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POSTRELEASE SURVIVAL OF CALIFORNIA BROWN PELICANS (*PELECANUS OCCIDENTALIS CALIFORNICUS*) FOLLOWING OILING AND REHABILITATION AFTER THE REFUGIO OIL SPILL

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ABSTRACT: Oil spills represent a continued threat to marine wildlife. Although the public expects, and the State of California, US requires, oiled animals to be rescued for rehabilitation and release, scientists have questioned the welfare and conservation value of capture and rehabilitation of oiled wildlife, based on poor postrelease survival documented in the few available studies. In May 2015, Plains Pipeline 901 spilled >100,000 gallons of oil near Refugio State Beach, California. Many California Brown Pelicans (*Pelecanus occidentalis californicus*) were oiled; capture and rehabilitation efforts began within 1 d. Ultimately, 65 live birds were captured, including 50 pelicans. Forty-six pelicans survived and were released. Of these, 12 adults (six male, six female) were fitted with solar-powered GPS satellite Platform Terminal Transmitters (PTT) and released in June 2015. In early July, we captured eight adult (three male, four female, one unknown), unoiled pelicans from the Ventura, California area. These control birds were similarly instrumented and released immediately. At 6 mo after release, PTTs from nine of 12 oiled pelicans and six of eight control pelicans were still transmitting; at 1 yr, those numbers decreased to two of 12 and two of eight, respectively. Survival analysis revealed no difference in survival between oiled and control birds. Although our sample size is limited, these data demonstrate that most oiled and rehabilitated pelicans can survive for 6 mo following release, and some individuals can survive over 1 yr.

Key words: Brown Pelicans, oil spills, *Pelecanus occidentalis*, postrelease survival, telemetry, wildlife rehabilitation.

INTRODUCTION

Marine oil spills are a well-recognized threat to seabirds and other wildlife (Munilla et al. 2011; Barros et al. 2014; Haney et al. 2014). Despite frequent efforts at capture and rehabilitation of oiled wildlife, the ultimate benefit of these activities—for both individuals and populations—is poorly understood, due to the rarity of long-term postrelease studies. Penguins are a notable exception; decades of data and substantial postrelease monitoring have shown that penguins tend to survive, reproduce, and reintegrate into the wild population after oiling and rehabilitation (Wolfaardt et al. 2009; Chilvers et al. 2015). Other seabirds, however, have been shown to have more variability in survival, based on the few studies that are available. A review of banding records in the US from 1969 to 1994 found very short survival times of oiled and rehabilitated alcids, grebes, and sea ducks (Sharp 1996). Similarly, oiled and rehabilitated American Coots (*Fulica americana*) had lower survival than unoiled controls after a southern California oil spill in 1995 (Anderson et al. 2000). California Brown Pelicans (*Pelecanus occidentalis californicus*) oiled in the 1990 American Trader tanker spill off the coast of California had lower survival rates than unoiled control pelicans (Anderson et al. 1996).

There is considerable interest on the part of the public and trustee agencies to rehabilitate oiled wildlife; in fact, in California, the rescue and rehabilitation of oil-affected wildlife with the goal of release are mandated by the 1990 Lempert-Keene-Seastrand Oil Spill Prevention and Response Act (Office of Spill Prevention and Response and California Department of Fish and Wildlife 2016), which directs the state to: "assess injury to, and provide full mitigation for injury to, or to restore, rehabilitate, or replace, natural resources, including wildlife, fisheries, wildlife or fisheries habitat, and beaches and other coastal areas, that are damaged by an oil spill" (article 2, section 8670.7). Rehabilitation efforts will therefore occur regardless of the debates surrounding success rates or conservation value. It is incumbent upon the scientific community to demonstrate the conservation benefit of rehabilitation (Estes 1991; Jessup 1997). Wildlife rehabilitation methods have continued to advance since the publication of the mentioned postrelease studies (Massey 2006; Jessup et al. 2012), but evaluating their effectiveness is difficult. Studies utilizing only band returns are inexpensive but yield little data; direct observational studies are labor-intensive and often limited in temporal or geographic scope, or both. Telemetry studies are logistically challenging and expensive, but they provide a large amount of data. Some recent studies have yielded results that better detail postrelease condition, behavior, and survival. For example, a study of rehabilitated Western Gulls (*Larus occidentalis*) after oiling in the 1997 Torch/Platform Irene Pipeline spill found 100% survival until transmitter failure, which was 3 to 4 mo after release (Golightly et al. 2002). After the Deepwater Horizon spill in 2010, a short-term observational postrelease study of oiled and rehabilitated Brown Pelicans did not record any mortality in a 6-wk time frame, although supplemental feeding was performed (Selman et al. 2012). Rigorous postrelease monitoring studies that go beyond the immediate postrelease period are needed to evaluate the efficacy of current rehabilitation methods.

