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PROGNOSTIC INDICATORS OF REHABILITATION OUTCOMES FOR ADULT AFRICAN PENGUINS (*SPHENISCUS DEMERSUS*)

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ABSTRACT: The Southern African Foundation for the Conservation of Coastal Birds facility near Cape Town, South Africa, receives ~900 African Penguins (*Spheniscus demersus*) for rehabilitation every year. Data were analyzed from 3,657 adult African Penguins over a 12-yr period (2002–2013), and multivariate logistic regression analysis was used to evaluate whether individual history and clinical parameters upon admission could predict the outcome of rehabilitation. Penguins admitted due to molt or debilitation were more likely to die during rehabilitation than those admitted due to oiling. Individuals admitted during summer and spring were more likely to die during rehabilitation than those admitted during winter. Penguins diagnosed with *Plasmodium* infection at some point during rehabilitation were more likely to die than those that were consistently negative, and no significant effect was found for other blood parasite infections. Penguins admitted with low body mass, low total plasma protein, or low hematocrit were more likely to die during rehabilitation than those with normal values. With regard to euthanasia, penguins admitted due to molt, debilitation, injury, or other causes and those admitted during spring or with low plasma protein were more likely to be euthanized.

Key words: African Penguin, conservation, mortality, prognosis, rehabilitation, seabird, South Africa, survival.

INTRODUCTION

The global population of African Penguins (*Spheniscus demersus*) has collapsed by 60% since 2001, and the species is currently classified as Endangered by the International Union for Conservation of Nature, with a total population of approximately 25,000 breeding pairs (Crawford et al. 2011; BirdLife International 2016). Major efforts have been made to manage the African Penguin population and to halt its decline, and rehabilitation has been an important component of this strategy (Nel and Whittington 2003; Department of Environmental Affairs 2013). Oiled, sick, and injured marine and coastal birds are frequently recovered and sent to Southern African Foundation for the Conservation of Coastal Birds (SANCCOB) for rehabilitation into the wild (Parsons and Underhill 2005). The SANCCOB facility at Cape Town (Western Cape, South Africa) receives about 900 African Penguins for rehabilitation every year, with an overall release rate of about 75%. Postrelease studies have demonstrated that oiled adults and hand-reared African Penguin chicks have relatively good survival and breeding productivity after being rehabilitated (Barham et al. 2006, 2008; Wolfaardt et al. 2008a, 2009b). However, limited data exist on the factors that impact successful rehabilitation.

Prognostic indicators of rehabilitation success (clinical parameters such as body condition, body mass, hematologic values, and severity of clinical signs) can be used to focus resources on those individuals with higher likelihoods of successful recovery and may also identify areas in which rehabilitation procedures can be improved (Molina-López et al. 2015; Martins et al. 2015; Duerr et al. 2016). In this study, we evaluate how individual history and clinical parameters can be used to predict the rehabilitation outcomes of adult African Penguins.

MATERIALS AND METHODS

Adult African Penguins admitted to the Cape Town facility (33°50′2″S 18°29′29″E) in the Western Cape, South Africa, between 2002 and 2013 were included in the analysis. All African Penguins underwent rehabilitation following standardized protocols (Parsons and Underhill 2005).

The following individual parameters were recorded for each penguin upon admission: date, location of capture, and reason for admission. The season of admission was categorized: spring (September equinox–December solstice), summer (December solstice–March equinox), autumn (March equinox–June solstice), and winter (June solstice–September equinox). We categorized the location of capture based on the following landmarks: Namibia (north of Alexander Bay, 28°37′60″S, 16°27′60″E); Lambert's Bay (32°5′37″S, 18°18′1″E); Cape Point (34°21′25″S, 18°29′52″E); Cape Agulhas (34°49′50″S, 20°0′44″E); Mossel Bay (34°11′9″S, 22°9′37″E); Cape St. Francis (34°12′49″S, 24°50′13″E); and Port Alfred (33°36′12″S, 26°54′8″E).

