SC/66a/SM/9

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INTERNATIONAL
WHALING COMMISSION

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ABSTRACT

Killer whales of ecotype C (*Orcinus orca*, TCKW) were studied in McMurdo Sound, Antarctica, during Dec 2014-Jan 2015 by dart biopsy sampling and photo-identification (photo-ID). We collected 33 dart biopsy samples including 27 samples from killer whales (26 type C, 1 type B) and 6 samples from Antarctic minke whales (*Balaenoptera bonaerensis*). With the exception of 7 type-B killer whales (TBKW; 5 adults, 2 calves), all killer whales sighted in the McMurdo Sound region were TCKW. By combining images from our 2013/14 and 2014/15 with an existing catalogue compiled by the Orca Research Trust ('AKWIC') and photos submitted by 'citizen scientists', we have created an expanded photo-identification catalogue for Antarctic killer whales that is scheduled to go online in 2015. Preliminary analysis of the database provides evidence for long-distance migrations of TCKW between the Ross Sea and New Zealand waters: (a) One adult female TCKW has been re-sighted in both New Zealand waters and McMurdo Sound, Antarctica; (b) a large proportion of TCKW sighted in McMurdo Sound (33-55%) bear marks caused by cookiecutter sharks that are currently assumed to be limited to north of 50°S. TCKW have also been re-sighted between years in New Zealand waters and in McMurdo Sound, with a minimum distance of 11 km between inter-annual sightings, indicating that TCKW may show seasonal site fidelity to areas of high ecological significance.

INTRODUCTION

Together with Weddell seals, type-C killer whales (TCKW; *Orcinus orca*) have been identified as one of the two top predator species in the Ross Sea most at risk from effects of the Ross Sea toothfish fishery (Torres *et al.* 2013, Eisert *et al.* 2014). TCKW are one of several morphologically distinct forms ('ecotypes') of Antarctic killer whales (Pitman and Ensor 2003) and are thought to specialize on fish prey, in particularly Antarctic toothfish (*Dissostichus mawsoni*), which means that Ross Sea populations face a potential trophic overlap with the toothfish fishery (Torres et al. 2013). While there is good evidence that TCKW eat toothfish (Eisert *et al.* 2014), it is not clear whether toothfish represent an irreplaceable part of TCKW diet, or whether the fishery may plausibly affect the availability of toothfish to TCKW.

With regard to the potential dependence on Antarctic toothfish, a key determinant of resilience of TCKW is their effective foraging range. TCKW are considered the most pagophilic among Antarctic killer whale types, and are commonly compared with the (comparatively well-studied) North-East Pacific (NEP) 'Resident'-type killer whale populations that have a restricted range and exceptionally narrow dietary spectrum relative to killer whales elsewhere (Ford *et al.* 2010). However, information on TCKW in the Ross Sea is still quite sparse and limited to the austral summer (Dec-Feb). One characteristic of TCKW that sets them apart from NEP Residents is that TCKW appear to undergo long-distance migrations, with repeated sightings as far north as southern Australia and northern NZ (Visser 1999, 2007, Dwyer and Visser 2011); Donnelly *et al*., unpublished observation). It is unclear whether TCKW have generally a wider distribution than previously assumed that includes areas north of the Antarctic Polar Front, or whether Antarctic TCKW routinely undergo long-distance migrations. It has been suggested that Antarctic killer whales perform rapid return travel to subtropical latitudes to facilitate skin regeneration but do not feed during these journeys and return south almost immediately (TBKW; Durban and Pitman 2011). Long-distance migrations

are a central component of the life history of many baleen whales, who give birth at low latitudes and travel to feed in the highly productive polar oceans (Oftedal 1997). However, the reproductive strategies of odontocetes and mysticetes diverge, and fasting migrations are not generally thought to be part of the odontocete life history (Oftedal 1997).

The question of where (and why) Antarctic killer whales spend their time matters, because extended residence time in the north would indicate that TCKW feed outside of the Ross Sea. This in turn implies that TCKW must have considerable dietary plasticity, simply because of the differences in prey spectrum and prey availability encountered along this extended latitudinal gradient.