On 19 May 2015, Plains Pipeline 901 spilled >100,000 gallons of crude oil near Refugio State Beach in central California. We initiated a postrelease monitoring study of California Brown Pelicans following this spill. Before release and after undergoing cleaning, rehabilitation, and a prerelease health examination, all pelicans were color-banded, and 12 were instrumented with satellite transmitters. An additional eight unoiled pelicans were captured and similarly instrumented to serve as controls. Here, we report results on the survival of these birds during the first year after release, based largely on telemetry but augmented with band sightings and carcass collection.

MATERIALS AND METHODS

Wildlife capture and rehabilitation efforts began within 1 d of the Refugio spill and continued for 2 mo. Fifty oiled pelicans were ultimately captured; of these, four were euthanized, and 46 survived to release. Capture and rehabilitation procedures and release criteria followed the Oiled Wildlife Care Network (OWCN) protocols (2014, 2015). Pelicans remained in rehabilitation for an average of 27 d, with a range of 14 to 85 d (median 23 d). This study was approved as protocol number 18823 by the University of California–Davis Institutional Animal Care and Use Committee, and authorized under US Geological Survey (USGS) Federal Bird Banding (BBL no. 23539), US Fish and Wildlife Service Rehabilitation (no. MB164976-1), US Fish and Wildlife Service Scientific Collection (no. MB191637-0), and California Department of Fish and Wildlife Rehabilitation permits.

All pelicans that had been oiled, washed, and rehabilitated were candidates for inclusion in the study (oiled and rehabilitated birds [OAR]). Upon capture, birds were weighed and evaluated via physical examination, complete blood counts (CBC), serum chemistry panels, and fibrinogen and protein electrophoresis (EPH) tests. Sex was assigned using culmen length (Palmer 1962). Pelicans were regularly evaluated for release using OWCN criteria, which include normal behavior, good body condition, waterproof plumage, and normal blood parameters (OWCN 2014). At the time of the release evaluation, pelicans were fitted with a USGS BBL band on one leg and a large, plastic, green, uniquely numbered (with the prefix "Z") band on the contralateral leg (Fig. 1). Twelve adult pelicans were selected for satellite tagging based on apparent health as they approached release readiness, and based on the

FIGURE 1. Oiled, rehabilitated, and tagged California Brown Pelicans (*Pelecanus occidentalis californicus*) released with GPS satellite Platform Terminal Transmitters were fitted with a large, plastic, green, uniquely numbered band on one leg and a metal federal band on the contralateral leg. Oiled birds had bands with the prefix "Z," while tagged control pelicans had similar bands that were blue with the prefix "N."

