue whale sightings in the Galapagos from 2001 to 2017 and average number of animals observed per sightings in each year.

warm surface waters coming from the Panama Bight, causes a warm and less productive season from December to May. From June to November, the Humboldt Current from the south is more prevalent, resulting in strong winds and cold productive waters with an average temperature of 22°C SST. Most of the upwelling is produced by the Cromwell current from the west, with strong upwelling plumes that extend to the south and north-central region of the Archipelago (Palacios, 2002). The Costa Rica Dome, with a mean position of 9°N and 90°W, is seasonally affected by large and coastal scale wind patterns (Kessler, 2006; Fiedler *et al*., 2006), which trigger a strong and shallow thermocline (Fiedler, 2002) (Fig. 2).

Survey methods

Using opportunistic platforms such as tourist boats, a total of 1,488 cetacean sightings, including 65 blue whale sightings, were collected between August 2001 and May 2018. We used field reports from trained tourist guides on cruise boats following regular routes, and opportunistic sightings during research cruises on fishing vessels or sailboats over a period of 920 sighting days (see Table 1). Because no information on survey effort is available, we use general cetacean sightings over the years to show a relative sighting effort. The presence of calves and juvenile whales was analysed according to month and season. Calves and juveniles were smaller whales and identified as blue whales according to the position of the dorsal fin in relation to the head and fluke. They were present in the same group as other blue whales, but no aerial images were available; therefore, calves should be treated as possible calf sightings. Seasonal presence was analysed from January 2001 to May 2018. Seasons were classified according to austral summer from the months November to April and austral winter from May to October. Behavioural observations were classified into travelling (*tr*), when whales were described moving at fast or moderate speed, resting (*re*) when whales were described as moving slowly, milling (*mi*) when whales had an irregular swimming direction, and feeding (*fe*) when whales were seen either lunging or rolling on the surface with an open mouth.

Whales were photographed when possible. Good quality photographs with clearly visible dorsal fin shape and pigmentation patterns were used for photo-identification. Whale photographs were compared to ID catalogues from whale sightings in Huinay, Chile (five whales left side dorsal fin, two whales right side dorsal fin), Costa Rica (96 whales left side dorsal fin, 97 whales right side dorsal fin) and the Baja Catalogue with 518 blue

Table 1
Sightings of all cetaceans in relation to blue whales in the Galapagos Archipelago from January 2001 to May 2018.

	Cetacean sightings		Blue whale sightings		% Blue whale sightings	Yearly % of all sightings from 2001 to 2018
Year	Austral summer	Austral winter	Austral summer	Austral winter	All seasons	All seasons
2001	44	120	0	8	4.88	11.46
2002	106	94	2	3	2.5	13.98
2003	80	114	1	5	3.09	13.56
2004	34	46	0	2	2.5	5.59
2005	8	28	0	0	0	2.52
2006	26	33	0	3	5.08	4.12
2007	49	39	0	3	3.41	6.15
2008	62	33	0	0	0	6.64
2009	33	42	4	3	9.33	5.24
2010	46	40	1	4	5.81	6.01
2011	42	2	0	0	0	3.07
2012	20	33	0	3	5.66	3.70
2013	34	4	2	3	13.16	2.66
2014	11	0	0	0	0	0.77
2015	23	34	0	5	8.77	3.98
2016	11	23	0	6	17.65	2.38
2017	17	40	0	5	8.77	3.98
2018	31	29	2	0	3.33	4.19
Total	677	754	12	53	4.54	100

whales identified in the Loreto region along the West Coast of the Sea of Cortez. Photographs of individual blue whales were compared visually using the following identification criteria: dorsal fin, pigmentation patterns on the back close to the dorsal fin, and the presence of scars or nicks (Sears *et al*., 1990). Since there were few ID pictures available, matches were compared by authors who are experienced in photo identification and additional experts (Paula Olson, John Calambokidis, Azucena Ugalde de la Cruz).