We categorized the reason for admission into five groups: oiling, injury, molt, debilitation, and other. The "molt" category included individuals with arrested molt, as well as those with that were undergoing normal molt but were captured because they were in high risk areas (e.g., urban areas where they could be attacked by dogs). The "debilitation" category included individuals that were prostrate, lethargic, dehydrated, emaciated, or otherwise weakened but not exhibiting signs of molting, injury, or oiling. The "other" category included miscellaneous uncommon reasons for admittance: healthy penguins (18 individuals), neurologic symptoms (6), allergic reactions (3), eye infections (3), blindness (2), prolapsed cloaca (2), bee sting (1), and exposure to urban pollutants (paint=1, sewerage=1, tar=1). For birds in the "injury" category, the anatomic distribution and probable cause of the injuries was recorded.

We collected the following health parameters within a week of admission: body mass (kilograms), hematocrit (percentage), and total plasma protein (grams per deciliter). Body mass was obtained by using a floor scale (accuracy to 0.02 kg). Blood was collected from the metatarsal vein to fill a heparinized capillary tube, which was centrifuged at 10,000 × G for 5 min, with the hematocrit measured by using a Hawksley microhematocrit reader and total plasma protein concentration estimated with a temperature-compensated clinical refractometer. We prepared thin blood smears at admission and weekly thereafter. Smears were stained with a modified Wright-Giemsa stain (Kyro-Quick, Kyron Laboratories, Benrose, South Africa) and examined for blood parasites under 500× magnification for ~10 min. If, at some point during rehabilitation, a positive diagnosis was made, the individual was recorded as positive for that parasite genus.

Finally, the outcome of rehabilitation was categorized as release, natural death, or euthanasia. The date of outcome was recorded and used to calculate the duration of stay. African Penguins exhibit limited external sexual dimorphism, and morphometric sexing has limited accuracy (Campbell et al. 2016). For a subset of the individuals that died or were euthanized, sex was determined through the dissection of the gonads; one-proportion tests were used to test if sex was equally distributed between groups.

The Kolmogorov-Smirnov test of normal distribution was used to determine if body mass, hematocrit, and total plasma protein met the assumption of normality for the analysis of variance (ANOVA) comparison. All three measures met the assumption of normality. The ANOVA with Tukey post hoc tests were used to compare clinical parameters (body mass, hematocrit, and total plasma protein) among categories of reason for admission. As reference values, we used clinical parameters from apparently healthy adult African Penguins sampled at breeding colonies throughout South Africa (Parsons et al. 2015). Clinical parameters of penguins upon admission for rehabilitation were categorized as "low," "normal," or "high" based on the 20 and 80% percentiles of the reference dataset from Parsons et al. (2015): body mass (low: <2.6 kg; normal: 2.6 to 3.2 kg; high: >3.2 kg); hematocrit (<41%; 41 to 50%; >50%); and total plasma protein (<5.0 g/dL; 5.0 to 6.5 g/dL; >6.5 g/dL).

We examined the following descriptive variables as potential predictors of the outcome of rehabilitation: season of admission, reason for admission, body mass, hematocrit, total plasma protein, duration of stay, and *Babesia*, *Borrelia*, *Leucocytozoon*, and *Plasmodium* infection status. Using outcome as dependent variables, potential independent variables were tested separately by using a test of proportions and were included in the final regression if $P<0.05$. We tested potential variables affecting outcome for collinearity. We used multivariate logistic regressions (as implemented in SPSS 23.0, IBM, Armonk, New York, USA) to evaluate all significant independent variables together as predictors of the outcome. We performed this analysis separately for natural death and euthanasia, using released individuals as the reference category in each case. Odds ratios (OR) and their 95% confidence intervals were generated for each category and considered statistically significant if the OR did not include the null value of one.

TABLE 1. Individual histories of adult African Penguins (*Spheniscus demersus*) admitted for rehabilitation to the Southern African Foundation for the Conservation of Coastal Birds in Cape Town between 2002 and 2013 by reason for admission.