FIGURE 2. Oiled, rehabilitated, and tagged California Brown Pelicans (*Pelecanus occidentalis californicus*) were fitted with GPS satellite Platform Terminal Transmitters attached as backpacks with Teflon ribbon. The units weighed 65 g and were custom designed to have a sloping front edge to reduce drag during diving.

absence of compounding factors, such as previous illness, severe pododermatitis, or healed fractures (oiled, rehabilitated, and tagged birds [ORT]). Once pelicans were deemed healthy enough for release, they were instrumented and released at the recently decontaminated Gaviota Beach within 1 wk. We affixed 65-g solar-powered GPS satellite Platform Terminal Transmitters (PTTs; Geotrak Inc., Apex, North Carolina, USA) with a Teflon ribbon harness as described in Lamb et al. (2016) and shown in Figure 2. Birds were observed in aviaries for approximately 3 h after PTT (tag) attachment, to ensure that they were able to walk and swim (Lamb et al. 2016). All tagged birds were released the day after transmitter attachment, on 12 and 27 June 2015.

On 7 and 8 July 2015, eight adult pelicans were captured from the Ventura, California, harbor to serve as unoiled control birds (CON). Birds were baited with fish and then dip-netted from a boat or dock. These birds were fitted with a USGS BBL band on one leg and a large, plastic, blue, uniquely numbered (with the prefix "N") band on the contralateral leg; one bird had only a USGS BBL band placed. Four females, three males, and one bird of unknown sex were captured, examined, bled, and tagged as for the rehabilitated birds; they were released within 2 h of capture and observed until they flew out of sight.

The online wildlife tracking database Movebank (www.movebank.org) was used to collect data from the PTTs. Initially, the duty cycle of the PTTs was 8 h on and 30 h off, with 12 GPS locations reported per day. On 1 September 2015, the duty cycle was predetermined to revise these settings, based on daylight hours, to 8 h on and 36 h off, with 10 GPS locations reported per day, and on 1 November 2015, the duty cycle was revised again to 8 h on and 45 h off, with eight GPS locations reported per day. Additional information on data management can be found in Lamb et al. (2018).

When a PTT stopped transmitting, attempts were made to find a carcass and document mortality (or a bird with a missing or malfunctioning PTT), by searching the location where the PTT last transmitted. In California and Oregon, where members of the research team or partners were available, searches were conducted immediately following signal loss. However, areas in Baja California, Mexico, were less accessible, and our efforts to find carcasses were made at a few predetermined times when staff were in the area. When a carcass was found, the date of death assigned was the last day of movement based on telemetry. Birds whose PTT stopped transmitting but whose carcasses were not found were "right-censored": a term used in survival analysis that indicates that the final outcome of the bird was unknown.

TABLE 1. Means and SDs of body weights and blood values of oiled and rehabilitated (ORT; n=12) vs. unoiled control (CON; n=8) California Brown Pelicans (*Pelecanus occidentalis californicus*) prior to release with satellite tags. P-value is for Mann-Whitney U-tests comparing values of ORT with CON pelicans. Values in parentheses are number of individuals. Significant differences are in bold type.[a]

	ORT (n)	CON (n)	P value
Weight (males) (kg)	4,168.8±173.1 (6)	3,822.0±534.4 (3)	0.2893
Weight (females) (kg)	3,789.3±193.6 (6)	3,610±183.8 (2)	0.3694
Hematocrit (%)	46.4±2.3 (12)	46.0±2.2 (8)	0.7807
White blood cells (10^9/L)	15,541.7±2,835.2 (12)	13,728.3±4,362.0 (8)	0.3842
Heterophil (10^9/L)	**10,989.8±2,867.7 (12)**	**6,310.8±3,713.0 (8)**	**0.0104**
Lymphocyte (10^9/L)	2,777.5±1,099.9 (12)	3,446.0±1,803.8 (8)	0.3692
Monocyte (10^9/L)	1,484.4±843.1 (12)	1,484.4±422.4 (8)	0.9609
Eosinophil count	**851.8±564.3 (12)**	**1,971.8±1,281.7 (12)**	**0.0456**
Basophil (10^9/L)	559.9±331.3 (12)	649.8±360.1 (8)	0.5814
Heterophil:lymphocyte ratio	**4.7±2.4 (11)**	**2.5±2.0 (8)**	**0.0383**
Total protein (g/L)	**0.049±0.003 (12)**	**0.041±0.004 (8)**	**0.0004**
Fibrinogen (hp) (g/L)	3.97±0.79 (12)	3.13±1.13 (8)	0.1113
Fibrinogen (C) (g/L)	2.26±0.72 (10)	1.73±0.51 (8)	0.1037

[a] hp = heat precipitation; C = modified Clauss method for fibrinogen quantification.