RESULTS

Galapagos sightings of blue whales

From August 2001 to May 2018, a total of 1,431 cetacean sightings were reported as opportunistic sightings, with a total of 65 blue whale sightings. In 56 of these sightings, information on group size was available. Average group size and frequency of different group sizes, such as singletons, pairs, triads, 4+ and 10+, were calculated across all sightings. Blue whales were seen on 65 occasions, with a total of 155 animals seen throughout these years. The highest number of blue whales was seen in September 2016, when one group of 30 or more whales was spotted by one of us (MN) off Punta Vicente Roca (Isabela Island) during an oceanographic cruise of the BAE Orion. Overall, sightings of blue whales have been irregular over the years, and none were seen in 2005, 2008, 2011 or 2014.

More than half of these blue whales, for which group size information was available, were singletons (53%). Pairs were observed in 27% of the sightings, and large groups of 10 or more whales were present in 5% of all sightings (Fig. 3).

Seasonal presence

Blue whales were present year-round in the Galapagos, but most sightings occurred in August during the peak of the austral winter, when 82% (n = 53) of the blue whale sightings occurred. Calves (n = 8) were only seen during the austral winter months of June (n = 2), July (n = 1), August (n = 2) and September (n = 1). 18% (n = 12) of the blue whale sightings occurred during the austral summer with nine seen between November and February (Table 1, Figs 4a and b). Descriptions of behaviour were available for six sightings in the austral summer and 20 in the austral winter. While our observations of travelling (*tr*) whales were most frequent in both seasons ($tr_{austral\ summer}$ n = 5 and $tr_{austral\ winter}$ n = 9), feeding (fe) was observed in the austral winter only ($fe_{austral\ winter}$ n = 7) (Fig. 7c).

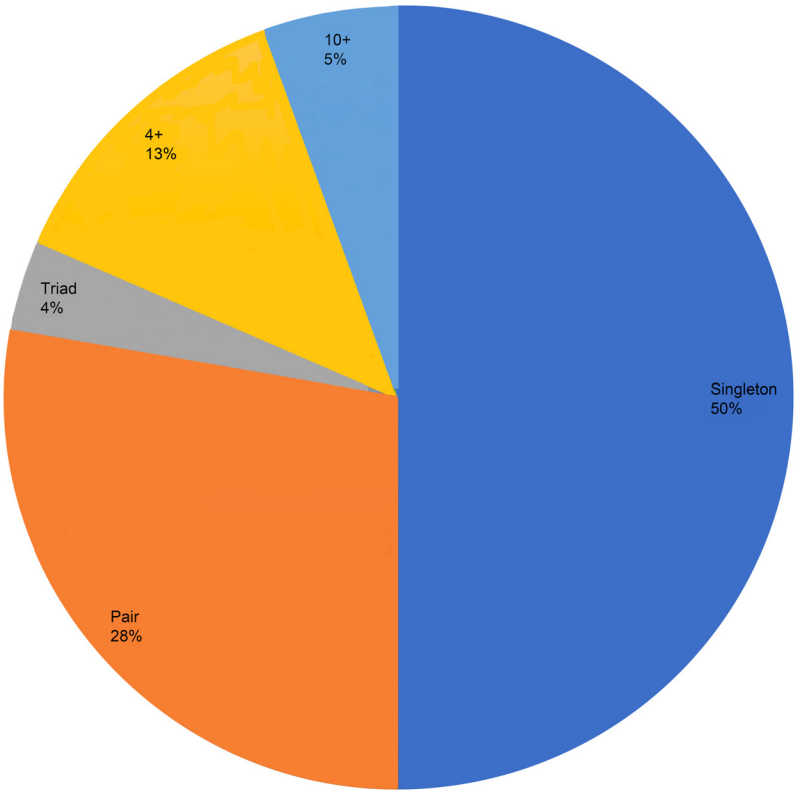

Fig. 3. Blue whale group size frequency observed in the Galapagos (N = 56).

Blue whale sighting distribution

Blue whale sightings were logged along the regular tourist cruise routes, which remain close to the Islands. Blue whales were sighted predominantly in the most productive areas in the Southwestern Archipelago, namely the Bolivar Channel west of Isabela and north of Floreana Island. Blue whales were also seen in the central Archipelago and north of San Cristobal Island (Fig. 5).