The key knowledge gaps that currently limit our ability to assess risks to TCKW in the Ross Sea are: (a) diet of TCKW and seasonal variation thereof, (b) foraging areas, habitat use, and migration patterns, and (c) abundance and population structure. The Top Predator Alliance of New Zealand (TPA) started an Antarctic killer whale research programme in 2013 specifically to address these uncertainties. To this aim, we have (1) collected biopsies for stable isotopes collected in early Dec and mid-late January to assess general trophic position and increase knowledge about summer diet and (2) together with collaborators, compiled a photo-identification (photo-ID) catalogue from multiple sources, including citizen-science efforts. This catalogue will be used to estimate abundance from mark-recapture analysis, and investigate migration patterns, habitat use, and site fidelity of TCKW and other killer whale types in the Ross Sea sector of the Southern Hemisphere, including areas outside the Antarctic. We report here preliminary findings on TCKW ecology from the first two seasons of the Top Predator Alliance (TPA) killer whale research programme.

METHODS

Field methodology. All Antarctic field observations took place in the McMurdo Sound area during the austral summer season. Killer whales were studied during helicopter flights and from the sea fast ice in southwestern McMurdo Sound during the period from 20 to 28 January 2014 and from 06 Dec 2014 to 27 January 2015. The research was staged from the New Zealand Antarctic station, Scott Base (77°51' S, 166°46' E) using a AS350 B2 helicopter operated for Antarctica NZ by Southern Lakes Helicopters, NZ.

Our research priorities were to (1) photograph killer whales for photo-identification (photo-ID) and (2) collect dart biopsy samples from killer whales as well as from minke whales (*Balaenoptera bonaerensis*) on an opportunistic basis. All biopsied animals were photographed. Biopsy samples will be analysed for DNA and stable isotopes ($\delta^{13}C$, $\delta^{15}N$) to obtain information on diet and trophic position of whales. We also recorded whale behaviour and underwater acoustics, and trialled the collection of skin swab samples.

Whales were photographed both from the air (through the open door of the helicopter) and from the ice edge using 3 Canon Eos 7D cameras equipped with stabilized 28-300, 70-200 mm and 18-85 mm zoom lenses. Biopsy samples were collected from the ice edge using Paxarms B24 guns fitted with a tethered biopsy dart system and exchangeable barrels. Whale vocalisations were recorded using a Tascam DR 680 recorder together with a hydrophone deployed over the ice edge at a depth of *ca*. 5-10 m. Whales were filmed underwater using 'GoPro' video cameras (3+ black edition) fixed to poles. Skin swab samples were collected using sterilised household scrubbing pads fixed to extendable poles.

Photo-identification database. The photo-identification database was assembled by adding new material from two research seasons in McMurdo Sound (2013-14 and part of 2014-15) and from other sources (tour operator Heritage Expeditions collection, staff and visitors of Scott Base) to a large existing database, the Antarctic Killer Whale Identification Catalogue, ('AKWIC'; Berghan and Visser 2001) established by the Orca Research Trust in 2001 (Table 1). In addition to photographs of killer whales taken in the Southern Ocean, the AKWIC database also contains images of type-C killer whales photographed in New Zealand waters.

A preliminary analysis of photo-ID matches has been carried out to identify re-sightings of Antarctic killer whales between Antarctic and New Zealand waters and between seasons in the same locations (New Zealand, McMurdo Sound).

Images of killer whales photographed in Antarctica were also analysed to determine the prevalence of marks attributable to cookiecutter shark bites (*Isistius* spp.) to estimate the minimum proportion of whales that had spent time north of *ca*. 50°S (Dwyer and Visser 2011; unpublished trawl survey data, Ministry of Primary Industries). The

proportion of marked whales was estimated separately for left and right sides and classified according to Dwyer & Visser (2011) as either 'assumed' cookiecutter bite marks (only marks attributable to *Isistius* with a high degree of confidence) or 'suspected' (similar in appearance to marks in the 'assumed' category but less clear definition of the bite mark or scar; likely caused by cookiecutter sharks).

RESULTS

Sample collection and foraging behaviour. We collected 33 dart biopsy samples including 27 samples from killer whales (26 type C, 1 type B) and 6 samples from Antarctic minke whales. Two skin swab samples were collected from TCKW. With the exception of 7 type-B killer whales (TBKW; 5 adults, 2 calves), all killer whales sighted in the McMurdo Sound region belonged to type C (TCKW). Feeding behaviour was observed on multiple occasions, but prey could only be tentatively identified as *Pagothenia borchgrevinki* and *Trematomus* spp. In contrast to the 2013/14 season, when toothfish predation was observed on five occasions (Eisert *et al.* 2014), no feeding on Antarctic toothfish (*Dissostichus mawsoni*) was observed during the 2014/15 season.

