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Short Note

Immigration and emigration in the isolated White Island Weddell seal (*Leptonychotes weddellii*) population

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Introduction

The small, isolated population of Weddell seals (*Leptonychotes weddellii* Lessen) at White Island, Antarctica, is the southernmost breeding population of mammals in the world and occurs alongside an island surrounded by thick, glacial ice (Hückstädt 2017). Historical records suggest that the White Island population was founded at some point in the late 1950s by immigrant seals from the nearby Erebus Bay Weddell seal population when part of the Ross Sea and McMurdo ice shelves broke out, which allowed seals to swim underneath the ice shelf to reach White Island (Heine 1963, Shaughnessay 1969). However, as the Ross Sea and McMurdo ice shelves advanced, the distance between White Island and the ice-free ocean to the north grew, which trapped and isolated the founding seals at White Island (for a more detailed history of the population, see Gelatt *et al.* 2010). Recent genetic work suggests that 18 seals founded the population, though it is possible that as few as three females and two males were the original founders (Gelatt *et al.* 2010, Miller *et al.* 2021). In the late 1990s, the population size was estimated at 26 individuals, which is substantially more than were observed in the late 1960s (Stirling 1972, Testa & Scotton 1999). This small population size has resulted in inbreeding, reduced pup survival and low genetic variability (Gelatt *et al.* 2010). Without gene flow, the persistence of the White Island population is uncertain. Our aim in this short note is to provide an update on the pupping at White Island and to formally document the movement of seals between White Island and Erebus Bay.

Weddell seals are a true seal species distributed circum-Antarctica (Wilson 1905, Hückstädt 2017). Weddell seals are exceptional divers, with full-grown adults regularly holding their breath for 30 min and diving between 300 and 400 m deep (Kooyman 1967, Zapol 1987). Early research suggests that their horizontal swimming radius from a dive hole is 4.6 km (Kooyman 1967) or ~9.2 km straight-line distance, which is consistant with their swimming velocity and maximum dive times (Castellini *et al.* 1992); however, pups and juvenile Weddell seals have shorter dive times and shallower dive depths than adults (Burns 1999, Burns & Castellini 1996). Breeding and reproduction occur during the summer (October–December), and in most pupping colonies mothers raise their single pup on the annually occurring sea ice, but at White Island mothers give birth on an ice sheet (i.e. glacial ice) that surrounds the colony (Stirling 1969, Siniff *et al.* 1977, Testa & Scotton 1999).

The White Island colony (77°100'S, 167°200'E; Fig. 1) is located ~20 km south of open ocean and is surrounded by the Ross Sea and McMurdo ice shelves. Despite the incredible diving abilities of Weddell seals, it was thought that the distance between White Island and Erebus Bay was too far for a Weddell seal to swim. Instead, to access open ocean at White Island, Weddell seals use the narrow crack along the north-west side of the island kept open by tidal action and ice-shelf movements (Stirling 1972). This crack is the only known access to the ocean surface, with the rest of the ice in the vicinity being more than 15 m thick (Castellini *et al.* 1984).

Methods

The population at White Island has been observed since 1961 and studied with sporadic capture-mark-recapture work until 1991, when systematic, annual capture-mark-recapture efforts began (Stirling 1972, Testa & Scotton 1999). To mark individual seals, individually identifiable plastic livestock tags (variety of manufacturers and models) are applied to the interdigital webbing of the rear flippers. Tag retention is between 0.950 and 0.999 for the nearby Erebus Bay colony, and rates for White Island are most probably similar (Testa 1992). Since 1991, researchers have conducted at least two trips to White Island during the summer to tag all pups encountered, to conduct resight surveys and to replace any broken or lost tags on previously tagged individuals. In 1994, 1996, 2020 and 2021, only one trip to White Island was conducted per year. In the nearby Erebus Bay population (77°42'S, 166°30'E; Fig. 1), extensive efforts to tag every single pup in the study area began in 1982. Recruiting adults without tags are also individually marked when first encountered, maintaining an entire population of uniquely marked individuals. Therefore, since 1991, the Weddell seal populations at both White Island and Erebus Bay remain almost completely individually marked

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Figure 1. (a) White Island (yellow) and Erebus Bay (blue) colonies relative to the Antarctic continent. (b) A closer look at the White Island Weddell seal colony (yellow), the ice-shelf boundary (blue line), the Erebus Bay Weddell seal colony (blue) and the four discussed locations (green circles). Produced with *Quantarctica* (https://www.npolar.no/quantarctica); LIMA high-resolution imagery (15 m); SCAR Antarctic Digital Database Version 7.0.

and identifiable, allowing researchers to track any potential movement between the two colonies.

