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MORTALITY DURING TREATMENT: FACTORS AFFECTING THE SURVIVAL OF OILED, REHABILITATED COMMON MURRES (*URIA AALGE*)

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ABSTRACT: After major oil spills, hundreds to thousands of live stranded birds enter rehabilitative care. To target aspects of rehabilitative efforts for improvement and to evaluate which initial physical examination and biomedical parameters most effectively predict survival to release, medical records were examined from 913 Common Murres (*Uria aalge*; COMUs) oiled during the November 2001–January 2003 oil spill associated with the sunken *S.S. Jacob Luckenbach* off San Francisco, California, US. Results showed that 52% of all deaths occurred during the first 2 days of treatment. Birds stranding closest to the wreck had greater amounts of oil on their bodies than birds stranding farther away. More heavily oiled birds were in better clinical condition than birds with lesser amounts of oil, as shown by higher body mass (BM), packed cell volumes (PCV), total plasma protein (TP), and higher survival proportions. Additionally, BM, PCV, TP, and body temperature were positively correlated. For comparison, medical records from all nonoiled COMUs admitted for rehabilitation at the same facility during 2007–09 (n=468) were examined, and these variables were also found to be positively correlated. Oiled birds with BM under 750 g had approximately 5% lower PCV than BM-matched nonoiled COMUs. More heavily oiled COMUs may be in better condition than less oiled birds because heavily oiled birds must beach themselves immediately to avoid drowning and hypothermia, whereas lightly oiled birds may postpone beaching until exhausted due to extreme body catabolism. The strong relationship of PCV to BM regardless of oiling provides evidence that anemia commonly encountered in oiled seabirds may be a sequela to overall loss of body condition rather than solely due to toxic effects of oiling. Clinical information garnered in this study provides guidance for triage decisions during oil spills.

Key words: Anemia, Common Murre, oiled wildlife, oil spill, seabird, *S.S. Jacob Luckenbach*, *Uria aalge*.

INTRODUCTION

On 14 July 1953, the *S.S. Jacob Luckenbach* (hereafter SSJL), a cargo vessel transporting railroad parts to the Republic of Korea, sank 27.4 km southwest of the Golden Gate Bridge (37°40′22.8″N, 122°47′35.4″W) in San Francisco, California, US, at a depth of 53.6 m, near Southeast Farallon Island. Beginning in the 1970s, oiled birds were found sporadically and in varying numbers on beaches from Carmel-by-the-Sea in Monterey County (36°33′15.8″N, 121°55′27.8″W) to Bodega Bay in Sonoma County (38°20′10.7″N, 123°02′47.0″W), primarily associated with winter coastal storm activity. After large events resulting in several thousand affected birds during the winters of 1997–98 and 2001–02, chemical "fingerprinting" of oiled feather samples identified the SSJL as responsible for these and other mystery spills along the central California coast as far back as 1992–93. This ship was strongly suspected as the source of earlier events involving oiled wildlife despite inadequate historical samples to prove a direct relationship (Luckenbach Trustee Council 2006). A salvage operation initiated in the summer of 2002 removed 378,541 L of bunker C fuel oil from the wreck (McCleneghan 2003). This operation succeeded in removing approximately 22% of the estimated original load of oil, but more than 500 oiled birds were subsequently collected from beaches in the winter of 2002–03 immediately following large storm events (Hampton et al. 2003). Since 2003, a precip-

itous decline of oiled birds has been seen in this region, with only 11 birds found with oil consistent with SSJL on its feathers from 2003 to 2010 (Henkel et al. 2013), indicating that oil removal from the wreck successfully reduced impacts to seabirds.

Between November 2001 and January 2003, 1,105 live oiled birds were recovered and determined to be affected by oil from SSJL via chemical fingerprinting. Common Murres (*Uria aalge*; COMUs) comprised 917 of the collected birds. Due to low day-to-day caseload, animals that might have been euthanized due to more stringent triage criteria during a more intense spill response were allowed to progress through the rehabilitation process with medical decisions based on each animal's prognosis. The aim of this study was to glean information from patient records of COMUs treated during the SSJL spill event of 2001–03 to explore relationships among clinical findings, identify patterns of mortality during care to target aspects of the rehabilitation process for improvement, and ascertain which easily and commonly measured parameters most effectively predict survival of rehabilitated oiled seabirds to release, thus providing guidance for triage decisions during future oil spills. After preliminary results from this study were examined, records from nonoiled COMUs undergoing rehabilitation at the same facility were examined for comparison purposes to illuminate whether relationships found among clinical parameters were specific to oiled COMUs.