	% Total for each reason for admission					
	Oiling (n=2,604)	Molt (n=143)	Debilitation (n=155)	Injury (n=717)	Other (n=38)	Total (n=3,657)
Location of capture						
Namibia	4.8	0	0	0	0	3.4
Lambert's Bay–Cape Point	21.5	27.3	38.1	26.9	34.2	23.6
Cape Point–Cape Agulhas	68.0	60.8	49.7	71.5	52.6	67.5
Cape Agulhas–Mossel Bay	1.5	1.4	1.3	0.4	0	1.3
Mossel Bay–Cape St. Francis	0.2	9.8	9.7	1.0	5.3	1.1
Cape St. Francis–Port Alfred	4.0	0.7	0	0.1	2.6	2.9
East of Port Alfred	0	0	1.3	0	5.3	0.1
Season						
Spring	10.1	31.5	21.3	21.6	10.5	13.7
Summer	3.2	41.3	32.9	18.4	34.2	9.2
Autumn	22.2	22.4	22.6	22.7	26.3	22.3
Winter	64.6	4.9	23.2	37.2	28.9	54.7

RESULTS

A total of 3,657 adult African Penguins were admitted for rehabilitation between 2002 and 2013 with an mean (SD) of 305 (195) individuals per year (range: 108–642), an overall release rate of 83.3% (7.5%) and a median duration of stay of 24 d for released birds. Adult penguins were admitted from all geographic areas except between Alexander Bay and Lambert's Bay. Of the individuals for which sex was determined, 53% of naturally deceased and 66% of euthanized penguins were females; the sex ratio was significantly different for euthanized penguins (P=0.01) but not for those naturally deceased (P=0.55). The most frequent reasons for admission were oiling (71.2%), injury (19.6%), debilitation (4.2%), molt (3.9%), and other (1.0%; Table 1). The body mass, hematocrit, and total plasma protein varied considerably among individuals, depending on their reason for admission (Table 2 and Fig. 1), as did the temporal distribution of outcomes (Fig. 2). Approximately 70% of the deaths (both natural death and euthanasia categories) occurred within the first week of admission.

Both year of admission (P<0.001) and geographic location (P<0.001) were significantly associated with reason for admission; therefore, only the reason for admission (independent variable) was selected for inclusion in the final model (Table 3). Despite its significance in the univariate analysis, duration of stay was considered a consequence of other prognostic indicators rather than an independent variable determining the rehabilitation outcome; therefore, it was not included in the final model.

The following variables were, therefore, included in the final multivariate logistic regression model (P<0.001, R^2=0.29): season of admission, reason for admission, *Plasmodium* infection, body mass, hematocrit, and total plasma protein (Table 4). The OR results (presented in Table 4) may be interpreted as a measurement of the relative probability that an animal belonging to a category will have a natural death or euthanasia outcome when compared with the reference category. Two examples were given 1) when compared with an oiled penguin, an injured penguin was 13.14 times more likely to be euthanized (instead of being released) and 2) a penguin that was admitted during summer was 2.56 times more likely to suffer a natural death

TABLE 2. Mean clinical parameters and duration of rehabilitation for adult African Penguins (*Spheniscus demersus*) admitted to the Southern African Foundation for the Conservation of Coastal Birds between 2002 and 2013 by reason for admission.

	Reason for admission, mean (SD), *n*					
	Oiling	Molt	Debilitation	Injury	Other	Total
Body mass (kg)	2.55 (0.43), 2,598	2.58 (0.71), 143	2.29 (0.60), 152	2.58 (0.57), 672	2.76 (0.58), 37	2.55 (0.48), 3,602
Hematocrit (%)	45 (5.9), 2,371	38 (7.8), 125	36 (11.0), 115	35 (8.3), 501	41 (7.1), 33	43 (7.8), 3,145
Total plasma protein (g/dL)	5.7 (1.1), 2,355	5.2 (1.9), 124	5.2 (2.0), 114	5.8 (1.5), 498	6.1 (1.4), 33	5.7 (1.3), 3,124
Duration of stay (d)						
Released	25 (15), 2431	54 (97), 79	51 (76), 82	50 (65), 430	41 (83), 25	30 (36), 3,047
Died naturally	12 (21), 150	20 (23), 52	6 (15), 58	17 (29), 93	18 (20), 6	13 (23), 359
Euthanized	1 (28), 23	28 (35), 12	5 (6), 15	8 (26), 194	7 (11), 7	10 (27), 251

(instead of being released) than a penguin that was admitted during winter.