Photo-ID database - sources, design, scope. The present composition of the Antarctic killer whale database, including the sources and date range of images, is shown in Table 1.

Table 1. Total number of killer whale images in the photo-identification database and their sources.

	Date range	**Type A**	**Type B**	**Type C**	**Type unknown**	**All**
AKWIC (Southern Ocean & NZ)	2001 - 2015	1,108	672	2,135	1	3,916
Heritage Expeditions (Ross Sea region)	2008 - 2014	9	1	183	0	193
TPA photographs (McMurdo Sound)	2013/14 - 2014/15 (partial)	-	902	5,019	321	6,242
Scott Base staff (McMurdo Sound)	2013/14	-	878	164	21	1,063
Total number of photographs	**2001 - 2015**	**1,117**	**2,453**	**7,501**		**11,414**

Photo-ID database - resightings. One adult female TCKW (ID: ANT-C-0008) was matched between New Zealand waters and McMurdo Sound over a linear distance of *ca*. 4,660 km, with multiple re-sightings in both locations (Table 2, Fig. 1). According to a preliminary analysis of the database, 8 TCKW were re-sighted between years in McMurdo Sound (Table 3, Figures 2-4). Linear distances between re-sighting locations in McMurdo Sound ranged from 11 to 42 km, and the convex polygon bound by the re-sighting locations covers an approximate of 843 km^2 (Fig. 2).

Photo-ID database - marks attributable to cookiecutter shark bites. Approximately three-quarters of images of individually identifiable killer whales photographed in Antarctica were of sufficient quality (98/143 left side, 125/162 right side) to allow identification of marks caused by cookiecutter shark bites (Fig. 5, 6). Marks attributable to cookiecutter sharks with a high degree of confidence ('assumed' category according to Dwyer & Visser 2011) were found on *ca*. one-third of individual whales examined, and 50-60% of individuals were found to have marks suspected to have been caused by cookiecutter sharks (Fig. 7). Because these estimates only apply to the body surface of the whale visible in photographs, they likely represent the lower limit of prevalence.

Table 2. Repeated sightings of the adult female TCKW ANT-C-0008 off Northland, New Zealand, and in McMurdo Sound, Antarctica. The distance between repeat sighting locations in McMurdo Sound in the 2013/14 and 2014/15 seasons is approximately 11 km. Data compiled by E.N. Ovsyanikova.

Date	Location	Latitude	Longitude	Group size	Group composition	Project/ Photographer	Comments
24/01/2001	Whangarei, Northland, New Zealand	35° 56' S	174° 38' E	~20	At least 7 adult males; 3 females with calves (including neonates); at least 8 unclassified.	AKWIC/I. N. Visser	The group was observed travelling south in 38m of water.
01/03/2006	Bream Head, Whangarei, Northland, New Zealand.	35° 59' S	174° 37' E	≤10	At least 3 adult males; 2 females (identified from other years); at least 1 neonate calf; at least 1 unclassified.	AKWIC/Ian Graham	The group was seen travelling north.
03/03/2011	Bay of Islands, Northland, New Zealand	~	~	~20	At least 12 adult males; 2 females with calves (including neonate); at least 14 unclassified.	AKWIC/ Photographs collected by Jochen R. Zaeschmar Explore Images.	-
22/01/2014	McMurdo Sound, Ross Sea	77° 42' 27" S	165° 1' 19" E	n/r	n/r	TPA/P. H. Ensor	Near the ice edge.
27/01/2014	McMurdo Sound, Ross Sea	77° 42' 27" S	165° 1' 19" E	n/r	At least 5 adult males; 4 females with calves; others.	TPA/P. H. Ensor	Near the ice edge. The group was foraging on toothfish.
15/01/2015	McMurdo Sound, Ross Sea	77° 37' 32" S	165° 16' 36" E	n/r	n/r	TPA/P. H. Ensor	-

Figure 1: Adult female TCKW ANT-C-0008 in Northland, NZ (**A**), and in McMurdo Sound, Antarctica (**B**).