Photographs of individually identifiable blue whales, where pigmentation patterns close to the dorsal fin and shape of the fin were clearly visible, have only been available since 2009. By June 2018, a total of 13 blue whales were identified (nine right and five left, including one individual BWGal008 identified on both sides). The photographs were compared with a catalogue provided by Verena Häusserman (Hiunay, Chile) with four left and two right fins. ID photos were also sent to John Calambokidis (Cascadia Research Collective) for comparison with blue whale sightings in Costa Rica, and Rodrigo Hucke-Gaete (Universidad Austral de Chile) for comparison with sightings in Chile. As a result, a blue whale individual coded BWGal008 was found to match a blue whale identified at the Costa Rica Dome (CRC 2801) and the Galapagos in May 2016 (Fig. 6). Matching photographs were confirmed with three independent experts (Paula Olson at SWFSC, La Jolla California; John Calambokidis at Cascadia Research Center; Azucena Ugalde de la Cruz at Cascadia Research Center) (Fig. 7). BWGal008 was first seen as a singleton and photographed on 17 February 2009, off the southern Isabela Island at Caleta Iguana (–0.974249, –91.46359). The whale was moving in random directions in the bay for at least 90 minutes and was next seen the following afternoon. About five years later, on 15 January 2014, the same whale was spotted at the Costa Rica Dome area (9.8468, –87.2881) at a straight-line distance of about 600nm. Two years later, BWGal008 was again seen in the Galapagos during a Bryde's whale survey on 16 May 2016, off the north coast of San Cristobal Island (–0.619996/–89.230611), with another blue whale coded as BWGal013 (Figs. 6 and 8).

DISCUSSION

Blue whale sightings in the Galapagos Archipelago are rare compared with other baleen whale species, such as the Bryde's (*Balaenoptera edeni*) or humpback whales (*Megaptera novaeangliae*) (Denkinger *et al.,* 2013). Here