Statistics

Statistical analyses were performed using R version 3.5.2 (R Core Team 2016) and the Survival package version 2.44-1.1 (Therneau 2015). Body weights and biomedical parameters were not normally distributed based on the Shapiro-Wilk test for normality; therefore, these parameters were compared using Mann-Whitney U-tests. Survival analyses were performed using telemetry data only; band sightings were not included. For statistical purposes, survival was capped at 365 d postrelease. Kaplan-Meier curves were generated for ORT and CON pelicans, with confirmed mortality as the event of interest. Multivariate Cox proportional hazard models were generated to compare survival of ORT and CON birds and selected biomedical parameters. Cox models were also generated for ORT birds for numerous covariates, including days of rehabilitation, biomedical parameters, and body weight. Akaike information criteria (AIC) values were used in a stepwise procedure to determine the best-fitting models (Moore 2016). Significance was accepted at $P \leq 0.05$.

RESULTS

The ORT birds were captured from 21 May to 2 June 2015, spanning the entire 13 d during which pelicans were collected, with the exception of the first day. Data on body weights, packed cell volume (PCV), total protein (TP), CBC, serum chemistry panels, and EPH were available for 43 OAR pelicans that survived to release. The oiled birds chosen for tagging (n=12; six males and six females) did not differ from the general population of OAR birds (n=31) in number of days in rehabilitation care, intake or release weights, intake and release PCV and TP, or any components of the CBC or serum chemistry panel (data not shown). On EPH, ORT birds had a significantly smaller mean±SD beta globulin fraction compared to the general OAR population (ORT=1.04±0.16 vs. OAR=1.28±0.35, P=0.0184). Only body weight and CBC parameters were available for the CON pelicans. The release weights of ORT pelicans did not differ from those of CON birds of the same sex (Table 1). However, ORT pelicans had significantly higher mean heterophil counts, heterophil to lymphocyte ratios (H:L), and TP levels compared to CON birds (Table 1). Eosinophil counts were significantly higher for CON birds (Table 1).

Telemetry history for all birds is summarized in Table 2. Based on battery levels and other PTT-specific data, all satellite PTTs appeared to function normally for the first 3 mo of the study. The PTT of female ORT

TABLE 2. Survival and mortality summary for 12 oiled, rehabilitated, and tagged (ORT), and eight control (CON) California Brown Pelicans (*Pelecanus occidentalis californicus*) that were equipped with GPS satellite tags and tracked for 1 yr. Dates of postrelease anecdotal sightings of some pelicans are included, but many birds eventually traveled to remote areas where sightings would not be expected. "Alive" indicates the pelican was transmitting or photographed alive; "lost" ("censored" in survival analysis terminology) indicates that the pelican was no longer transmitting; and "dead" indicates that the bird's carcass was found.[a]