Injury cases were anatomically distributed as follows: leg (349 individuals), flipper (61), abdomen (56), head (41), back (21), neck (21), chest (19), tail (9), and multiple or other (140). The release rate for all penguins admitted with injuries varied between 52% and 71%, depending on body part affected. Duration of stay (SD) of released penguins was longest for individuals with chest (130 [163] d), back (85 [94] d), and abdomen injuries (68 [60] d), followed by neck (59 [65] d), tail (52 [44] d), leg (45 [67] d), flipper (44 [48] d), multiple or other (43 [46] d), and head injuries (33 [25] d). Only 40 injury cases could be attributed to a specific cause: medium-sized predator attack (31 individuals), entanglement with fishing gear (5), hit by car (3), and entanglement with plastic (1).

DISCUSSION

We identified the season of admission, reason for admittance, *Plasmodium* infection status, and body mass, hematocrit, and total plasma protein upon admission as significant prognostic indicators for African Penguins admitted for rehabilitation. Individuals with the following characteristics were more likely to suffer natural death during rehabilitation: admission during summer and spring, admission due to molt or debilitation, low body mass, hematocrit or total plasma protein upon admission, or positive *Plasmodium* diagnosis during rehabilitation. Conversely, individuals admitted during spring, with low total plasma protein upon admission and with any reason for admittance other than oiling were more likely to be euthanized.

Oiling as a reason for admission

Oil pollution is a historical threat to the conservation of African Penguins (Nel and Whittington 2003). The most significant incident was the *Treasure* spill in June 2000, when approximately 19,000 oiled penguins were admitted for rehabilitation (Crawford et al. 2000; Wolfaardt et al. 2008b). By compar-