A. 24 Jan 2001. Photo: AKWIC/ Ingrid Visser

03 March 2011 Photo: AKWIC/ J.R. Zaeschmar

B. 27 Jan 2014. Photo: TPA/ Paul Ensor

15 Jan 2015. Photo: TPA/ Paul Ensor.

Table 3. Re-sightings of type-C killer whales and number of identified individual killer whales in McMurdo Sound, Antarctica, within and between seasons. n/a, not yet analysed

	Whale ID	14-Feb 2008	26-Jan 2010	20-Jan 2014	22-Jan 2014	23-Jan 2014	24-Jan 2014	25-Jan 2014	27-Jan 2014	12-Apr 2014	11-Dec 2014	12-Dec 2014	13-Dec 2014	15-Jan 2015
1	ANT-C-00098	+	-	-	-	-	-	-	+	-	-	-	-	
2	ANT-C-00099	+	-	-	-	-	-	-	+	-	-	-	-	
3	ANT-C-00219	-	-	+	+	-	+	-	-	-	-	-	-	
4	ANT-C-00183	-	-	-	+	-	-	-	+	-	-	-	-	
5	ANT-C-00257	-	+	-	+	-	-	-	-					
6	ANT-C-00258	-	+	-	+	-	-	-	-					
7	ANT-C-00275	-	-	-	+	-	-	-	+	-	-	-	-	
8	ANT-C-00281	-	-	-	+	-	-	-	+	-	-	-	-	
9	ANT-C-00292	-	-	-	+	-	-	-	-	-	+	-	-	
10	ANT-C-00297	-	-	-	+	-	-	-	-	-	+	-	-	
11	ANT-C-00293	-	-	-	+	-	-	-	-	-	+	+	-	
12	ANT-C-00295	-	-	-	+	-	-	-	+	-	-	-	-	
13	ANT-C-00300	-	-	-	+	-	-	-	-	-	-	+	-	
14	ANT-C-00008	-	-	-	+	-	-	-	+	-	-	-	-	+
15	ANT-C-00311	-	-	-	-	-	+	-	-	-	+	-	-	
16	ANT-C-00317	-	-	-	-	-	+	-	+	-	-	-	-	
Total Photo-IDs		**7**	**7**	**10**	**63**	**1**	**18**	**6**	**58**	**6**	**17**	**6**	**23**	**n/a**

