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SHORT COMMUNICATION

Initial insights into leopard seal moult in Aotearoa New Zealand

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Abstract: Leopard seal (*Hydrurga leptonyx*) moult affects the application of glued tags used to monitor activity. Considering the possible effects of climate change on leopard seal activity and climate on pinniped moult, we assessed aspects of leopard seal moult in a warm region (New Zealand) of their range for the first time. Moult pelage colours resembled those found in their primary range and indicated a progressive degeneration akin to that of the pre-moult of other pinnipeds. Unexpectedly, pelage loss commonly resulted in black areas, that may be skin or short dark post-moult pelage. The reverse pattern of moult, reported for the first time in this species, was more prevalent than the standard pattern. In the reverse pattern, black areas commonly progressed from the neck down the spine. Pre-moult was uncommon, but active moult occurred year-round. Year-round moulting may have implications for glued tagging in climatically similar regions of their range.

Keywords: fur, *Hydrurga leptonyx*, molt, moult phenology, phocid

Introduction

As leopard seals (*Hydrurga leptonyx*), rāpoka | popoiangore | poipopiangori | popoikore (hereafter 'leopard seals') are primarily found in the remote Antarctic pack ice and sub-Antarctic Islands (Laws 1977; Rogers 2013), the effects of climate change on sea ice (including pack ice) may have considerable implications for their activity (Meade et al. 2015). External tracking devices applied to the pelage, such as glued tags, have assisted in monitoring leopard seal activity (Rogers et al. 2005; Krause et al. 2016; Kienle et al. 2022), but their usage is limited by the loss and replacement of pelage during the annual moult (e.g. Rogers et al. 2005; Kienle et al. 2022).

Moult in pinnipeds, including leopard seals, maintains pelage functionality such as crypsis (Caro et al. 2012), hydrodynamic (Yochem & Stewart 2009) and thermal (Kvadsheim & Aarseth 2002) properties. As a major facet of pinniped life history, moult phenology and environmental variation across different regions have been widely studied (Badosa et al. 2006; Cronin et al. 2014; Fernández-Martín et al. 2016; Tapia-Harris et al. 2017). For leopard seals, the relatively limited published descriptions of pelage appearance during the three moult stages (pre-moult, active moult or moult, post-moult), active moult progression and the timing of pre- and active moult are focused on their primary range (see Appendix S1 in Supplementary Material).

Given the effects of a changing global climate and that moult varies with environmental conditions, initial insights into leopard seal moult in a warm region (relative to their primary range) may prove useful to glued tag application across their entire range. Here, we assess the moult of wild leopard seals in Aotearoa New Zealand (hereafter 'NZ') for the first time.

Methods

Moult records

Records of leopard seals collected opportunistically via LeopardSeals.org researchers and citizen scientists were collated in the NZ Leopard Seal Database (NZLSD; Hupman et al. 2020), including those containing photographs from 1889 to 2022. A 'moult record', defined as any record containing both good- and poor-quality photographs (Appendix S2) of moulting leopard seals (Table 1; Fig. 1a), was determined using published descriptions of moult pelage appearances (Appendix S1) and observations made during this study (Appendix S3). The use of poor-quality photographs and areas of wet pelage within photographs (making it difficult to discern moult; Daniel et al. 2003; Beltran et al. 2019) was restricted (see Appendix S4).

Annual moults

We attempted to assign moult records to unique individuals through photographic identification using good quality photographs. Photographic identification features included pelage patterns and injuries/scars following Hupman et al. (2020), as well as pelage appearances and signs of active moult (Table 1; Fig. 1a). A unique individual was only confirmed when a photograph of the left side of the face with visible pelage patterns was present (Hupman et al. 2020). This was not always possible because moult records did not always

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Figure 1. Photographs of leopard seals moulting in New Zealand. (a) '1–3' are representative examples of the three successive active moult sub-stages (1–3) in the reverse pattern from three annual moults. Sub-stage 1: Mostly non-uniform and browned or discoloured active moult pelage, few small black areas or minimal uniform and silvery post-moult pelage. Sub-stage 2: Decreasing active moult pelage, increasing black areas (either numerous and small or few and large) or post-moult pelage. Sub-stage 3: Minimal active moult pelage remains, few black areas may be present, mostly post-moult pelage. (b) side-on and (c) ventral perspectives, respectively, of a leopard seal highlighting body groups A–G (white letters) used to assess the progression and pattern of moulting in New Zealand: (A) nostrils, snout, eyes; (B) face and top of the head (head); (C) neck and throat; (D) shoulders and axillae; (E) fore and hind flippers; (F) chest and abdomen; and (G) the spine, upper and lower flanks (adapted from Badosa et al. 2006; Cronin et al. 2014). Photograph credits: (a1, b) Sarah Taylor; (a2) Alex Weller; (a3) Giverny Forbes; (c) Alexander Fohringer.