MATERIALS AND METHODS

Data collection

Data were extracted from medical records of COMUs oiled by SSJL and admitted for rehabilitation at International Bird Rescue's wildlife clinic at the San Francisco Bay Oiled Wildlife Care and Education Center in Fairfield, California, US between 23 November 2001 and 26 January 2003. Parameters examined for this study included the following information: percentage of bird's body oiled, body mass (BM; in g), cloacal body temperature (T; in C), packed cell volume (PCV; in %), total plasma protein (TP; in g/dL), and blood glucose (BG; in mg/dL). Dehydration assessment (none, mild, moderate, or severe), body condition score (BC; normal, thin, very thin, emaciated), and age (based on stranding date, plumage, and oral mucosa characteristics; designated as hatch-year chick [HY-Chick], juvenile [HY-Juv] or after hatch-year [AHY]), were considered as ordinal variables. Dichotomous variables included capillary refill time (normal if $\leq$2 s, prolonged if $>$2 s), presence of leg and/or skin lesions (yes/no, if skin burns noted anywhere on the body or swollen hocks/feet at admission), respiratory problems (yes/no, if wheezes or crackles on auscultation or other abnormal respiratory findings such as open mouth breathing were noted at admission), presence of pale mucous membranes (yes/no), presence of gastrointestinal bleeding (yes/no, if blood was grossly visible in regurgitated material or stool or on the gavage tube), occurrence of regurgitation during prewash stabilization (yes/no), development of later leg and/or skin lesions (yes/no), and development of later respiratory problems (yes/no). Birds were counted as developing a later leg/skin lesion only if the anatomic location was different from the original site. Only birds without respiratory problems at admission were counted as developing later respiratory problems. Sex of all birds was unknown because this species is not sexually dimorphic. Final disposition (released, died, or euthanized) was treated as a dichotomous variable, with comparison of "released" vs. "died + euthanized" groups to capture all data, and a more conservative comparison that excluded euthanized animals through comparison of "released" vs. "died" groups. Stranding location (six California counties plus the Farallon Islands) as well as number of days from collection to disposition, from collection to wash, and from wash to disposition were assessed to explore geographic trends and temporal patterns of mortality during care.

Medical records from all nonoiled COMUs admitted for rehabilitation at the same facility during the years 2007–09 (n=468) were examined. Admission BM, PCV, TP, T, age, disposition (released, died, or euthanized), and number of days from collection to disposition were tabulated.

All parameters were compared pairwise to create a clinical image of the state of affected animals. These comparisons allowed assessment of questions such as whether BM was related to PCV, whether birds identified as having pale mucous membranes were cold, anemic, or hypoproteinemic, whether birds with burned skin on admission had heavier oil burdens, and which parameters, if any, were associated with survival through rehabilitation.

TABLE 1. Effect of age on physiologic parameters measured in Common Murres (*Uria aalge*; COMUs) oiled by the *S. S. Jacob Luckenbach* oil spill, and nonoiled COMUs rehabilitated for other reasons (birds with unknown age excluded). Comparisons without a parenthetical capital letter in common are different at a significance of $P<0.05$.

Numeric parameters[a]	AHY[b]		HY-Juv[c]		HY-Chick[d]	
	n	Mean±SD	*n*	Mean±SD	*n*	Mean±SD
Oiled COMUs						
Body mass (g)	610	716±79.5(A)	209	694±71.8(B)	9	315±91.5(C)
PCV (%)	590	35.0±12.6(A)	205	36±12.3(A)	9	33±8.3(A)
TP (g/dL)	589	2.6±1.41(A)	205	2.6±1.14(A)	9	2.7±0.94(A)
Temp (C)	600	39.4±1.19(B)	205	39.4±0.98(B)	9	40.4±0.91(A)
BG (mg/dL)	500	274±77.6(A)	188	266±68.8(A)	4	237±52.2(A)
Percentage oiled (%)	598	35±23.2(B)	203	40±24.5(A)	9	52±31.8(A)
Percentage released (%)		35.7		35.7		0
Nonoiled COMUs						
Body mass (g)	292	684±93.1(A)	86	559±123.3(B)	72	316±138.8(C)
PCV (%)	268	35±12.3(A)	82	29±12.0(B)	70	26±11.4(B)
TP (g/dL)	266	3.3±1.59(A)	82	3.2±1.69(AB)	70	2.8±1.46(B)
Temp (C)	288	39.8±1.11(A)	84	40.0±1.26(B)	72	40.2±1.24(B)
Percentage released (%)		24.4		31.8		36.1

[a] PCV = packed cell volume; TP = total plasma protein; BG = blood glucose.
[b] AHY = after hatch year.
[c] HY-Juv = hatch-year, not chick.
[d] HY-Chick = young of the year, not yet fully grown.