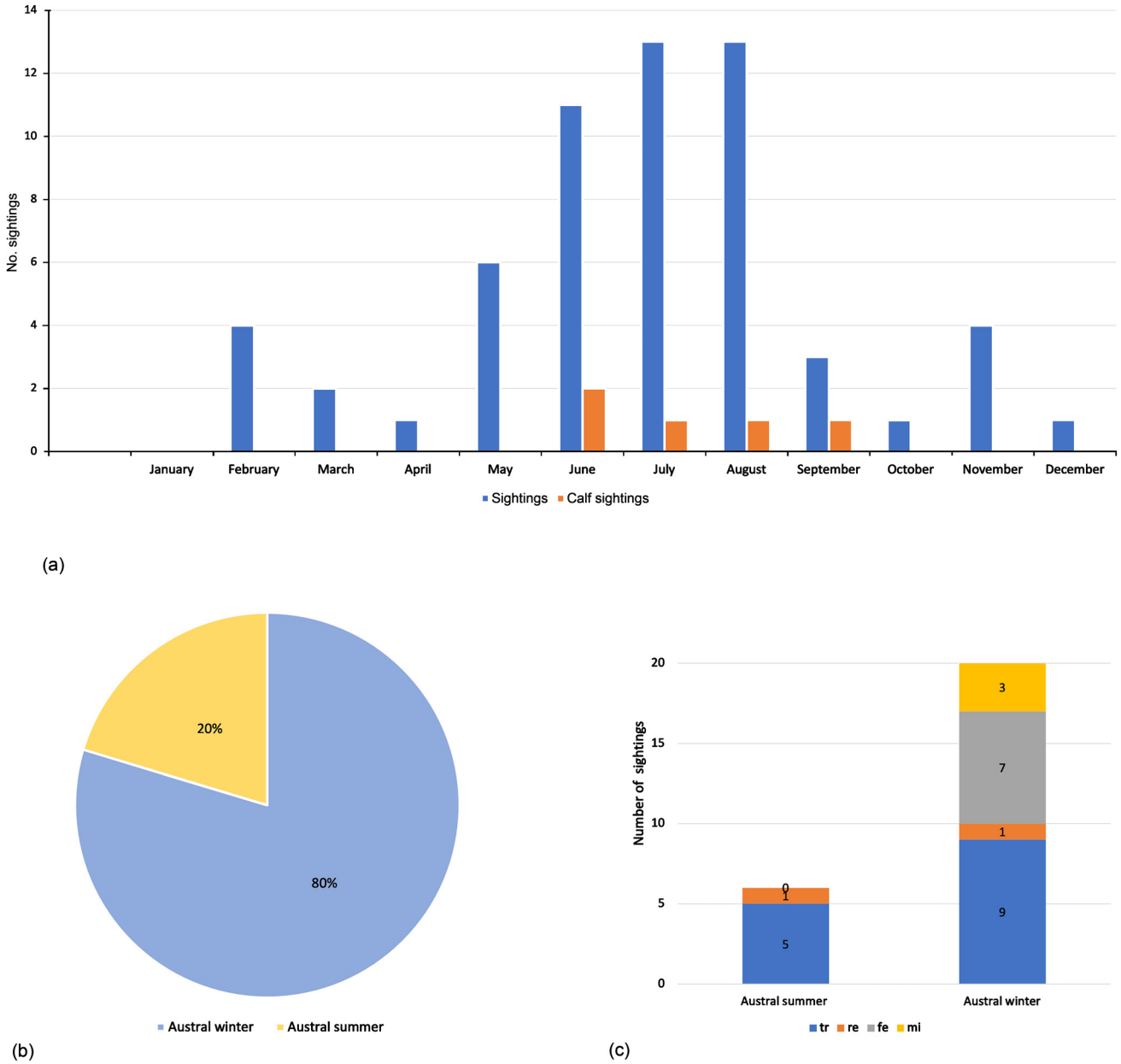

Fig. 4. a) Seasonal presence of blue whales and their calves in the Galapagos from January 2001 to April 2018; b) blue whale sighting frequency (% of total) in the Galapagos during the austral summer (November–April) and austral winter (May–October); c) blue whale behaviour during austral summer and austral winter observations.

we report the results of 65 sightings over the course of a 17-year period (08/2001 to 04/2018). Despite extensive survey efforts, Palacios (1999) observed a total of 55 whales over 23 occasions during a 17-year period from 1978 to 1995. In our study, trained tour guides acquired cetacean sighting data on regular cruises. Despite the tour guides' inconsistent reporting on group size (53 out of 65 sightings include that information), they observed at least 161 animals, almost three times more than Palacios reported. This could be due to overestimating the number of individuals, but it could also be consistent with reports of an increasing population trend (Reilly *et al*., 2008; Cooke, 2018).

According to Reilly *et al*. (1990) and Palacios (1999), blue whales in the ETP are rather solitary animals, but in the Galapagos, groups (2+) were more common than single animals. However, with the larger set of sightings from 2001 to 2018, sightings of singletons (50%) matched sightings of groups, confirming the presence of single whales and blue whale aggregations. In September 2016, about 30 blue whales were seen at Punta Vicente Roca in the North of Isabela Island (1°22,34''S/ 91°59,98''W), and in June 2004, a group of 12 in Post Office Bay at Floreana Island (01°12.40'S/90°27.124'W).