Group	Band	Intake date	Sex	Date of last transmission	Days of transmission	Days postrelease at last sighting	Date of death	Status at 6 mo	Status at 1 yr
ORT	Z29	21 May 2015	F	14 Sep 2015	241	NA	U	Alive	Lost
ORT	Z11	22 May 2015	F	6 Nov 2015	337	280	U	Alive	Lost
ORT	Z39	22 May 2015	M	18 Nov 2015	271	141	U	Alive	Lost
ORT	Z02	24 May 2015	F	10 Feb 2015	94	393	U	Lost	Lost
ORT	Z34	25 May 2015	M	31 Dec 2015	369	95	U	Alive	Alive
ORT	Z05	27 May 2015	M	1 Jan 2016	275	422	U	Alive	Lost
ORT	Z31	27 May 2015	M	28 Dec 2015	188	75	U	Alive	Lost
ORT	Z04	27 May 2015	M	12 Jan 2016	345	NA	U	Alive	Lost
ORT	Z01	29 May 2015	F	7 Feb 2016	448	NA	U	Alive	Alive
ORT	Z32	29 May 2015	F	22 Feb 2016	134	80	6 Nov 2015	Dead	Dead
ORT	Z37	30 May 2015	M	7 Mar 2016	256	497	U	Alive	Lost
ORT	Z35	2 Jun 2015	F	22 Mar 2016	146	115	U	Lost	Lost
CON	N10	7 Jul 2015	F	12 Mar 2016	215	130	7 Feb 2016	Alive	Dead
CON	N11	7 Jul 2015	F	13 Apr 2016	178	169	U	Lost	Lost
CON	N12	7 Jul 2015	F	13 May 2016	433	256	U	Alive	Alive
CON	N13	7 Jul 2015	F	21 May 2016	433	NA	U	Alive	Alive
CON	N15	8 Jul 2015	M	28 Jun 2016	188	NA	U	Alive	Lost
CON	N16	8 Jul 2015	M	12 Sep 2016	176	183	31 Dec 2015	Dead	Dead
CON	N17	8 Jul 2015	U	12 Sep 2016	280	532	U	Alive	Lost
CON	NICK	8 Jul 2015	M	2 Sep 2016	155	NA	U	Lost	Lost

[a] F = female; M = male; U = unknown; NA = not applicable.

pelican Z02 ceased to transmit 94 d after release on 12 June 2015, but mortality could not be confirmed. The first documented mortality was recorded on 1 December 2015, when the carcass of female ORT pelican Z32 was found after 134 d of PTT transmission. Data transmissions ceased from three additional PTTs (ORT Z35, CONs N11, and N16) between days 134 and 180 after release. We retrieved the carcass of only one of these, N16; that bird's PTT had transmitted for 176 d. The carcass of N10 was recovered just past the 7-mo mark. All three carcasses, however, consisted of only bones and feathers when they were found, so no information regarding cause of death was evident. By 1 yr (365 d) after release, tags of two ORT birds (17%) and two CON birds (25%) were still transmitting.

Photographic sightings from our team or citizen scientists documented several PTT failures, where birds that were initially recorded as dead were subsequently photographed alive, indicating PTTs that failed or were lost. Three of 12 ORT birds, including Z02, the first bird to stop transmitting, were photographed approximately 5, 8, and 9 mo after their last transmission. One of eight CON birds, N17, was photographed 8 mo after its PTT had stopped transmitting. Overall, this indicates a 20% PTT failure or loss rate.

Based on telemetry, the ORT birds survived an average of 251±93.7 d, compared to the average of 240.3±85.6 d for CON birds (*t*-test, df=16.1, P=0.80). This is an underestimate, both because some PTTs failed and because four bird's PTTs continued transmit-

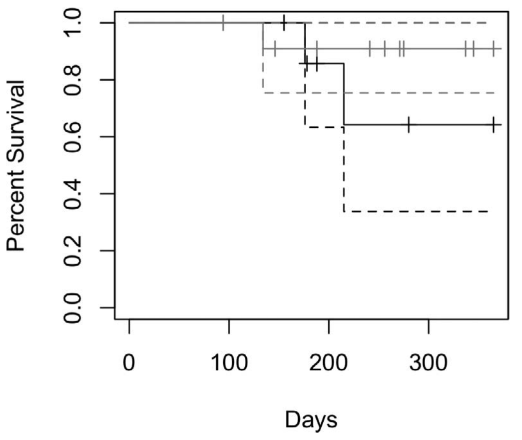

FIGURE 3. Kaplan-Meier curves with 95% confidence intervals (dashed lines) for 12 oiled, rehabilitated, and tagged (gray) and eight control (black) California Brown Pelicans (*Pelecanus occidentalis californicus*) followed for 1 yr after release using telemetry. Tick marks indicate time of disappearance (censoring) of individual birds. Log-rank test; chi-square=0.9, P=0.3.