Statistical analyses

Basic descriptive statistics (mean, SD, range) were calculated for all numeric variables, with assessment of normality through Shapiro-Wilk tests. Statistical tests were chosen dependent on the type and distribution of data compared, and included ordinary least squares regressions, analysis of variance, Kruskal-Wallis tests, *t*-tests, chi-square analyses, and Fisher's exact tests. All statistical analyses were conducted using SPSS statistical software (Version 16, SPSS, Chicago, Illinois, USA) and JMP (Version 10, SAS Institute Inc., Cary, North Carolina, USA). *P* values <0.05 were considered statistically significant.

RESULTS

Oiled SSJL COMUs (n=913) included 626 AHY, 210 HY-Juv, 9 HY-Chicks, and 68 unknown age birds: 332 (36.4%) died in care, 274 (30.0%) were euthanized, and 307 (33.6%) were released. Nonoiled COMUs (n=468) entered into rehabilitation for reasons other than oiling included 299 AHY, 88 HY-Juv, 72 HY-Chicks, and nine unknown age birds: 74 (15.8%) birds died, 265 (56.6%) were euthanized, and 129 (27.6%) were released. Survival to release by age class is shown in Table 1. Four oiled and nine nonoiled COMUs that were collected alive were dead on arrival at the rehabilitation center: These records were not included in analysis.

The seven strand locations are arrayed in a general north-south axis along the California coast (Fig. 1). Oiled COMU admissions peaked in December of each winter, and most were collected from San Mateo and Monterey counties. Oiled chicks stranded during late June–August. Oiled COMUs stranding farther from the wreck were significantly less oiled than those stranding closest (Fig. 1). Stranding location showed a statistically significant relationship to T, BM, and PCV in Sonoma County (lowest T, BM, and PCV) and San Francisco County (highest T, BM, and PCV). Nonoiled chicks also entered care in July–August each year, and nonoiled COMUs admissions peaked in October.

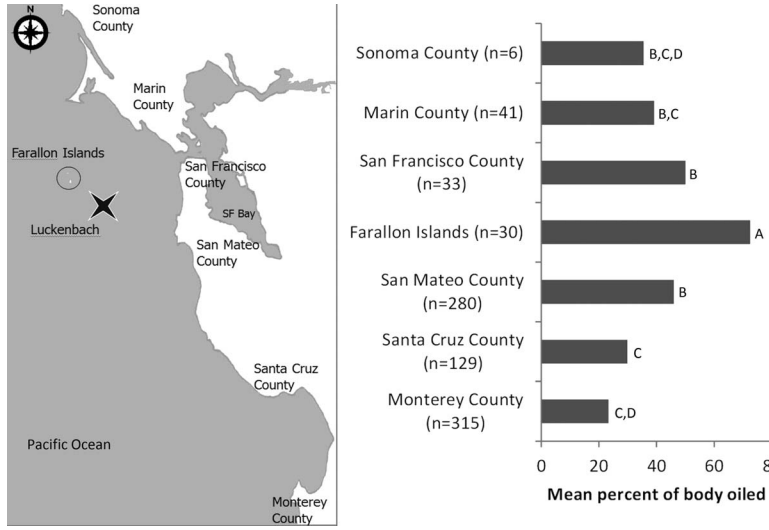

FIGURE 1. Geographic locations of stranding for oiled Common Murres (*Uria aalge*) oiled by the *S.S. Jacob Luckenbach* oil spill 2001–03, by county (California, USA), with mean percentage of body covered in oil, showing that birds captured closer to the wreck stranded with higher oil burdens. Values from locations without a letter in common are significantly different at $P<0.05$.

In oiled COMUs, 52.0% of 606 mortalities occurred in the first two days of care, with 108 dying or euthanized on the day of admission, 141 additional birds dying/euthanized on day 1, and 66 additional birds on day 2. Birds euthanized within the first 24 h typically were extremely lethargic, obtunded, moribund, or had extremely low PCV. In nonoiled COMUs, 207 of 339 mortalities (61.6%) also occurred during the first two days of care. Nonoiled HY-Chicks spent significantly more time in care than older birds (mean±SD=39±14.4 days for chicks vs. 15–19 days for other age groups, all P values <0.001); there were no other statistically significant differences in the number of days in care by age or oiling status. A total of 486 oiled birds survived long enough to be washed, with a mean of 3.4 d (range=0–9 d) to become medically stabilized prior to being washed. One hundred seventy-nine birds (36.7%) died or were euthanized subsequent to being washed, with 98 (54.7%) of

TABLE 2. Values of physiologic parameters measured in After-Hatch-Year Common Murres (*Uria aalge*; COMUs) oiled by the *S. S. Jacob Luckenbach* oil spill 2001–03, and nonoiled After-Hatch-Year COMUs rehabilitated for other reasons 2007–09, by final disposition (euthanized birds not shown). na = not applicable, nd = not determined.