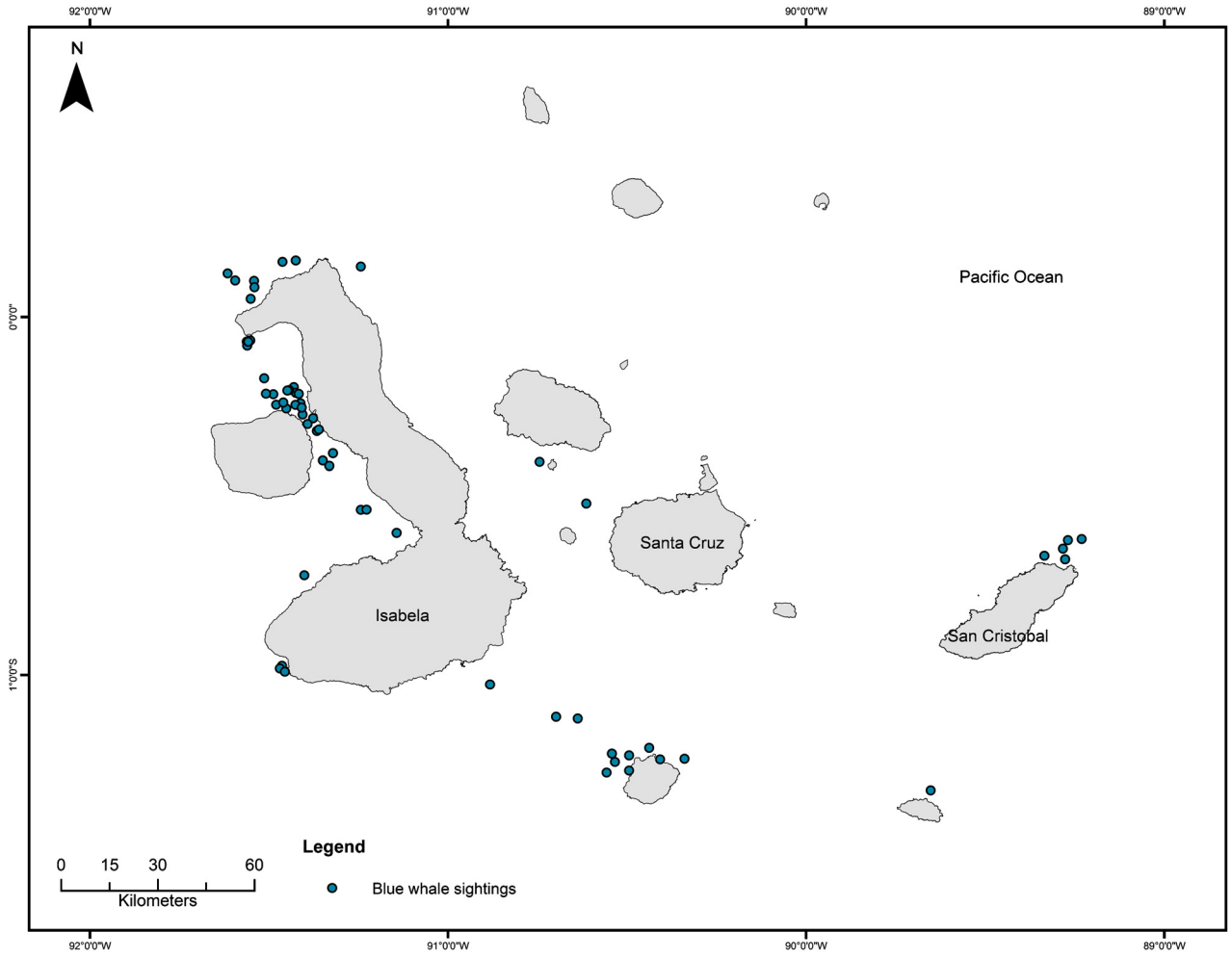

Fig. 5. Distribution of blue whales opportunistically sighted during tourism cruises in the Galapagos Marine Reserve from 2001–18.

Whaling data suggest that blue whales rarely feed in the ETP (Mackintosh, 1966). But since that anecdotal observation, their distribution has been closely linked to euphausiid biogeography (Brinton, 1979), especially in the primary equatorial and the Costa Rica Dome upwelling areas (Love ,1972). Feeding therefore appears to be important to blue whales at low latitudes (Reilly *et al*., 1990). A blue whale seen off the coast of Ecuador in July 2006 (Felix *et al*., 2007) was observed feeding as it was moving fast and rolling on its side with an open mouth. The same behaviour was described in nine out of 20 sightings in the austral winter. These observations provide evidence that blue whales feed in the ETP, where their distribution is closely linked to upwelling areas (Palacios, 1999). Feeding in low latitudes explains why they can remain for longer periods in the ETP and close to the Galapagos, clarifying the year-round presence of blue whales in the Galapagos Marine Reserve. In the Galapagos, they are most frequently seen in the most productive southwestern areas of the Archipelago, the Bolivar Channel and close to Isabela Island. Blue whales have a rather pelagic habitat, preferring oceanic upwelling areas (Reilly *et al*., 1990; Palacios, 1999), but sighting coverage in this study was limited to coastal areas of the Galapagos Archipelago due to the cruise ship itineraries. Nevertheless, more sightings were recorded than Palacios' 1999 study. The Bolivar Channel and north shore of Isabella are both characterised by strong upwelling due to the Cromwell current.