Table 1. Descriptions of leopard seal moult stages and sub-stages and associated pelage appearances in New Zealand.

Stage	Description	Pelage appearance
Pre	Pre-moult pelage present anywhere on the body and signs of active moult are not yet visible.	Pelage is non-uniform, browned or discoloured (dulled or lightened), and longer than post-moult pelage. Pelage patterns are faded.
Active	Varying degrees of active moult pelage, black areas, and post-moult pelage anywhere on the body. Split into three sub-stages (see Fig. 1).	Pelage resembles that of the pre-moult alongside signs of active moult (loose pelage, black areas, or post-moult pelage). Black areas may represent difficult to see short dark post-moult pelage (Gray et al. 2008) or bald skin. Pelage may become browned or increasingly discoloured as the active moult progresses.
Post	All pelage is post-moult pelage and signs of active moult are no longer visible.	Pelage is uniform, silvery, and shorter than pre-moult and active moult pelage. Pelage patterns return as pelage grows.

contain photographs of the left side of the face or visible pelage patterns due to fading or pelage loss. As moulting typically occurs annually and progresses over successive stages, pelage appearances and signs of active moult were compared chronologically with moult records within 12 months. Using one or a combination of these features, we were able to assign moult records to separate 'annual moult(s)', defined as a collection of moult records belonging to the same annual moult of a seal (Appendix S5). As such, although unlikely, it is possible that multiple different annual moults belong to one individual (e.g. in different years; Appendix S5). When individuals had more than one annual moult, only moult records belonging to the longest and most complete (i.e. from start to finish) annual moult were included.

Moult assessment

We qualitatively assessed moult records (following Cronin et al. 2014; Tapia-Harris et al. 2017; Beltran et al. 2019) for pelage colour, pattern, progression, and stages (including timing and duration). Several factors were considered to maximise the available data and reliability, including (1) determining that body sections on each side of the body could be used for moult assessment (Fig. 1b; Appendix S6), (2) that a reasonable proportion (≥ 66%) of one side or different sections of each side of the body was required for pelage colour and stage assessment, and (3) reliability testing (> 80%) with an external assessor (Appendix S4).

Moult pelage colour, pattern & progression

To assess variation in pelage colour during the pre and active moult, we determined pelage colours, including 'only browned', 'only discoloured', or 'both browned and discoloured', from pelage appearances (Table 1). We noted pelage colours and their changes in each annual moult by stage and pattern. Due to the uncertainty of what black areas were, we noted their prevalence separately.

To assess moult pattern and progression of each annual moult, all body sections were clustered into 'body groups' (adapted from Badosa et al. 2006; Cronin et al. 2014): (A) nostrils, snout, eyes, (B) face and top of the head (head), (C) neck and throat, (D) shoulders and axillae, (E) fore and hind flippers, (F) chest and abdomen, and (G) spine, upper and lower flanks (Fig. 1b, c; Appendix S6). The pattern of moult was either standard or reverse, depending on whether body sections in body groups A or E had started moulting before or after other body sections (Daniel et al. 2003; Appendix S4). We noted the frequency of signs of active moult around body openings and scars following Daniel et al. (2003). Moult progression was determined within body groups by (1) comparing moult codes that represent varying proportions of pelage appearances, including black areas (Appendix S7) between body sections, and (2) across body groups by comparing the average of moult codes applied to body sections in each body group.