	Oiled COMUs				Nonoiled COMUs			
	Died in care		Released		Died in care		Released	
Parameter[a]	*n*	Mean±SD	*n*	Mean±SD	*n*	Mean±SD	*n*	Mean±SD
Oil coverage (%)	278	33.8±22.38	301	40.8±24.79		na		na
Body mass (g)	297	689.0±86.24	304	749.8±70.92	54	604.3±101.17	102	665.9±123.45
Body temperature (C)	289	39.2±1.22	298	39.8±1.02	52	39.3±1.34	103	40.1±1.06
PCV (%)	272	34.0±12.56	303	41.0±9.55	50	33.2±16.62	103	37.4±10.93
TP (g/dL)	270	2.4±1.36	303	3.2±1.09	50	2.8±1.70	103	3.5±1.41
BG (mg/dL)	225	270.5±88.84	270	266.1±65.67		nd		nd

[a] PCV = packed cell volume; TP = total plasma protein; BG = blood glucose.

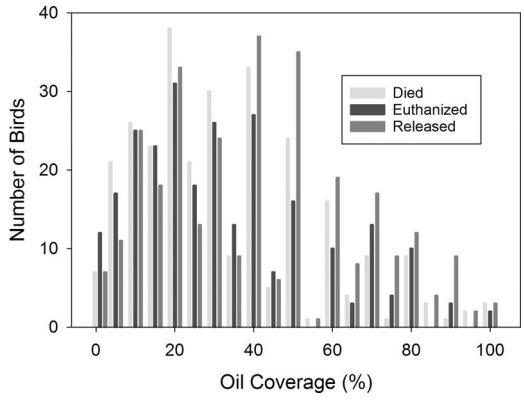

FIGURE 2. Numbers of Common Murres (*Uria aalge*) admitted for rehabilitation after oiling by the *S.S. Jacob Luckenbach* oil spill 2001–03, by final disposition and percentage of body covered in oil, grouped in 5% increments. Birds with higher oil burdens showed higher proportions surviving to release.

these mortalities occurring within four days of wash. No unifying characteristics were found for these birds (data not shown).

Oiled HY-Chicks had the lightest BM and AHY birds had the heaviest (Table 1). BM was significantly lower in HY-Juv than AHY birds by approximately 23 g ($P<0.001$). Oiled HY-Chicks were significantly warmer than older birds. Packed cell volume, TP, and BG did not vary significantly by age in oiled COMUs. Hatch-year chicks and HY-Juv COMUs had significantly heavier oil burdens than AHY birds. In nonoiled COMUs (Table 1) HY-Chicks were also warmer than older birds but PCV and TP were significantly lower in younger age birds.

Birds surviving to release had higher oil burdens than those that died (Table 2). Figure 2 shows final disposition and distribution of oil coverage in affected birds. When relationships between clinical factors and survival to release were examined for oiled and nonoiled COMUs, PCV was the only significantly associated factor, with higher values both with and without inclusion of birds that were euthanized (Table 3). No oiled murres survived to release if admitted with PCV<15% or TP<0.8 g/dL. Small numbers of nonoiled COMUs survived to release despite admission PCV as low as 8% or TP as low as 0.6 g/dL. Severely hypothermic birds did not survive well, and no oiled birds survived if entering care below 36.1 C. Birds arriving with T>39.4 C fared best up to the high end of the temperatures recorded.

Significance of clinical factors was similar regardless of age group (HY-Juv data not shown). Higher BM, higher T, higher PCV, higher TP, higher percentage oil coverage, and development of later leg/skin lesions were significantly related to survival to release for oiled AHY and HY-Juv with and without inclusion of euthanized birds (all $P<0.03$; Table 3). Nonoiled chicks showed higher PCV, higher TP, and higher T significantly related to survival to release with and without inclusion of euthanized birds (all $P<0.05$); BM was not significantly associated with release in nonoiled HY-Chicks. When euthanized birds were excluded, both AHY and HY-Juv showed development of later respiratory problems as significantly related to survival to release ($P=0.008$ and $P<0.001$, respectively). Pale mucous membranes were significantly related to disposition (nonsurvival) in AHY but not HY-Juv birds.

To explore the relationships between individual factors, pairwise regressions were done on numeric variables for oiled and nonoiled COMUs (chicks excluded; Table 4). Among oiled birds, heavier BM birds had higher T, PCV, TP and percentage oil coverage values while lower mass birds had lower values. Birds with higher PCV also had higher TP. More heavily oiled birds had higher PCV and TP. Birds with higher T had higher PCV and TP but lower oil burdens. Birds with higher PCV or TP had lower BG, as did birds with higher oil burdens. Nonoiled COMUs showed positive relationships among all pairings of BM, T, PCV, and TP.