According to Palacios (1999), blue whales have a marked seasonal presence in the Galapagos during the austral winter, which has been confirmed by recent sightings reported in this study, in which 80% of the blue whales seen from 2001 to 2018 were observed during the months of May to October. In the Sea of Cortez, blue whale sightings peak in February–March (Sears, 1990), and off Baja California in April–June, before decreasing in July–September (Reilly *et al*., 1990). In the Galapagos, most blue whales were seen from May to September with the highest number of sightings reported in August, while calves were seen from June to September. The

(a)

(b)

(c)

Fig. 6. a) Blue whale (ID: BWGaI008) identified on: a) 17 February 2009 at Caleta Iguana, south of Isabela Island (Photos: Judith Denkinger); b) 15 January 2014 at the Costa Rica Dome (Photos: Richard Sears); and c) 16 May 2016, off the northern coast of San Cristobal Island (Photos: Douglas Biggs).

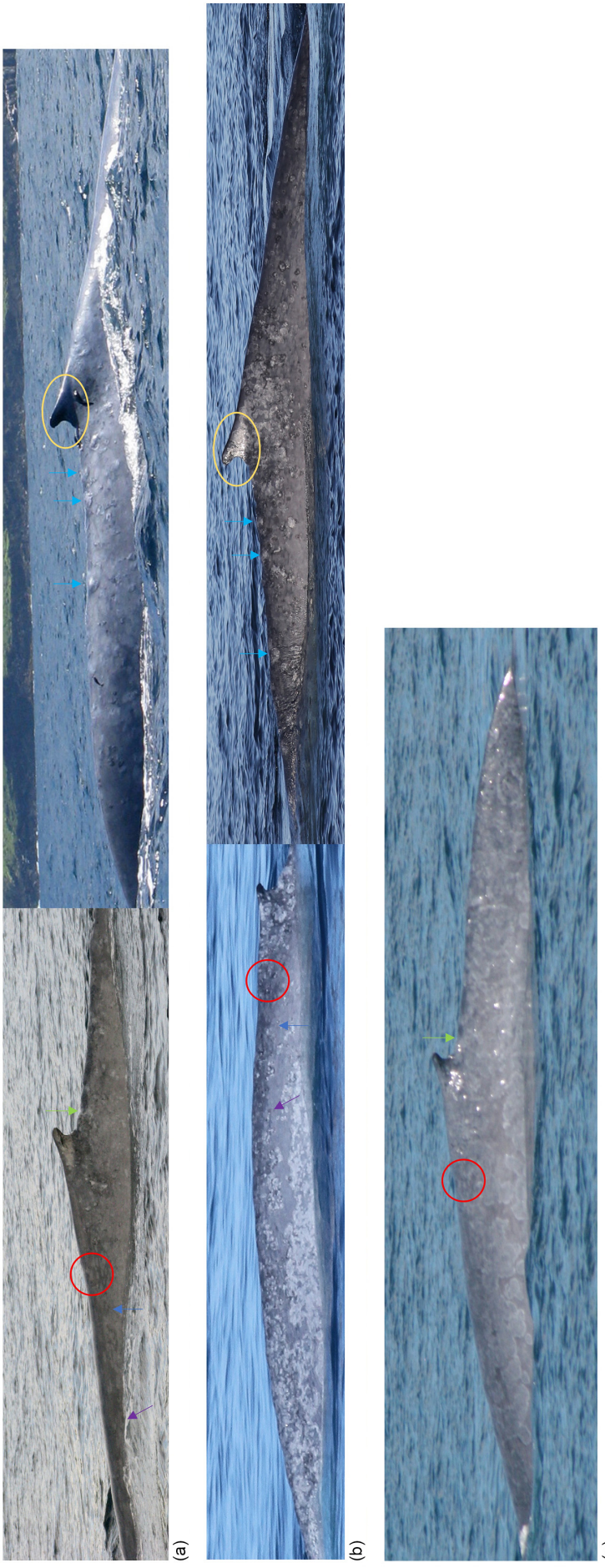

Fig. 7. Confirmed matching points with independent expert reviewers of blue whale photographs taken at: a) Caleta Iguana, Galapagos (Photos: Judith Denkinger); b) Costa Rica Dome (Photos: Richard Sears); and c) north of San Cristobal Island, Galapagos (Photos: Douglas Biggs).