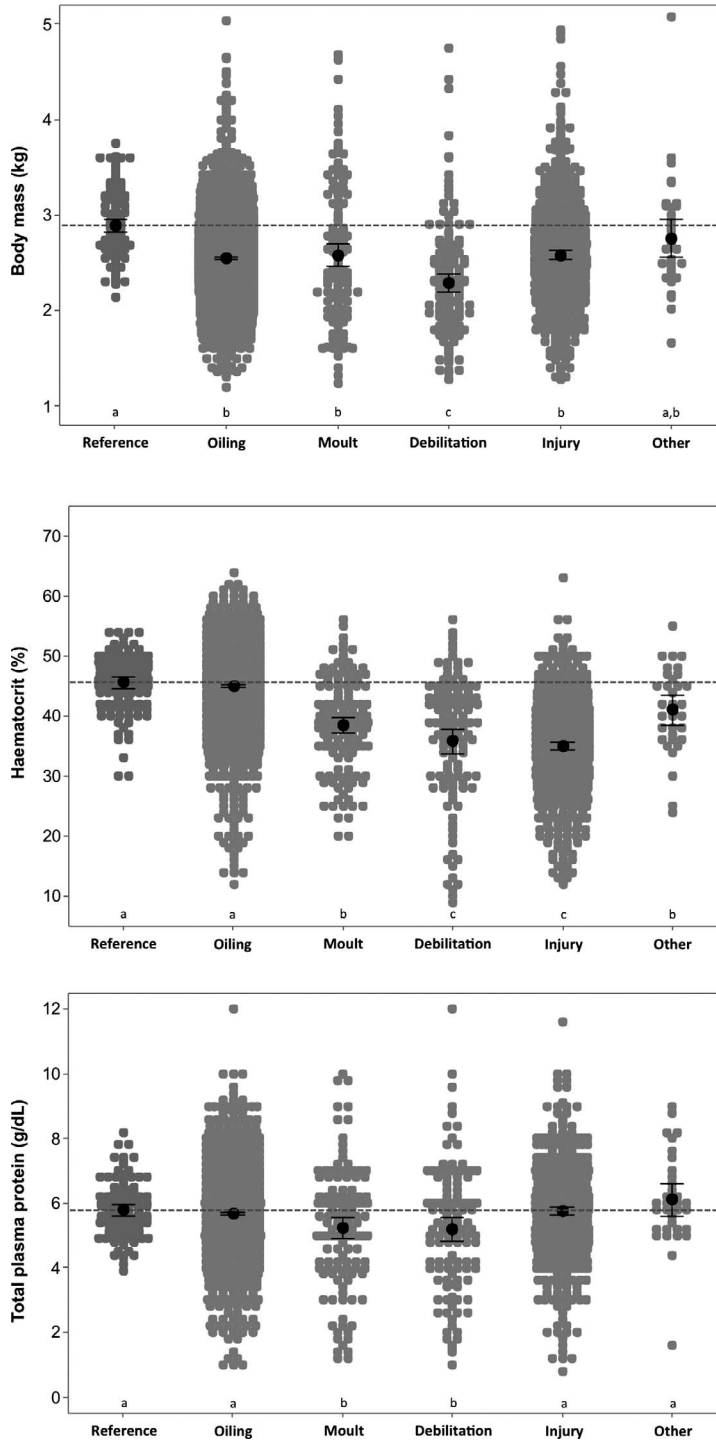

FIGURE 1. Individual plot distribution of the body mass (A), hematocrit (B), and total plasma protein (C) of adult African Penguins (*Spheniscus demersus*) upon admission for rehabilitation at the Southern African Foundation for the Conservation of Coastal Birds between 2002 and 2013. The mean (circle) and 95% confidence intervals (bars) are represented. Categories with different letters were statistically different (Tukey post hoc tests). Dashed lines denote the mean reference values from healthy wild adult African Penguins (Parsons et al. 2015).

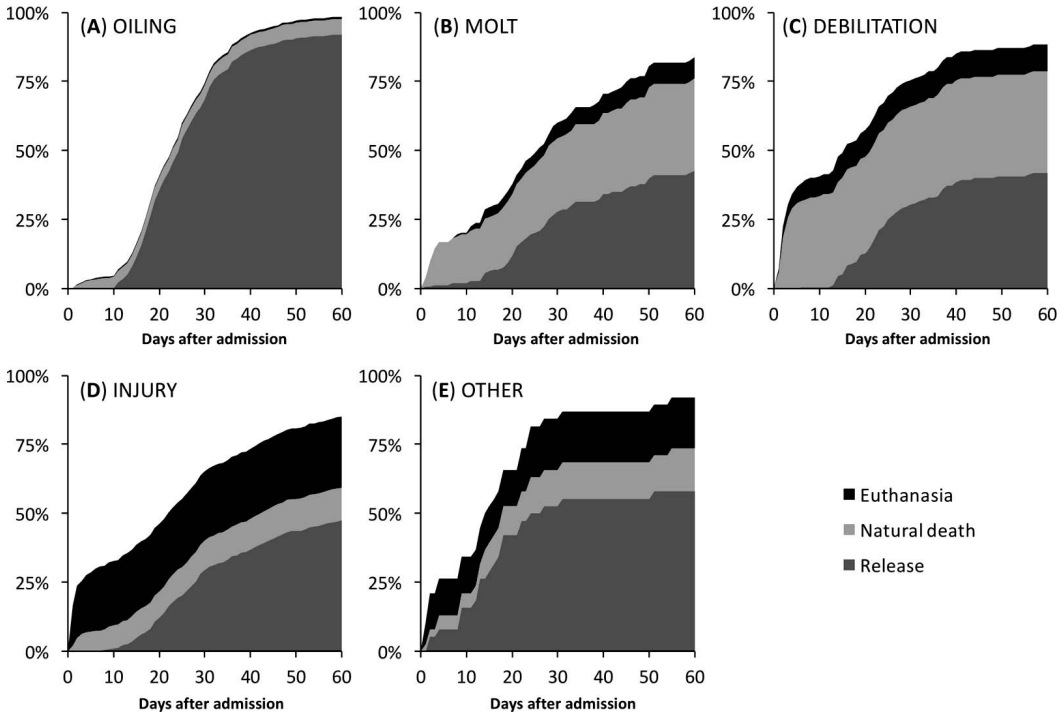

FIGURE 2. Cumulative distribution of the different rehabilitation outcomes of adult African Penguins (*Spheniscus demersus*) admitted to the Southern African Foundation for the Conservation of Coastal Birds between 2002 and 2013 during the first 60 d following admission, in relation to the reason for admission: (A) oiling, (B) molt, (C) debilitation, (D) injury, or (E) other.

ison, 2,604 oiled adult penguins admitted over 12 yr is a relatively small number.

On average, 93% of the oiled penguins admitted during the study period were rehabilitated successfully and released into the wild, similar to that recorded in previous studies in South Africa and elsewhere (Rogers and Holdsworth 1999; Crawford et al. 2000; Parsons and Underhill 2005). The release rate was considerably higher than that of penguins admitted due to other reasons (53–66%), which could have been due to the accumulation of international experience and optimization of the methods employed to rescue and rehabilitate oiled penguins (e.g., Rogers and Holdsworth 1999; García-Borboroglu et al. 2006). An additional factor was that oiled penguins were often admitted in good body condition and health status because they beached themselves immediately to avoid drowning and hypothermia, as well as being physically obvious to conservation officers for collection for rehabilitation.