Lower BM birds showed a lower PCV whether oiled or nonoiled (Fig. 3). Oiled COMUs displayed a steeper slope to the relationship than nonoiled birds, particularly at masses indicative of marked emaciation (wild mean mass 1,022 g; Newman 1998). This relationship was also seen in HY-Juv birds (data not shown). When BM data were categorized into 50 g blocks, PCVs of oiled COMUs <750 g were approximately 5%

TABLE 3. Association of clinical factors with final disposition (died, euthanized, released) in Common Murres (*Uria aalge*; COMUs) oiled by the *S.S. Jacob Luckenbach* oil spill 2001–03, and nonoiled COMUs rehabilitated for other reasons 2007–09 (chicks excluded), as determined by *t*-tests or chi-square analyses. ns = not significant at $P<0.05$.

Factor	Value associated with release	Released vs. died		Released vs. died + euthanized	
		n	*P*	*n*	*P*
Oiled COMUs					
Strand county	Closer to wreck	630	<0.001	898	<0.001
Body mass	Higher	608	<0.001	864	<0.001
Body temperature	Higher	598	<0.001	863	<0.001
Packed cell volume	Higher	578	<0.001	844	<0.001
Total plasma protein	Higher	576	<0.001	840	<0.001
Later leg/skin lesions	Presence thereof	574	<0.001	839	<0.001
Pale mucous membranes	Absence thereof	576	<0.001	841	0.001
Percentage oil coverage	Higher	588	0.005	849	<0.001
Prewash regurgitation	Absence thereof	575	0.005	839	0.028
Age (older)	Older	585	0.047	852	0.005
Later respiratory problems	Presence thereof	575	<0.001	840	0.218
Blood glucose	Nonextreme (136–396 mg/dL)	496	0.012	718	0.050
Gastrointestinal bleeding	Absence thereof	576	0.085	842	0.034
Intake leg/skin lesions	ns	575	0.051	841	0.131
Dehydration assessment	ns	561	0.250	810	0.147
Intake respiratory problems	ns	575	0.170	838	0.403
Body condition score	ns	549	0.775	797	0.201
Capillary refill time	ns	540	0.440	777	0.668
Nonoiled COMUs					
Body mass	Higher	156	0.011	385	0.220
Body temperature	Higher	155	<0.001	380	0.065
Packed cell volume	Higher	153	0.039	357	<0.001
Total plasma protein	Higher	153	0.014	357	0.065

lower than nonoiled birds in the same block. Of 306 oiled COMUs arriving with PCV<30%, only 47 (15.4%) were released, 113 died (36.8%), and 146 (47.6%) were euthanized. All 13 oiled COMUs admitted with BG<136 mg/dL died or were euthanized and only one of 10 birds with BG>500 mg/dL survived to release. BG was not evaluated in nonoiled birds.

Those COMUs with leg/skin lesions on admission had significantly more oil covering the body than birds without such lesions, as well as higher PCVs. Birds that later developed leg/skin lesions had higher admission PCV, TP, BM, and T than birds that did not develop lesions (Table 5). Common Murres with pale mucous membranes had significantly lower PCV, TP, BM, and T than birds not identified as having pale mucous membranes. Birds with prewash regurgitation had lower TP and BM than birds not regurgitating. Birds exhibiting gastrointestinal bleeding had lower BG than those without. Birds with prolonged capillary refill time were significantly colder than those with normal refill time. Presence of (or later development of) respiratory problems did not show any significant relationships to the numeric variables measured. Nonsignificant relationships are not shown.

Birds with leg/skin lesions on intake and those that developed later respiratory problems were likely to develop additional leg/skin lesions while in care (both $P<0.001$). Common Murres with respiratory problems on admission were not likely to develop later respiratory problems ($P=0.007$). Birds exhib-

TABLE 4. Relationships between paired physiologic parameters measured in Common Murres (*Uria aalge*; COMUs) oiled by the *S. S. Jacob Luckenbach* oil spill 2001–03, and nonoiled COMUs rehabilitated for other reasons 2007–09 (chicks excluded). ns = not significant at $P<0.05$.