Moult stages and sub-stages: timing & duration

The three stages of moult, including the three sub-stages of active moult (hereafter sub-stage 1–3), were assigned to each moult record by assessing pelage appearance (Table 1). An 'unknown' sub-stage was also assigned when photographs were not sufficient or reliable enough for assigning a sub-stage of active moult (Appendix S4). For each annual moult we grouped moult records by pre-moult, active moult sub-stage, and post-moult within a calendar month into 'monthly moult record(s)'. Unknown sub-stages were only included when they were the only type of moult record recorded in that month. When more than one stage or sub-stage were present in one month, separate monthly moult records were reported (e.g. two monthly moult records for an annual moult with moult records in sub-stages 1 and 2 in November). Monthly moult records were then pooled across years.

We assessed the timing of moult stages and sub-stages and identified the peak active moult (PAM, defined as the month with the highest number of monthly sub-stage records). When assessing the duration of the active moult, we arbitrarily used the first and last moult record from annual moults with an active moult period of more than seven days.

Results

We collated 203 moult records between 2001 and 2022 (1015 good quality and 88 poor quality photographs). These were assigned to 87 annual moults; 19 annual moults from 19 unique individuals and 68 annual moults from an unknown number of individuals: 14 males, 18 females, and 55 undetermined.

Moult pelage colour, pattern & progression

Pre-moult pelage was only browned ($n = 8$) or both discoloured and browned ($n = 4$). Active moult pelage was only browned ($n = 8$), both browned and discoloured ($n = 22$) or only discoloured ($n = 33$), and generally became more discoloured (e.g. dulled to white) or became browned ($n = 5$). The standard pattern ($n = 13$) contained only browned ($n = 8$) or browned and discoloured (n = 5) pelage, while the reverse pattern ($n = 50$) contained browned and discoloured ($n = 17$) or only discoloured ($n = 33$) pelage. Black areas were observed on all sections of the body and were common in annual moults observed during the active moult (98.7%, $n = 79$). For body group A, black areas usually appeared foremost around the nostrils, snout, and eyes in the standard and reverse pattern, but also below the mouth in the reverse pattern. Around other body openings (mammary glands, penile opening, urogenital slit) and scars, black areas were observed early in the active moult during sub-stages 1 ($n = 11$) and 2 ($n = 4$).

Due to few observations, we could not determine a common progression in the standard pattern or post-moult pelage growth ($n = 9$). In the reverse pattern (Fig. 1a), black areas most commonly progressed from body groups B or C ($n = 18$), and appeared to spread to body group D and further down the spine ($n = 40$), with varied progression across body groups E, F, and G. Post-moult pelage was observed immediately replacing moult pelage (i.e. no black areas) and more delayed (from black areas). The next body section to lose pelage or display post-moult pelage was not contingent upon the previous body section to finish losing pelage or display post-moult pelage.

Moult stages and sub-stages: timing and duration

Moult records formed 130 monthly moult records (16 pre-moult, 113 active moult, and 1 post-moult; Appendix S8). Three annual moults contained more than one moult stage in the same month and six contained more than one sub-stage. Four monthly moult records were assigned as an unknown sub-stage. Pre-moult occurred in every season and displayed no peak. Active moult occurred year-round, peaking in October ($n = 29$). Most monthly sub-stage 1 records (66.7%, $n = 63$) occurred before and during PAM; most monthly sub-stage 2 records (78.4%, $n = 37$) within two months of PAM; and most monthly sub-stage 3 records (66.7%, $n = 6$) during and after PAM. Low pre-moult records precluded the determination of its duration. The mean (± SD) active moult duration, obtained from 18 annual moults, was 53 (± 41) days. One annual moult (the longest, lasting 267 days), was separated from this assessment due to its relatively higher resighting rate. Two individuals were observed moulting across multiple years (i.e. annual moults), with their recorded (shorter) active moults falling within the date ranges of their longest.

Discussion

Pelage colour variations during the pre- and active moult of leopard seals in NZ resemble the limited published descriptions of leopard seals moulting in their primary range. These colour variations indicate a progressive degeneration of pelage akin to the pre-moult of other pinnipeds (Daniel et al. 2003; Cronin et al. 2014; Tapia-Harris et al. 2017). However, there are indications that pelage loss reported here is atypical or premature (i.e. before visible post-moult pelage develops): pelage commonly remained discoloured prior to its loss, pelage loss commonly resulted in black areas, and post-moult pelage only occurred alongside browned pelage, often later in the active moult (sub-stage 3).