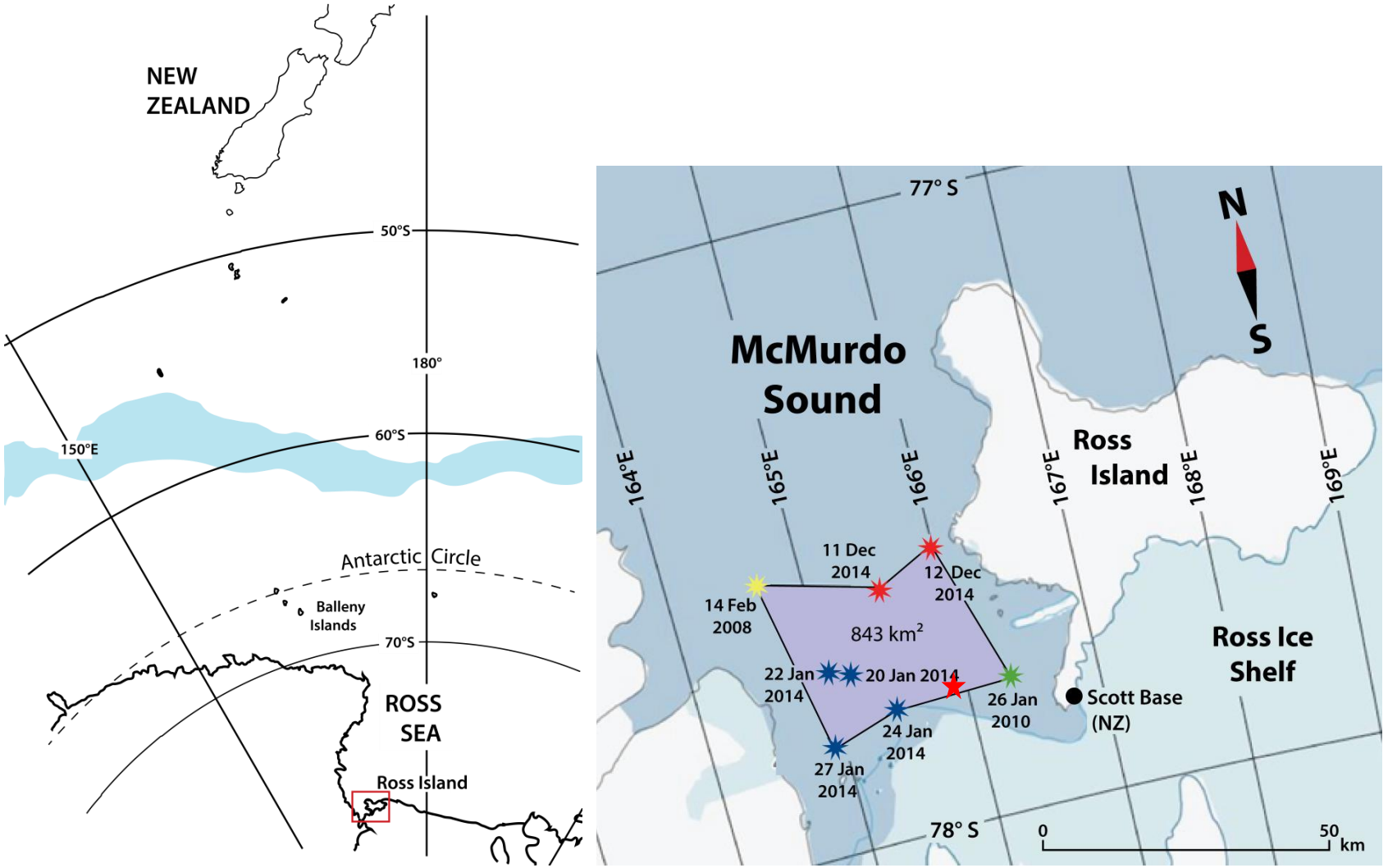

Figure 2: Map of the Ross Sea region and of McMurdo Sound (inset) showing locations of re-sightings of type-C killer whales and the associated convex polygon area in McMurdo Sound. Colours denote seasons (yellow = 2007/8, green= 2009/10, blue=2013/14, red=2014/15). The approximate position of the Antarctic Polar Front is shown in light blue (Moore *et al.* 1999).

Figure 3A: Adult female TCKW ANT-C-00098 "Stumpy" with calf, at 77° 33' S 164° 40' E, 20:31 14 Feb 2008. Photo: AKWIC / Santiago Imberti

Figure 3B: "Stumpy" at 77° 49' 56"S 164° 56' 43"E 10:25 AM 27 Jan 2014 Distance 2008-2014: 32 km. Photo: TPA / Paul Ensor

Fig. 3C: "Stumpy" with calf, at 77° 36' 43.554" S, 165° 30' 14.19" E, 19:02 15 January 2015, 27 km from Jan 2014 sighting, 21 km from Feb 2008 sighting. Photo: TPA / Rohan Currey

Figure 4: Another example of a re-sighting of a type-C killer whale in McMurdo Sound, Antarctica, in 2007 and 2015 (in addition to data shown in Table 3 above).

Adult male TCKW "Adam", photographed in the McMurdo icebreaker channel, ca. 5 km N of McMurdo Station, on 23 Jan 2007.

Photo: AKWIC / Mike White

"Adam"

Photographed at the sea ice edge in McMurdo Sound at 77° 37' 38.442" S, 165° 8' 30.276" E, *ca*. 40 km NW of 2007 sighting, on 15 Jan 2015. Photo: TPA / Rohan Currey

Figure 5: Type-C killer whale with a fresh wound inflicted by a cookiecutter shark, photographed in the Bay of Islands, New Zealand, 23 April 2015. Photo supplied by Ingrid Visser/ORT

Figure 6: Type-C killer whale with a scar left by a healed cookiecutter bite in McMurdo Sound, Antarctica. Photo: Paul Ensor.