Results and discussion

Between 1991 and 2023, an average of 4.82 pups (SD = 2.01) were encountered and tagged each year at White Island (Fig. 2), and the adult population has remained relatively stable throughout that time (J.J. Rotella, unpublished data). There is no record of individuals moving between the White Island and Erebus Bay populations before 2016. From 2016 to 2023, there were multiple observations of movements between the two populations.

In 2016, the skeleton of a 2 or 3 year-old seal that had been tagged at White Island in 2012 as a pup (unique identifier: 30135) was found on the shallow ocean floor near a dive hole at the base of Arrival Heights in Erebus Bay (Fig. 1; J. Burns, S. Rupp & B. Konar, personal communication 2016). The seal was aged using the cementum annuli in its well-preserved tooth (J. Burns, personal communication 2017). It is unknown how the seal came to rest at this location or whether it arrived at the location as a live or dead animal.

In 2017, a yearling female (unique identifier: 24258) that was tagged as a pup in 2016 at the Turtle Rock sub-colony in Erebus Bay was observed twice at White Island (Fig. 1). She has not been seen since, which is not unexpected. Although females born in Erebus Bay are typically resighted for the first time at 4.5 years old and recruit into the population at 7.6 years old, there is individual heterogeneity in resight and recruitment patterns (Hadley *et al.* 2006, Stauffer *et al.* 2013).

In 2021, an 8 year-old male (unique identifier: 30139) that was tagged at White Island as a pup in 2013 was recorded once during a resight survey in Erebus Bay. He was seen at Pram Point, the sub-colony closest to White Island (Fig. 1). He was never seen at White Island or Erebus Bay before the encounter, and he has not been seen at either location since 2021.

In 2022, a 6 year-old female (unique identifier: 24403), originally tagged as a pup at the Turtle Rock sub-colony in 2016, was observed at White Island in November with a newborn female pup (unique identifier: 30183). It is unknown whether she was bred by a male from White Island or Erebus Bay. In November and December of 2023, the same adult female (unique identifier: 24403) was observed back in Erebus Bay near the Turtle Rock sub-colony on four separate resight surveys; she was not seen with a pup in 2023. Also in 2023, her pup (unique identifier: 30183), at that point a yearling, was observed directly in front of McMurdo Station on 10 December 2023, over 25 km from her birth location. We do not know whether the mother and pup emigrated from White Island together, but we do know that after being observed at White Island in 2022, they were both seen in Erebus Bay during the subsequent year.

Although previously thought impossible, we document two different adults and two different subadults moving in and out of the White Island colony for a total of five movement events (Table I). These are the first confirmed records of movement in or out of White Island (with one of these sightings already mentioned in Miller *et al.* 2021). These observations show that, although rare, it is possible for both adults and juveniles to travel between the two locations. An additional emigration event in 2024 of a 3 year-old male born at White Island (unique identifier: 30180) that was resighted at Tent Island in Erebus Bay highlights the increasing prevalence of these migration events. Further genetic work is required to determine whether gene flow has occurred as a result of these movements.

We speculate on a few potential explanations for the increase in movement events:

1) Travel between the two colonies has always been possible, but because of the small population size at White Island and the rarity of migration events, travel is infrequently observed. While it was assumed the distance between the two colonies was greater than a Weddell seal could swim, many seal species demonstrate individual heterogeneity in diving behaviour depending on sex, reproductive status, prey availability and