Historical photographs (Fig. 2; Bailey & Sorensen 1962) may display the black areas reported here, but without accompanying descriptions or colour photographs this cannot be confirmed. In other pinnipeds, similar black areas have been observed during the moult, particularly around body openings (Badosa et al. 2006; Tapia-Harris et al. 2017). Black areas elsewhere on the body during the pinniped moult have been linked to: (1) the first long moult of juveniles (S. Sayer, Cornwall Seal Group Research Trust, pers. comm.), (2) physical wear of pelage by the environment (Borowicz et al. 2021), and (3) atypical photoperiod conditions in healthy captive animals (Mo et al. 2000). In contrast, black areas may be caused by factors such as disease or physiological stress (Colegrove et al. 2018). Notably, Pugliares-Bonner et al. (2018) hypothesised that compromised immune systems, pathogens or viral agents in warm water temperatures, poor diet, or stress may have caused similar black areas on the neck and shoulders of grey seals (*Halichoerus grypus*). Furthermore, the reverse pattern of moult in other pinnipeds has been associated with both poor

Figure 2. Photographs of leopard seals with similar-appearing black areas from Campbell Island. Photographs taken by J. H. Sorensen (left) and Jack A. Murphy (right) were originally published in Bailey and Sorensen (1962). Permission for use of these reproductions was obtained from the Denver Museum of Nature & Science Archives.

health (Lydersen et al. 2000), and warmer regions of the range in healthy individuals (Fernández-Martín et al. 2016). One or more of these factors may explain the prevalence of black areas and the reverse moult pattern in leopard seals in NZ.

Sub-stages generally occurred sequentially around a peak; however, we note several factors when interpreting the timing and duration of moulting leopard seals in NZ. Firstly, if pelage loss resulting in black areas does represent premature loss in the moult, this may partially explain the scant pre-moult records. Secondly, higher tourist numbers during December and January may result in a higher number of opportunistic moult records contributed by citizen scientists during the summer. Thirdly, relatively few sub-stage 3 records may indicate rapid post-moult pelage growth and less time spent on land later in the moult, as observed in other pinnipeds (Worthy et al. 1992). Lastly, the true active moult duration is likely longer because most annual moults were observed in only one sub-stage, while the longest recorded active moult may be longer because of human disturbance while hauled out in the marinas where that individual typically resided (KvdL. unpubl. data), which can prolong moult (Paterson et al. 2012).

The year-round occurrence of discoloured pelage and black areas observed among leopard seals in NZ indicate an atypical moult. Without a wider comparative study, questions surrounding leopard seal moult in climatically similar regions and the use of glued tags amid a changing global climate remain unanswered. Overall, our data suggest that variation in leopard seal moult progression, including reverse moult, may be regionally-influenced.

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Additional information and declarations

Author contributions: AAG and XJN developed the study idea and design, and contributed to writing. AAG, INV and KvdL were fundamental in collecting field data and collating the NZLSD. AAG undertook data analysis. INV, KvdL and XJN provided comments on the manuscript.

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Data and code availability: Raw data are described in the results and Supplementary Material.

Ethics: This work was conducted under permit numbers 63499-MAR (KvdL) and 63877-MAR (INV) issued by the Department of Conservation, New Zealand.

Conflicts of interest: The authors declare no conflicts of interest.

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Supplementary material

Additional supporting information may be found in the supplementary material file for this article:

Appendix S1. Worldwide published descriptions of leopard seal moult aspects, including pelage appearances, progression, stages (pre-moult, active moult or moult, post-moult) and timing (including peak), from locations across their primary range.

Appendix S2. Metadata of records in the NZLSD, which were used to determine moult records, included date, time, location, region, approximate latitude and longitude coordinates and availability of photographs.

Appendix S3. Photographic examples of observations of leopard seals moulting in New Zealand.

Appendix S4. Maximising data and reliability of moult assessment.

Appendix S5. Annual moult data descriptions.

Appendix S6. Body sections and body groups of a leopard seal used for moult assessment in New Zealand.

Appendix S7. Moult codes (adapted from de Kock et al. 2021) applied to body sections of leopard seals in New Zealand.

Appendix S8. Pooled number of monthly moult records of leopard seal annual moults in New Zealand per moult stage and active moult sub-stages from 2001 to 2022.

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