ting beyond the 1 yr period of the study. Survival analysis was performed at 6 mo (180 d) and 1 yr (365 d). Death as the final outcome was known for only two birds at 6 mo (Z32 and N16) whose carcasses were recovered. The 18 remaining birds (11 ORT, 7 CON) were right-censored. At 1 yr, an additional carcass (N10) was recovered, so the ultimate fate of three birds (Z32, N16, and N10) was known. The 17 remaining birds (11 ORT, 6 CON) were right-censored. There was no significant difference in survival between ORT and CON birds at either 6 mo (P=0.800; df=1) or 1 yr (P=0.967; df=1). This is illustrated by the Kaplan-Meier curves, seen in Figure 3, where the 95% confidence intervals of the two groups overlap extensively.

A multivariate Cox proportional hazard model for all pelicans with PTT tags (ORT and CON) was generated first (null model), and then a model comparing the ORT and CON birds was generated. Neither had a significant likelihood ratio test. The null model had a slightly lower AIC (16.40 vs. 17.51). Adding in the covariates treatment group (ORT vs. CON), hematocrit, white blood cell (WBC) count, heterophil count, lymphocyte count, eosinophil count, monocyte count, basophil count, TP, and fibrinogen for complete cases in a stepwise evaluation of AIC, the best model included treatment group, WBC count, heterophils, and eosinophils. This final model had a slightly higher AIC (16.67) than the null model. Two covariates, quantitative fibrinogen and sex, were not included in the model because of missing values. They were included in a separate but smaller model with the missing cases deleted; this did not result in a lower AIC. Therefore, none of the models was superior to the null model, indicating that treatment group (i.e., ORT vs. CON) was not an important predictor of survival time. Model parameters and statistical test results can be seen in Table 3.

More covariates for the ORT birds were available, and these were incorporated into a multivariate Cox model separately from the CON birds. Initial intake values (PCV, total solids, date, weight); number of days in care; and prerelease values (weight at release, TP, WBC count, PCV, eosinophil count, alpha globulin-1, alpha globulin-2, beta globulin, and gamma globulin) were included in the starting model (AIC=4.80). After forward stepwise evaluation using AIC, the final model (AIC=2.00) included only TP (Table 3).

DISCUSSION

No difference was seen in survival time between ORT and CON birds, with survival rates in both groups equal to 75% at 6 mo. In contrast, an older study of Brown Pelicans after the 1990 American Trader oil spill found that by 6 mo postrelease, ORT birds were sighted at a significantly lower rate than CON birds. Our study demonstrates that pelicans oiled in anthropogenic spills that are captured and rehabilitated using current protocols can survive for at least 1 yr postrelease and have survival rates similar to unoiled birds at 6 and 12 mo after release.

Opportunities to compare intraspecific responses to oiling and rehabilitation within the

TABLE 3. Parameter values of Cox proportional hazard models comparing survival of California Brown Pelicans (*Pelecanus occidentalis californicus*) following the Refugio oil spill in 2015. Final selected models are in bold type.

Model[a]	Variable	Beta coefficient	Hazard ratio exp (coefficient)	Standard error beta	*z* statistic	95% Confidence interval		*P* value	AIC
a. ORT vs. CON pelicans									
A	**Null**								**16.4**
B	Group	−6.606114	0.001352	4.799659	−1.376	1.111E−07	6.462	0.169	16.7
	White blood cell count	0.001959	1.001961	0.001834	1.068	9.98E−01	1.006	0.285	
	Eosinophil count	−0.010778	0.98928	0.008868	−1.215	9.72E−01	1.007	0.224	
	Heterophil count	−0.002085	0.997918	0.001835	−1.136	9.94E−01	1.002	0.256	
C	Group only	−1.1202	0.3262	1.2301	−0.911	2.93E−02	3.636	0.362	17.5
b. ORT pelicans only									
A	**Total protein**	**5.32E+01**	**1.24E+23**	**7.34E+04**	**0.001**	**0**	**inf**		**2**
B	Null							0.989	4.8