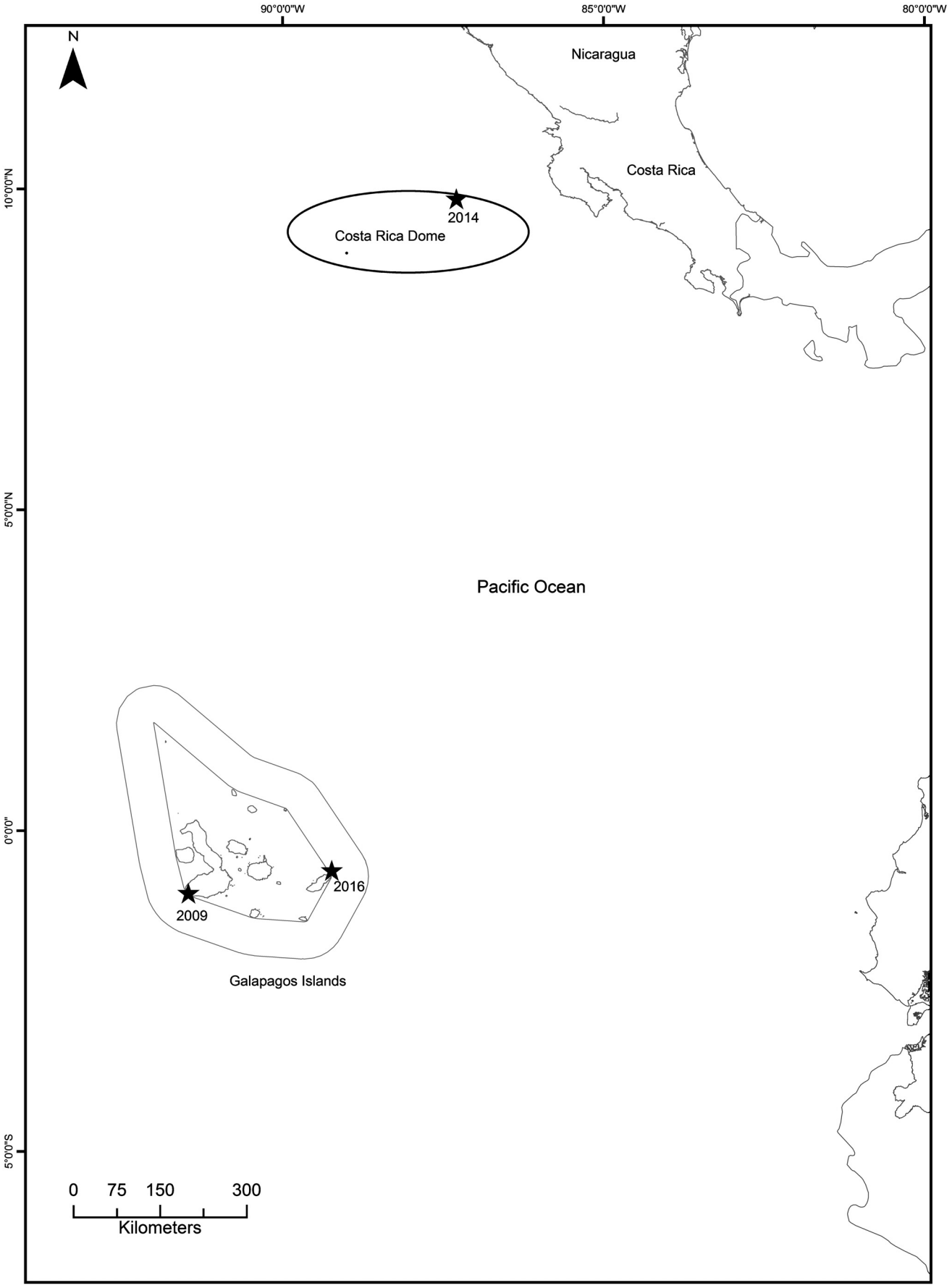

Fig. 8. Sighting locations of BWGaI008 at Galapagos and Costa Rica Dome.

peak of sightings in August could be explained by the austral winter migration of blue whales. The fact that calves are seen from June to September provides further evidence that the Galapagos area is used as a Southern Hemisphere blue whale breeding ground (Reilley *et al*., 1990; Palacios, 1999; Branch *et al*., 2007). Use of acoustic detectors has documented the migration of blue whales feeding off Chile's northern Patagonia to the ETP as far north as 8°S, 95°W south of Galapagos. Peak recordings were during the month of June, suggesting a seasonal migration from Chiloe to the ETP during June/July (Buchan *et al.*, 2015). However, using whaling and survey data, Donovan (1984) documented a peak of blue whale sightings off the coast of Peru in January /February. This could mean that some of the blue whales sighted in Galapagos during the austral summer are Southern Hemisphere blue whales moving as far north as the Galapagos Islands. BWGal008 is the first match of a blue whale seen at the Galapagos and the Costa Rica Dome area. The fact that BWGal008 was first seen south of Isabela in 2009, then at the Costa Rica Dome in 2014, and again in the Galapagos in 2016, revealed a dispersal pattern which could indicate that blue whales seen off the Galapagos during the early austral summer are part of the resident ETP population or part of populations in both hemispheres (see Reilley *et al*., 1990).

The scarcity of knowledge of blue whales in the Galapagos suggests they belong to the Southern Hemisphere stock. This is supported by a sighting of two calves in August 1993 during the austral winter migration (Palacios, 1999; Branch *et al*., 2007). In the present study, out of 65 sightings, six sightings included calves, with all the calf sightings occurring in the austral winter (most in June), confirming their relationship to the Southern Hemisphere