Molt as a reason for admission

African Penguins have a prolonged breeding season, but the annual molt is synchronized to a higher degree and may be the key driver of the annual cycle (Kemper and Roux 2005; Kemper et al. 2008; Wolfaardt et al. 2009a). This highly physiologically demanding process undoubtedly represents the most vulnerable stage in the annual cycle of an adult African Penguin, pushing their physiologic limits and rendering susceptible to other health challenges.

An additional factor leading molting penguins to rehabilitation centers is that the inability to fatten up sufficiently before molt may result in an arrested molt, wherein the molt is interrupted prematurely (Cooper 1978; Webster et al. 2016). These penguins have a plumage that is a mosaic of old worn-

TABLE 3. Individual history and clinical parameters compared by rehabilitation outcomes of adult African Penguins (*Spheniscus demersus*) admitted to the Southern African Foundation for the Conservation of Coastal Birds between 2002 and 2013. Values are shown as *n* (%), except for body mass, hematocrit, and total plasma protein, where values are shown as mean (SD). The *P* values refer to comparisons between outcomes and individual parameters.

	Parameter *n* (%)			
	Release	Natural death	Euthanasia	*P* value
Location of capture				<0.001[a]
Namibia	122 (96.8)	4 (3.2)	0	
Lambert's Bay–Cape Point	691 (80.1)	107 (12.4)	65 (7.5)	
Cape Point–Cape Agulhas	2,059 (83.4)	229 (9.3)	180 (7.3)	
Cape Agulhas–Mossel Bay	37 (78.7)	9 (19.1)	1 (2.1)	
Mossel Bay–Cape St. Francis	34 (81.0)	5 (11.9)	3 (7.1)	
Cape St. Francis–Port Alfred	100 (93.5)	5 (4.7)	2 (1.9)	
East of Port Alfred	4 (100)	0	0	
Season of admission				<0.001[a]
Spring	357 (71.4)	87 (17.4)	56 (11.2)	
Summer	202 (59.8)	90 (26.6)	46 (13.6)	
Autumn	690 (84.5)	69 (8.4)	59 (7.1)	
Winter	1,798 (89.8)	113 (5.6)	91 (4.5)	
Reason for admittance				<0.001[a]
Oiling	2,431 (93.4)	150 (5.8)	23 (0.9)	
Molt	79 (55.2)	52 (36.4)	12 (8.4)	
Debilitation	82 (52.9)	58 (37.4)	15 (9.7)	
Injury	430 (60.0)	93 (13.0)	194 (27.1)	
Other	25 (65.8)	6 (15.8)	7 (18.4)	
Plasmodium				<0.001[a]
Positive	163 (72.8)	54 (24.1)	7 (3.1)	
Negative	2,877 (89.7)	219 (6.8)	111 (3.5)	
Sex				0.083[a]
Male	—	63 (73.3)	23 (26.7)	
Female	—	70 (61.4)	44 (38.6)	
Duration of stay				<0.001[a]
≤1 wk	15 (3.5)	223 (51.5)	195 (45.0)	
1–3 wk	1,167 (94.0)	55 (4.4)	19 (1.5)	
>3 wk	1,865 (94.0)	81 (4.1)	37 (1.9)	
	Mean (SD)			
Body mass, kg	2.60 (0.45)	2.16 (0.55)	2.49 (0.50)	<0.001[b]
Hematocrit, %	43.6 (6.9)	36.8 (11.3)	35.2 (10.3)	<0.001[b]
Total plasma protein, g/dL	5.8 (1.2)	4.6 (1.9)	5.2 (1.6)	<0.001[b]

[a] Compared by outcome using chi square.

[b] Compared by outcome using analysis of variance.

out feathers, new feathers, and areas of bare skin and often need to stay in care for extended periods (several weeks or months) until their plumage is fully replaced. They may develop health problems secondary to their prolonged stay in captivity, hence, the high proportion of naturally deceased and euthanized penguins after 3 wk in rehabilitation.