[a] a = survival of oiled, rehabilitated, and tagged (ORT) pelicans compared with unoiled control (CON) pelicans; b = survival of ORT pelicans.

same geographic region are rare. Along the southern California coast, however, Brown Pelicans were directly affected by both the American Trader spill of 1990 and the Refugio spill of 2015. After the 1990 spill, oiled and rehabilitated pelicans had higher mortality rates than controls; oiled pelicans began to disappear within 60 d of release, while no control birds disappeared until 150 d after release (Anderson et al. 1996). Those authors concluded that rehabilitation techniques were not effective in releasing healthy birds. The lack of difference in mortality rates between ORT and CON birds in our study may be explained by improved capture, reconnaissance, and rehabilitation methods. Other possible explanations include better assessment of release readiness, timing of the spill, environmental conditions (e.g., food availability), or other unknown factors. The Refugio spill occurred about 250 km north of the American Trader spill, and approximately 2 mo later in the year. The winter/spring season of 2015 experienced a very strong El Niño event, which tends to result in lower breeding success in California pelicans (Anderson et al. 2017). In contrast, 1990 had neither an El Niño nor a La Niña event (Anderson et al. 2017). These differences may have had an impact on survival that was unrelated to the spill and subsequent rehabilitation. During the Refugio response, 92% of pelicans that arrived at the rehabilitation center alive were released (overall, 68% of birds were released) (OWCN data); percentages of pelicans released after the American Trader spill were not reported. However, a study of three large-scale California spills from 1997 to 2003 found that only 37% of more than 2,000 birds were released (Massey et al. 2005). These data support the conclusion that rehabilitation of oiled birds to the point of release has become more successful.

One challenge of postrelease survival studies is the ability to definitively assign mortality to individuals. We attempted to accomplish this via satellite telemetry, which we were simultaneously using to assess habitat use (Lamb et al. 2018) and which has been used with terrestrial species (e.g., Kelly et al. 2015). Using satellite telemetry to assess mortality carries the assumption that tags will not cease transmission prior to the mortality event. Tag failure or loss can therefore lead to overestimated rates of mortality. Due to numerous documented transmitter failures in this study, cessation of transmission could not reliably be equated with mortality, and instead our data would better represent a minimum survival time postrelease. We relied on carcass retrieval to confirm death, and we censored (i.e., did not specify an outcome) the birds that disappeared. We did not adjust the status of birds who were resighted after they ceased transmitting because this would introduce bias, as not all birds had an equal likelihood of being resighted (White and Garrott 1990). Birds that were living in urban areas and places that were easily accessible to field personnel and the public were presumably much more likely to be resighted than those living in more remote areas, such as western Sonora, Mexico. While this artificially decreased survival time of ORT birds more than that of CON birds, there was no significant difference between the groups. Incorporating the resighting data and assuming that only four tags failed, five of 12 (42%) ORT pelicans and three of eight (38%) CON pelicans were still alive 1 yr after being released.

Despite the aforementioned challenges of using telemetry to assess mortality postrelease, tracking individuals still provides a relatively unbiased means to assess survival of oiled birds postrelease (Helm et al. 2015). While the incidence of tag failures in this study resulted in higher estimated mortality before sightings were added to the data stream, a reliance only on sightings was also fallible. Nine of the tagged birds were last sighted prior to the cessation of transmission; had we relied on sights alone to assess mortality, these nine birds would have been considered dead. Hence, the use of telemetry and sightings was complementary.