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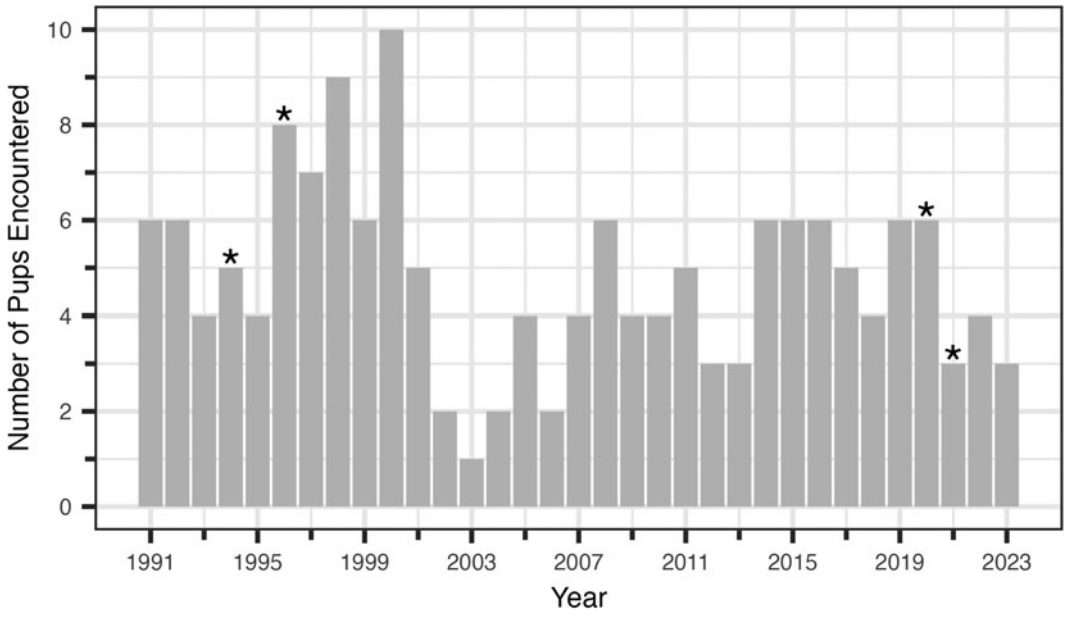

Figure 2. The number of Weddell seal pups encountered and tagged at White Island each year since records began in 1991, with years when only one survey was conducted denoted by asterisks.

Table I. Summary of all recorded Weddell seal movement events between White Island and Erebus Bay.

Year seen	Unique identifier	Sex	Direction	Birth location	Observation location	Age when sighted	Seen alive?
2016	30135	M	Emigration	White Island	Arrival Heights, Erebus Bay	2–3 years	No
2017	24258	F	Immigration	Turtle Rock, Erebus Bay	White Island	1 year	Yes
2021	30139	M	Emigration	White Island	Pram Point, Erebus Bay	8 years	Yes
2022	24403	F	Immigration	Turtle Rock, Erebus Bay	White Island	6 years	Yes
2023	24403	F	Emigration	-	Turtle Rock, Erebus Bay	7 years	Yes
2023	30183	F	Emigration	White Island	McMurdo Station, Erebus Bay	1 year	Yes

F = female; M = male.

environmental conditions (Lea *et al.* 2002, Beck *et al.* 2003, Shero *et al.* 2018).

2) Recent decreases in sea-ice extent have shortened the distance between the two colonies (Parkinson 2019). For example, in February of 2021 and 2022, the sea ice in Erebus Bay broke out all the way to the ice shelf, decreasing the distance between White Island and open ocean in Erebus Bay to just over 18 km (NASA Worldview: https://worldview.earthdata.nasa.gov/). This could have allowed the male (unique identifier: 30139) to swim to Erebus Bay before we observed him in December 2021, or the female (unique identifier: 24403) to swim to White Island before we observed her with a pup in November 2022.
3) The Ross Sea and McMurdo ice shelves have changed in structure or size, potentially providing usable breathing areas for seals transiting between the two locations. The instability of the McMurdo Ice Shelf combined with fluctuating ice thicknesses as a result of a warmer undercurrent in years with less sea ice may result in a vastly different underwater ice-shelf structure than in previous years (Glasser *et al.* 2006, Robinson *et al.* 2010).
4) Shifts in oceanic conditions have changed the ocean currents occurring under the ice shelves, making it easier to swim to White Island, as the predominant ocean current is from Erebus Bay to White Island (Barry & Dayton 1988). The velocity of ocean currents under the McMurdo Ice Shelf depends on the season, amount of warm water and salinity (Mahoney *et al.* 2011), which may be altered if the ocean composition changes.
5) Overland travel has become more viable. Weddell seal tracks have been observed on the surface of the ice shelf originating from White Island and travelling as far as 3 km in the direction of Erebus Bay (M. Castellini, personal communication 2024).

Perhaps a combination of the above events has led to more interchange between the two populations.

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Competing interests. The authors declare none.

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