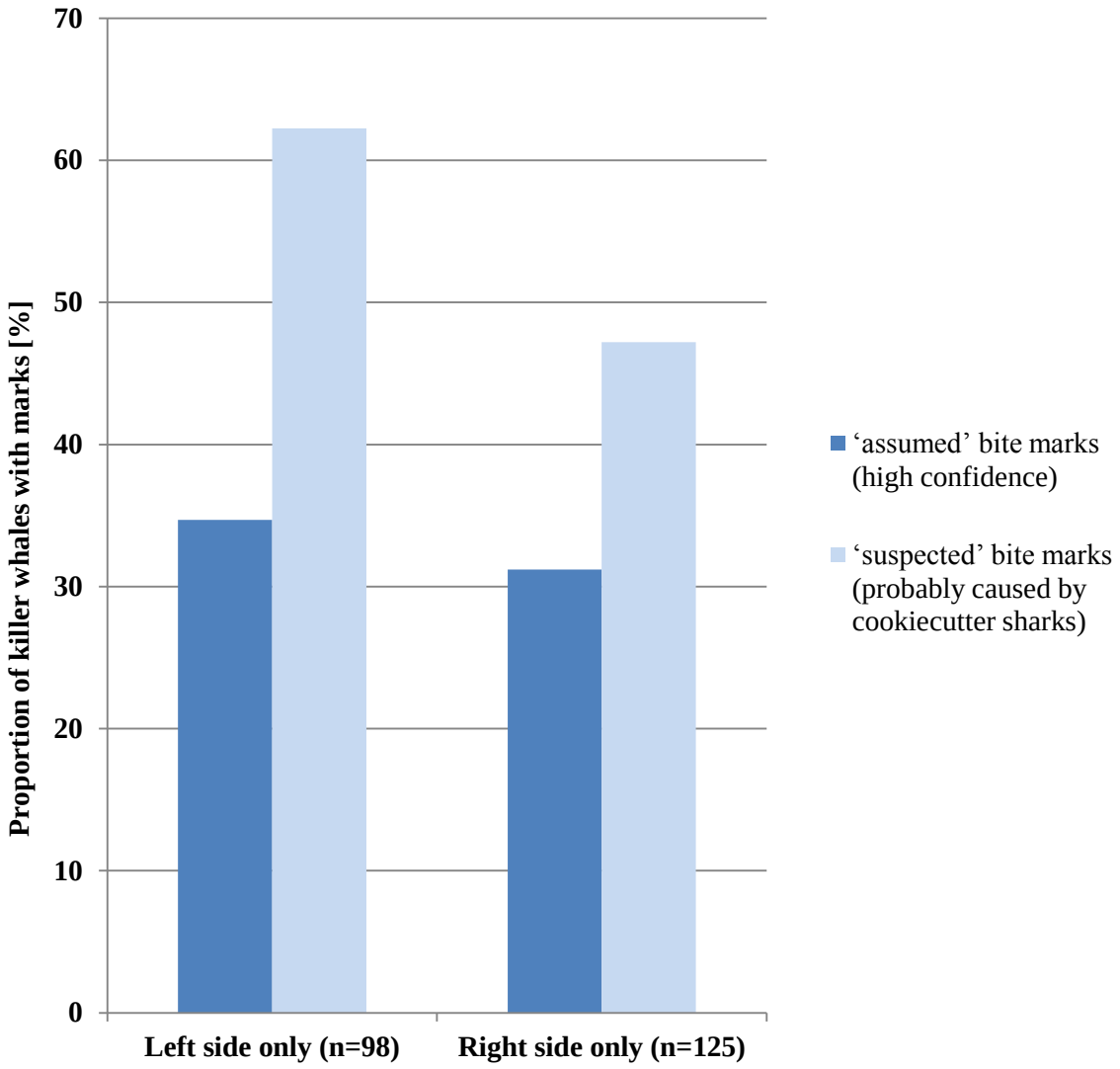

Figure 7: Proportion of type-C killer whales sighted in Antarctic waters with marks attributed to bites from cookiecutter sharks (*Isistius* spp.). Marks were classified according to Dwyer & Visser (2011). Data compiled by E.N. Ovsyanikova.

DISCUSSION

Antarctic killer whales, primarily TCKW but also TBKW, have been sighted repeatedly off the coast of New Zealand and Australia during the austral spring, summer, and autumn (Visser 1999, 2007, Dwyer and Visser 2011). While this means Antarctic killer whales have a larger distribution than previously assumed, it is not clear whether some populations primarily inhabit waters north of the Antarctic Polar Front and others live further south, or whether these sightings result from long-distance movements or even regular migrations.