Penguins admitted to the rehabilitation center while undergoing molt or due to arrested molt, therefore, had low release rates and were more likely to die or to be euthanized than oiled penguins. The body

TABLE 4. Multivariate logistic regression of individual history and clinical parameters as predictors of two categories of mortality of adult African Penguins (*Spheniscus demersus*) admitted for rehabilitation to the Southern African Foundation for the Conservation of Coastal Birds between 2002 and 2013, using released birds as the reference category in each case. The *P* values refer to the significance of each variable as a predictor of natural death or euthanasia.

Variable	Odds ratio (95% CI)			
	Natural death	*P* value	Euthanasia	*P* value
Season				
Spring	2.56 (1.69–3.86)	<0.001	1.70 (1.00–3.22)	0.052
Summer	2.45 (1.54–3.91)	<0.001	1.07 (0.55–2.09)	0.841
Autumn	1.41 (0.94–2.11)	0.088	0.97 (0.53–1.76)	0.923
Winter	1.00	—	1.00	—
Reason for admittance				
Molt	5.91 (3.50–9.98)	<0.001	15.06 (6.24–36.36)	<0.001
Debilitation	2.87 (1.67–4.96)	<0.001	11.18 (4.68–26.70)	<0.001
Injury	1.39 (0.90–2.14)	0.130	13.14 (6.89–25.09)	<0.001
Other	3.16 (0.96–10.34)	0.061	25.02 (7.44–84.06)	<0.001
Oiling	1.00	—	1.00	—
Plasmodium				
Positive	3.41 (2.28–5.16)	<0.001	0.88 (0.37–2.12)	0.781
Negative	1.00	—	1.00	—
Body mass				
Low (<2.6 kg)	3.43 (2.28–5.16)	<0.001	1.52 (0.91–2.54)	0.110
Normal (2.6 to 3.2 kg)	1.00	—	1.00	—
High (>3.2 kg)	1.01 (0.48–2.11)	0.967	1.22 (0.58–2.59)	0.602
Hematocrit				
Low (<41%)	1.99 (1.40–2.82)	<0.001	1.65 (0.97–2.82)	0.074
Normal (41 to 50%)	1.00	—	1.00	—
High (>50%)	1.51 (0.90–2.55)	0.119	1.85 (0.72–4.75)	0.200
Total plasma protein				
Low (<5.0 g/dL)	2.95 (2.13–4.08)	0.005	2.52 (1.52–4.18)	0.004
Normal (5.0 to 6.5 g/dL)	1.00	—	1.00	—
High (>6.5 g/dL)	0.79 (0.20–1.25)	0.320	1.12 (0.64–1.98)	0.690

mass of penguins admitted due to molt or arrested molt had the highest standard deviation, which is consistent with the admission of birds at different stages of the molting process. The molting process is known to induce a substantial drop in the hematocrit, especially in its later stages (Mazzaro et al. 2013), which is consistent with the relatively low hematocrit values herein observed. Poor nutritional status of arrested molters also helps to explain the low body mass, hematocrit, and plasma protein, and these poor clinical parameters may explain the high death rate within the first week postadmission (Fig. 2).

Debilitation as a reason for admission

Debilitated penguins were seen as lying down on admission, did not attack when handled, had no evidence of oiling, injuries, or molting, and their beaks were relatively easy to open (Parsons and Underhill 2005). Because this is a diagnosis of exclusion, it is not possible to pinpoint the causes or mechanisms that led these birds to become debilitated, which may be complex and multifold. However, it is likely that they went through extended periods of food deprivation and negative energetic balance (Rodrigues et al. 2010; Duerr and Klasing 2015) and may also present profound anemia, liver atrophy,

gastrointestinal hemorrhages, and increased parasite loads (Hocken 2000, 2005; Rodrigues et al. 2010). As a result, the tissue damage accumulated over a long period of malnutrition might be irreversible and continue to manifest beyond the first week of rehabilitation, explaining the poor release rate for this group.