An important consideration in the comparison of survival rates between ORT and CON birds is the condition of the individuals selected for tagging, including but not limited to the health or level of debilitation of individuals. Bias can therefore be avoided by choosing birds for instrumentation that are captured both early and late in the response, and birds that have varying degrees of visible oiling. At the same time, the ethics of rehabilitation require that birds ready for release are not held in captivity for an extended period while logistics are completed, as this could lead to the development of new, captivity-related problems (Tseng 1999). Another challenge is to ensure that birds selected for tagging are healthy enough to carry the additional weight of the tag yet still represent the overall population available. We used various health metrics such as CBC data to compare eligible individuals. The only difference detected between the general rehabilitated population and the birds chosen for tagging was in beta globulins. This blood parameter is used as a marker for underlying inflammatory conditions that are not clinically apparent. In fact, two birds with elevated beta globulins had problems manifest during rehabilitation and were excluded from the study, which may partially explain this difference.

Selecting control animals that are similar to the oiled population is also important but difficult, particularly in a species that undergoes seasonal migrations. Due to the needs of birds in rehabilitation, and restricted access to beaches during environmental clean-up operations, we were unable to capture a control group until 2 mo after the spill. For migratory birds, that means that the birds that were oiled on 15 May could have been in a different stage of migration or from a different subpopulation than the unoiled birds in the same general location in July (Anderson et al. 1996). There are several California Brown Pelican subpopulations with distinct migratory routes and breeding sites, as well as nonmigratory subpopulations, but they all may overlap spatially during spring migration (Anderson et al. 2017; Lamb et al. 2018). The CON pelicans used in this study had somewhat different hematologic profiles compared with the ORT birds. The higher mean heterophil counts and H:L ratio in the ORT birds probably reflected a higher stress level (Krams et al. 2012), which is not surprising given that these animals had experienced oiling, capture, cleaning, and weeks of captivity. The higher mean TP of the ORT compared to the CON birds contrasts with data in Anderson et al. (2000), in which oiled coots tended to have lower TP than controls. We posit that ORT pelicans in our study had higher protein because they were fed exclusively capelin, and food was provided ad libitum to encourage maximum intake and to minimize stress and competition among birds (Helm et al. 2015). Interestingly, among the ORT pelicans, the only variable that was associated with longer survival was TP, indicating that nutritional status, or ability to convert calories into body mass, may be a critical factor in survival of oiled and rehabilitated pelicans.

The higher eosinophil count in the CON birds may have been related to parasite load, inflammation, reproductive status, time of year, or other, unknown, factors (Samour 2008; Clark et al. 2009; Schumann et al. 2014). Pouch lice were observed on CON pelicans during their physical examinations, but burdens were low, ranging from zero to two. However, they may have had high burdens of internal parasites. It is likely that the ORT pelicans had lower parasite burdens than the CON pelicans at release, as the former were treated for parasites during rehabilitation, while CON pelicans were neither systematically evaluated nor treated for parasites. Although the CON birds may have had some unknown source of inflammation, this seems unlikely given that their mean heterophil count was significantly lower, and their mean leukocyte count and fibrinogen levels were lower (although not significantly so). Reproductive status of all birds at the time of capture was unknown. It is also possible that the ORT and CON pelicans originated from different subpopulations (Lamb et al. 2018), which may have had slightly different hematologic profiles. Finally, due to the method of capture for the CON pelicans, we may have inadvertently selected for a subset of the population more accustomed to the presence of humans and the exploitation of human food sources (Anderson et al. 2017; Lamb et al. 2018).

One limitation of the study is the fact that these birds were outfitted with external harnesses and transmitters. Although we used tags well within the recommended range for weight, the presence of the tag and harness has the potential to impact energy balance; aero- and hydrodynamics; behavior; and stress level (Warnock and Takekawa 2003; Vandenabeele et al. 2011; Jaques et al. 2019). The long-term survival of some birds despite the instrumentation, however, suggests that the tags were well tolerated.

In conclusion, California Brown Pelicans that were oiled during the Refugio oil spill and captured, cleaned, rehabilitated, and instrumented with PTT satellite tags did not have higher mortality in the year following release compared to unoiled pelicans that were captured and similarly instrumented. These results demonstrate that, at least in some circumstances, rehabilitating oiled birds can successfully restore them to their environment with a reasonable expectation of survival in the short- and medium-term.

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