stock. On the other hand, the Costa Rica Dome area is considered part of the North Pacific blue whale calving area, according to Northern Hemisphere migration patterns (Mate *et al.,* 2006) and molecular analysis (LeDuc *et al*., 2016). Using satellite-tagging data, the migration of blue whales from northern Patagonia in Chile to the southern Galapagos has been documented during the austral summer and early autumn off the coast of Chiloe (Hucke-Gaete *et al.*, 2018), and also for one genotyped and photo-identified whale observed in the Galapagos (1°18'S, 92°19'W) in November 1998 and Corcovado Gulf of southern Chile (43°52'S, 73°33'W) in February 2006 (Torres-Flores *et al*., 2015). Until now, the Galapagos has been considered a breeding destination for Southern Hemisphere blue whales (Buchan *et al*., 2015; Torres-Flores *et al*., 2014; Torres-Flores *et al*., 2015). But the sightings of blue whales in Galapagos during the austral summer from November to April, and the fact that BWGal008 was seen in the Galapagos in February 2009, Costa Rica in January 2014, and the Galapagos in May 2016, suggests that Northern and Southern Hemisphere populations overlap in geography and time.

Our findings provide an important background for conservation management of a migratory species and the need of migratory corridors from Galapagos to the Southern and Northern Hemisphere.

CONCLUSIONS

These findings provide a new perspective on population dynamics of blue whales for the North and Southeast Pacific. Genetic analysis would help confirm interbreeding of Southeast Pacific, Northeast Pacific and ETP populations. Such interbreeding could increase genetic diversity within both populations, but more research using satellite telemetry, genetic fingerprinting and photo-identification is necessary to fully understand the ecology of this endangered species and to implement effective conservation strategies in key habitats.

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