Injury as a reason for admission

Traumatic injuries were the second highest cause of admission of adult African Penguins, and trauma has also been found to be an important cause of death of penguins in New Zealand (Hocken 2000, 2005) and Australia (Cannell et al. 2016). Injured penguins had lower body mass than healthy wild adult penguins, suggesting these birds had suboptimal foraging success prior to (possibly making them more susceptible to a predator) or following the injury, whereas their low hematocrit value may be explained by blood loss related to their injuries. Traumatic injuries are conspicuous, their prognosis can be promptly evaluated by veterinarians, and severe lesions can be incompatible with the individual's welfare; therefore, it is not surprising that injured penguins were more frequently and promptly euthanized than other admission categories.

The duration of stay of injured penguins was found to vary considerably, depending on the distribution of their wounds, as penguins with limb and head injuries were, on average, released in 35–45 d, whereas those with injuries to the chest, abdomen, and back generally required more than 70 d under care before they could be released. This probably reflects the fact that these lesions require a longer recovery because of the time needed for feathers to grow and provide adequate waterproofing and could also be related to a greater clinical significance of the lesions inflicted to the core of the body.

Season of admission

The release rate varied considerably among the seasons, being highest in winter and lowest in summer. A possible explanation is that the overall population of adult penguins admitted are in poorer health condition during spring and summer after their substantial breeding investment during winter (see D'Amore and Jessop 1995). Factors modulating the health status of the penguins over the breeding season might include their sex, whether they were breeders or nonbreeders, whether they had bred early or late in the season, whether or not they had successfully reared chicks in that year (Moreno et al. 1998, 2002) and, perhaps most significantly, seasonal fluctuations in prey distribution and availability (Crawford et al. 2011; Sherley et al. 2013). Unfortunately, these variables could not be evaluated in this study.

Blood parasites

Plasmodium (avian malaria) was the only blood parasite identified as a significant prognostic factor for rehabilitation outcome. These mosquito-borne protozoans are well established for their ability to cause morbidity and mortality of penguins worldwide (Vanstreels et al. 2016). *Plasmodium* infection has been documented in wild African Penguins at the Western Cape of South Africa (Fantham and Porter 1944), and has also been documented to occur in African Penguins undergoing rehabilitation at the SANCCOB (Parsons and Underhill 2005). The relatively high apparent prevalence (6.5%) noted in this study contrasts with the failure to detect this parasite in a recent health survey in healthy wild adult African Penguins (Parsons et al. 2016). These findings therefore highlight the importance of minimizing time in rehabilitation, mosquito control, and early treatment of *Plasmodium* infections in the rehabilitation of African Penguins (Parsons and Underhill 2005).

Health parameters

Body mass and hematologic parameters are important criteria in the initial assessment and treatment of wildlife admitted for rehabilitation (Cousquer 2005; Rodrigues et al. 2010; Martins et al. 2015). A poor body condition may be an indication of poor food resources, physical or

behavioral problems, or a combination of them and is a significant predictor of survival of seabirds during rehabilitation (Rodrigues et al. 2010; Vanstreels et al. 2013; Martins et al. 2015). Low hematocrit and total plasma protein values were significant predictors of natural death in this study, a finding consistent with those of similar studies on penguins admitted for rehabilitation in Brazil (Rodrigues et al. 2010; Martins et al. 2015).

Directions for the future

Although the rehabilitation of oiled penguins has been well developed in past decades and has consistently produced high release rates, the success of rehabilitation techniques for penguins admitted due to molting problems, debilitation, and injuries has lagged behind. Because most of the mortality of these birds occurs within the first 10 d after admission, developing more effective approaches to rapidly reverse the severe dehydration, hypothermia or hyperthermia, anemia, and cachexia should be a key strategy to improve rehabilitation procedures. The early rescue of all penguins needing rehabilitation, as well as initial care given by rescuers (e.g., hydration and warming) before transport will tend to improve the health condition in which they are admitted to the rehabilitation center. For penguins with arrested molt, supplementation of hormones (Webster et al. 2016) and specific nutrients or high-protein diets (Tseng 1999; Martins et al. 2015) may also make a valuable contribution. The development of orthopedic techniques specifically adapted to the anatomically unique locomotor apparatus of penguins may also improve the prognosis of injured penguins.

As of 2005, the SANCCOB stopped placing metal flipper bands on all African Penguins before they were released, which unfortunately precludes an evaluation of postrelease survival and breeding success in this study. Future studies using microchips will hopefully allow for an investigation of how prerelease clinical parameters can predict postrelease survival and breeding success.

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