Parameter (y)	Regressed against (x)	n	P	R^2	Equation	Slope
Oiled COMUs						
Body mass (g)	vs. Body temperature (C)	841	<0.001	0.191	$y=29.966x–473.404$	pos
	vs. Packed cell volume (%)	830	<0.001	0.198	$y=2.803x+612.323$	pos
	vs. Total plasma protein (g/dL)	826	<0.001	0.233	$y=28.077x+636.716$	pos
	vs. Percentage oil coverage (%)	821	<0.001	0.033	$y=0.614x+688.204$	pos
	vs. Blood glucose (mg/dL)	711	ns			
Body temperature (C)	vs. Packed cell volume (%)	817	<0.001	0.093	$y=0.028x+38.484$	pos
	vs. Total plasma protein (g/dL)	813	<0.001	0.136	$y=0.310x+38.644$	pos
	vs. Percentage oil coverage (%)	806	<0.001	0.018	$y=-0.006x+39.691$	neg
	vs. Blood glucose (mg/dL)	699	ns			
Packed cell volume (%)	vs. Total plasma protein (g/dL)	831	<0.001	0.634	$y=7.373x+15.651$	pos
	vs. Percentage oil coverage (%)	800	<0.001	0.035	$y=0.099x+31.508$	pos
	vs. Blood glucose (mg/dL)	714	<0.001	0.088	$y=-0.047x+48.504$	neg
Total plasma protein (g/dL)	vs. Percentage oil coverage (%)	796	0.017	0.007	$y=0.676x–15.149$	pos
	vs. Blood glucose (mg/dL)	713	<0.001	0.034	$y=-0.003x+3.596$	neg
Percentage oil coverage (%)	vs. Blood glucose (mg/dL)	694	0.023	0.007	$y=-0.027x+43.495$	neg
Nonoiled COMUs						
Body mass (g)	vs. Body temperature (C)	378	<0.001	0.108	$y=33.186x–668.572$	pos
	vs. Packed cell volume (%)	356	<0.001	0.196	$y=4.105x+516.998$	pos
	vs. Total plasma protein (g/dL)	354	<0.001	0.135	$y=26.504x+566.999$	pos
Body temperature (C)	vs. Packed cell volume (%)	356	0.014	0.017	$y=0.011x+39.536$	pos
	vs. Total plasma protein (g/dL)	354	<0.001	0.205	$y=0.301x+38.912$	pos
Packed cell volume (%)	vs. Total plasma protein (g/dL)	355	<0.001	0.221	$y=3.632x+21.798$	pos

iting prewash regurgitation were likely to exhibit gastrointestinal bleeding ($P=0.009$). Birds with prolonged capillary refill time were likely to have intake leg/skin lesions, pale mucous membranes, thermoregulation problems, and gastrointestinal bleeding ($P=0.017$, $P=0.002$, $P=0.001$, $P<0.001$ respectively), but were not likely to develop later leg/skin lesions ($P=0.408$).

Birds assessed to have better BC were warmer than those assessed to be in worse BC ($P<0.001$). Body condition score was significantly related to BM ($P<0.001$), but birds assessed as very thin were only approximately 7 g heavier than birds assessed as emaciated. Body condition score was also significantly related to PCV and TP (both $P<0.001$) with birds assessed in better condition having higher values than those in worse condition. Dehydration assessment (as % dehydrated) had significant relationships with T ($P<0.001$) and TP ($P=0.006$), with more severely dehydrated birds colder and with lower TP. Other comparisons were not statistically significant.

In exploring why development of additional problems might be a significant predictor of survival for oiled COMUs, chi-square analysis of presence or absence of these problems versus BM categorized into 50 g blocks showed there was a much lower than expected incidence of later leg/skin lesions found in COMUs entering care at less than 650 g (data not shown). These 188 birds represent a cohort with extremely poor survival; 150 (79.8%) died or were euthanized within the first 48 h of care, 38 (20.2%) survived long enough to be washed and 19 (10.1%) survived to release. All 19 birds that survived to release, however, entered care with T>37.8 C, which was significantly higher than T of birds that did not survive, both with and without the euthanized cases included ($P=0.029$ and 0.012, respectively).

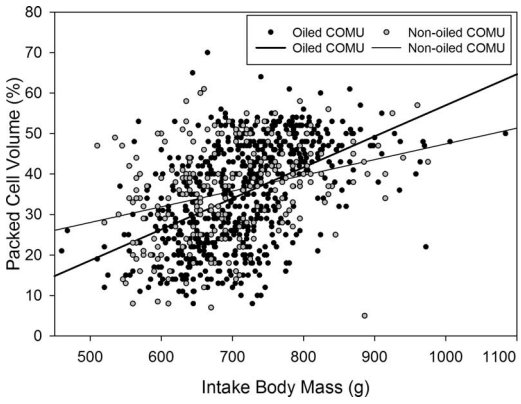

FIGURE 3. Body mass (BM) and packed cell volume (PCV) of Common Murres (*Uria aalge*; COMUs) admitted for rehabilitation after oiling by the *S.S. Jacob Luckenbach* oil spill 2001–03, and nonoiled COMUs rehabilitated for other reasons 2007–09 (chicks excluded). BM and PCV display a strong positive relationship in both oiled and nonoiled after hatch-year (AHY) COMUs (both $P<0.001$). Wild mean BM=1,022 g (Newman 1998). Duerr (2015) reported AHY COMUs as depleted of body fat stores at BM<675 g. Oiled (n=626, R^2=0.24, y=0.076x–19.85) and nonoiled (n=299, R^2=0.13, y=0.049x+2.06) COMUs differ significantly (P=0.003) between series, with oiled COMUs showing lower PCVs at low BM than nonoiled COMUs of comparable mass.