Our reported photo-ID match for the same individual adult female TCKW off the coast of Northland, NZ, and in McMurdo Sound, Antarctica, provides evidence that Antarctic killer whales from the Ross Sea region undergo long-distance migrations to at least northern New Zealand. Long-distance movement of Antarctic killer whales had previously been shown to occur by Durban and Pitman (2012), and has also been suggested based on evidence for cookiecutter shark parasitism of Antarctic killer whales (Dwyer and Visser 2011). Cookiecutter sharks (*Isistius* spp.) are small sharks occurring in temperate and tropical latitudes that feed by excising plugs of tissue from their prey, including cetaceans. Cookiecutter shark bites result in circular or oval lesions that heal to form diagnostic marks (Figures 5, 6), which may persist for at least several years (Dwyer and Visser 2011). During a preliminary analysis of our photo-ID database, we found marks attributable to attacks by cookiecutter sharks on 33-55% (depending on criteria used for identifying marks) of TCKW sighted in McMurdo Sound (Fig. 7), suggesting that a large proportion of these TCKW have spent time north of the Antarctic Polar Front. Even though the absolute southern limit of *Isistius* spp. cannot be ascertained at this time, it is likely to be north of 50°S, emphasizing that "Ross Sea killer whales" are by no means limited to the Ross Sea.

We also report a considerable number of inter-annual re-sightings of TCKW within McMurdo Sound. Importantly, distances between re-sighting locations were small (~10-40 km). This is in apparent agreement with the only previous study on movement patterns of TCKW in McMurdo Sound by Andrews *et al.* (2008), who found that TCKW ($n = 4$) travelled on average 20±8.3km.day^{-1} , with a maximum of 56 km per day. This relatively low rate of movement invites comparison of TCKW with the fish-eating Resident type of the eastern North Pacific (ENP; Andrews *et al.* 2008), but this analogy may be misleading. Firstly, three of four TCKW tagged were followed for less than two weeks, so it not clear how representative these results are for TCKW movement patterns. Secondly, during winter and spring (Apr-Nov), the area in McMurdo Sound were TCKW have been sighted is completely ice-covered and unlikely to be accessible to killer whales, which means that the whales cannot remain in the area but instead return seasonally to the same locations. The degree of site fidelity indicated by our preliminary analysis suggests that whales return to specific locations that are ecologically significant. A plausible scenario would be that that TCKW travel to McMurdo Sound from elsewhere and congregate during the austral summer to take advantage of seasonal peaks in prey abundance and / or of prey (*e.g.*, toothfish) made accessible to them by the recession of the sea fast-ice.

McMurdo Sound may be a particularly important foraging habitat, as it appears to contain a greater proportion of large toothfish than elsewhere on the Ross Sea Shelf (Mormede *et al.* 2014). Importantly, these fish are found in an area of relatively shallow bathymetry, *i.e.*, within the estimated diving range of TCKW (~600m, Pitman unpublished data cited in Torres *et al.* 2013) once the sea ice recedes. Differences in the observed foraging behaviour between the 2013/14 season (Eisert *et al.* 2014) and the 2014/15 season, specifically with regard to toothfish predation, are likely due to the greater degree of sea ice recession in 2013/14 that allowed killer whales access to areas of shallow water along the south-western margin of McMurdo Sound that is usually covered by sea fast-ice. Presence of large Antarctic toothfish in fast-ice covered parts of southern McMurdo Sound in 2014/15 was confirmed both by scientific collections (Parker *et al.* submitted) as well as frequent observations of toothfish predation by Weddell seals (Eisert *et al.*, unpublished data).

CONCLUSIONS

New data presented here confirm that Antarctic killer whales, in particular TCKW, travel between the southern Ross Sea and New Zealand waters. This suggests not only ecosystem connectivity between the Ross Sea and New Zealand, but also the need to re-evaluate the profile of potential threats faced by, and capacity for resilience in, this top predator. A preliminary analysis of photo-ID data indicates that TCKW in the McMurdo Sound area show a high degree of seasonal site fidelity, with whales possibly returning to areas of particular ecological significance.

The unexpectedly complex movement patterns and broad spatial scale exhibited by TCKW has important implications for our understanding of the ecology of this key Ross Sea predator, and would be best addressed by multi-national collaborative efforts that may be usefully informed by expertise on other migratory cetaceans, including baleen whales.

ACKNOWLEDGEMENTS

We thank our funders, the New Zealand Antarctic Research Institute (NZARI) and the Ministry of Primary Industries (MPI), for supporting our research. We thank Antarctica New Zealand for providing field logistics and the pilots at Southern Lakes for outstanding support. We are grateful to Heritage Expeditions and many people at Scott Base for contributing images to our database. We gratefully acknowledge assistance from Canon NZ Ltd. This work was carried out under a Marine Mammal Permit issued by the New Zealand Department of Conservation (37933-MAR) and Antarctic field work was authorised by the New Zealand Ministry of Foreign Affairs and Trade (MFAT).

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