DISCUSSION

Only a tiny fraction of oiled seabirds is ever found on beaches (Page et al. 1990; Wiese 2003). Higher amounts of oil found on COMUs from the Farallon Islands suggest that most heavily oiled birds may have perished at sea. Birds captured from San Francisco County had the highest oil burdens and highest proportion surviving to release. COMUs stranding with higher proportions of oil coverage were in better clinical shape than birds with less oil, as determined by higher PCVs, BMs, and survival proportions. Although it is counterintuitive that birds with more oil would be in better shape, it also seems unlikely that a bird with a heavy burden of oil impeding movement, foraging, and thermoregulation could travel a long distance. We suggest that heavily oiled birds need to beach themselves immediately to avoid drowning and hypothermia, whereas sparsely oiled birds may attempt to behave normally until forced to beach due to exhaustion from the extra metabolic demands of compromised plumage coupled with an inability to forage. Metabolic rates of eiders have been reported to climb 400% when externally oiled and

Table 5. Relationships between clinical problems and physiologic parameters measured in Common Murres (*Uria aalge*) oiled by the *S. S. Jacob Luckenbach* oil spill 2001–03 (chicks excluded).

Clinical problem	Parameter[a]	With problem		Without problem		P value
		n	Mean±SD	n	Mean±SD	
Intake leg/skin lesions	vs. Oil coverage (%)	331	40.5±24.26	479	32.8±22.66	<0.001
	vs. PCV (%)	483	37.0±11.26	331	34.1±13.14	0.001
Later leg/skin lesions	vs. PCV (%)	87	37.7±10.18	726	34.9±12.71	0.047
	vs. TP (g/dL)	87	2.8±1.32	722	2.6±1.36	0.020
	vs. Body mass (g)	87	737.4±68.20	741	707.6±79.66	<0.001
	vs. Body temperature (C)	81	39.8±1.01	733	39.4±1.13	0.008
Pale mucous membranes	vs. PCV (%)	82	29.4±12.56	733	35.9±12.35	<0.001
	vs. TP (g/dL)	81	2.0±1.25	730	2.7±1.35	<0.001
	vs. Body mass (g)	85	679.2±64.24	745	714.4±79.93	<0.001
	vs. Body temperature (C)	85	39.1±1.01	730	39.5±1.13	<0.001
Prewash regurgitation	vs. TP (g/dL)	56	2.2±1.15	753	2.7±1.37	0.018
	vs. Body mass (g)	57	690.3±75.83	771	712.5±78.99	0.041
Gastrointestinal bleeding	vs. BG (mg/dL)	20	238.5±68.87	687	272.4±74.84	0.042
Prolonged capillary refill time	vs. Body temperature (C)	124	39.3±1.23	628	39.6±1.09	0.012

[a] PCV = packed cell volume; TP = total plasma protein; BG = blood glucose.

forced to swim in cold water (Jennsen and Ecker 1991).

Younger COMUs had significantly greater oil burdens than AHY birds. This may reflect the inexperience of young birds in avoiding patchily distributed surface contaminants or may reflect distributions of age classes in habitat utilization.

Most birds affected by this spill had intake BM substantially lower than the low end of the published range (mean=1,022 g, range=805–1,175 g; Newman 1998). After hatch-year COMUs of this population reach a nadir of fat mass at approximately 675 g (66% mean wild mass), and BM alone is a good predictor of chemically analyzed tissue composition for this species (Duerr and Klasing 2015). The mean BM of AHY birds at arrival was 716 g (70.1% of wild mean mass). This suggests that approximately 40% of these birds were at or below the BM at which COMUs are devoid of body fat stores and were in late stage II to stage III starvation (Duerr and Klasing 2015). Nonoiled COMUs had even lower mean BM. The starved state of affected birds likely complicates recovery and may help explain generally low release proportions in this species. Most deaths occurred shortly after arrival into care or subsequent to being washed. The amount of time any particular bird spends becoming medically stable prior to washing is a trade-off between allowing the bird time to recover reserves necessary to survive the intensely stressful wash process, and prolonging exposure to often-caustic petroleum products. Further work is needed to investigate whether changed treatment protocols could improve survival during the critical first few days of care and after wash.

A strong positive relationship was seen between BM and PCV regardless of oiling status. Packed cell volumes declined rapidly in accordance with drops in BM in birds under 800 g. Although data limitations precluded evaluation of how much of the higher BM of heavily oiled birds was due to the oil itself, finding a similar positive relationship between BM and PCV in nonoiled COMUs supports the veracity of this relationship. It may be that there is a threshold of body catabolism below which murres start to metabolize all body tissues, including blood components. We suggest that anemia commonly encountered in oiled COMUs may be, at least in part, a sequela to catabolism rather than being solely due to toxic effects of oiling described in the literature (Leighton et al. 1983; Fry and Lowenstine 1985; Yamato et al. 1996; Troisi et al. 2007). Anemia in oiled seabirds is likely multifactorial, as suggested by low BM oiled murres showing approximately 5% lower PCV than nonoiled murres of comparable BM. Extreme catabolic states seen in wild oiled birds may be a reason for lack of success in eliciting anemia through experimental dosing of birds with oil (Fleming et al. 1982; Newman et al. 1999). Losses due to catabolism may obscure red blood cell losses due to oxidative damage.

Murres that died with high PCVs may represent birds with hemoconcentration due to severe dehydration, although this was not seen in comparisons between PCV or TP and dehydration assessment. Concurrent hypoproteinemia and marked dehydration may complicate interpretation of blood values and should always be considered in the development of triage criteria based on hematological parameters.

Several birds that had temperature data entered as a greater-than value were not included in any numerical analyses. Many hand-held digital thermometers only read up to 42.2 C, thus hyperthermia may have been incompletely evaluated. Although this species lacks a published normal range, normal T of most avian species is considered to be 41.7–44.4 C (Ritchie et al. 1994). Body temperatures of captive parrots have been shown to increase rapidly during routine handling by as much as 3.3 C within 5 min of initiation of handling (Greenacre and Lusby 2004); thus, stress may complicate interpretation of T in wild birds.

Blood glucose was routinely measured during the 2001–03 period but later ceased due to thoughts that BG did not provide enough clinical value. Common Murres normally maintain blood glucose from obligate

gluconeogenesis from pyruvate, lactate, propionate, and other substrates (Herzberg et al. 1988). Our data show some benefit of BG testing, but only 23 of 718 birds measured were identified as having extreme values. If time and resources allow, BG measurement may allow targeted delivery of intensive care or facilitate euthanasia decisions. Blood glucose was found to be negatively related to PCV and TP, which may reflect alterations in circulating energetic substrates during starvation or hypoproteinemia. In King Penguins (*Aptenodytes patagonicus*), BG was lower in stage III starvation than birds in stage II, but PCV of birds was not reported, and study birds were nutritionally within the range of normal annual variation (Bernard et al. 2002).

Although it seems logical that birds arriving with leg/skin lesions (e.g., burns) would be those birds with heavier oil burdens, this has not been reported previously in the literature. The development of later skin/leg lesions had appeared initially to be a significant predictor for survival to release; however, this seems most likely due to higher BM birds surviving long enough for lesions to develop while lower BM birds died or were euthanized. Birds that developed later leg/skin lesions also had higher PCV, TP, and T on arrival, which supports these birds being in generally better condition.

Development of later respiratory problems showed a positive survival benefit in this study. These animals may have benefited from closer attention or medication delivery. Medical treatment protocols were not directly evaluated in this study, but this is an area with very little published information that deserves future work.

With one exception, subjectively evaluated factors were largely not predictive of survival to release. While BC score did not show any predictive significance for survival, it was positively related to BM, T, PCV, and TP, higher values of which were associated with survival. Dehydration assessment did not have a significant relationship to survival either, nor did it relate to percentage oil coverage, as may have been expected. Capillary refill time was significantly associated with TP and T but not survival. Physical examination time spent assessing these factors may be more useful if objective scoring systems are developed. See Duerr (2013) for a discussion of subjective and objective body condition scoring in COMUs. Mucous membrane color, however, was a subjective assessment significantly associated with survival to release. Birds noted to have pale mucous membranes were likely to have lower T, BM, PCV, and TP, and were more likely to die than birds not thus identified. At the time of this spill, mucous membrane color was not routinely evaluated because COMUs normally have purple oral mucosa as chicks and yellow as adults. Consequently, evaluation of this parameter was limited by the skill of the observer and only noted when the examiner thought it relevant. Consistent assessment appears prudent.

In this study we found that lightly oiled, cold, anemic, emaciated COMUs were unlikely to survive, while heavier-oiled birds with higher BM, T, PCV, and TP were more likely to survive to release. Knowledge of the predictive value of factors may allow examiners to reduce time spent on nonpredictive data gathering and thus decrease handling time and patient stress, and provides guidance for identifying birds in need of either intensive care or euthanasia. This study showed that nonoiled conspecifics undergoing rehabilitation for other reasons may provide informative comparison groups for studying the effects of oiling on seabirds. Further work is needed to improve our knowledge of the clinical problems of oiled wildlife and our ability to provide these animals with the best achievable care.

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