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Movement patterns of California brown pelicans (*Pelecanus occidentalis californicus*) following oiling and rehabilitation

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A B S T R A C T

Direct mortality of wildlife is generally used to quantify the damage caused by pollution events. However, free-ranging wildlife that survive initial exposure to pollutants may also experience long-term consequences. Individuals that are rehabilitated following oil exposure have a known history of oiling and provide a useful study population for understanding behavior following pollution events. We GPS-tracked 12 rehabilitated brown pelicans and compared their movements to those of eight non-oiled, non-rehabilitated controls over 87–707 (mean = 271) days. Rehabilitated pelicans traveled farther, spent more time in long-distance movements, and occupied more productive waters than controls. These differences were more apparent among females than males. Rehabilitated pelicans also visited breeding colonies and nest sites at lower rates than controls. Our results indicate that, although rehabilitated pelicans undertake long-distance movements, they may display increased dispersion and reduced breeding investment, particularly among females. Such behavioral changes could have long-term effects on populations.

1. Introduction

At-sea oil pollution regularly affects marine wildlife and their habitats along coastlines worldwide (Islam and Tanaka, 2004). Direct mortality, calculated by surveying oiled carcasses and adjusting total counts based on measures of carcass persistence and detectability, is commonly used as an estimate of the impact of oiling on wildlife populations (Ford et al., 1987; Piatt et al., 1990; Wiese and Robertson, 2004; Haney et al., 2014). However, individuals that do not experience direct mortality as a result of oiling, either because they are exposed to oil at sub-lethal levels (Malcolm and Shore, 2003) or are found alive and rehabilitated (Helm et al., 2015), are not included in damage assessments. Organisms that survive exposure to crude oil may experience physiological, behavioral, and/or energetic effects including anemia (Lutcavage et al., 1995; Walton et al., 1997), reduced mobility or erratic movement patterns (Percy and Mullin, 1977; Mager et al., 2014; Maggini et al., 2017a), increased energy expenditure (Maggini et al., 2017b), organ damage (Szaro et al., 1978), and compromised immune function (Barron, 2012). Cumulatively, changes in mobility, behavior, and foraging due to oil exposure can have long-term effects on population parameters including annual survival and reproduction (Jenssen, 1996; Helm et al., 2015). Therefore, accurately assessing the impacts of oil pollution on wildlife populations requires measuring its effects on surviving individuals in addition to direct mortality.

Studies evaluating the effects of oil exposure have generally focused on captive animals (e.g., Szaro et al., 1978; Lutcavage et al., 1995; Mager et al., 2014; Maggini et al., 2017a, 2017b). This is not surprising because, in free-ranging populations, the effects of oiling on individuals that survive initial exposure are hard to quantify due to the difficulties of finding, identifying, and subsequently tracking exposed individuals. While carcasses of dead animals remain relatively stationary or move consistently on ocean currents (Munilla et al., 2011), live oiled wildlife can disperse unpredictably throughout the marine environment. Identification of exposed individuals is challenging since external oil exposure is not always visually evident. Moreover, exposure and subsequent physiological damage can also occur internally through ingestion of oil or oiled prey (Leighton, 1993; Fallon et al., 2017). Once an exposed individual is successfully identified, determining the

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consequences of exposure requires following its movements and behavior over time and across vast marine landscapes. Meanwhile, information on the variation of movements and behavior of non-oiled individuals in similar habitats is often unavailable, making it difficult to place post-exposure observations in the context of baseline conditions (Helm et al., 2015; Haney et al., 2017).

Individuals cleaned and released from rehabilitation centers following oil exposure provide an opportunity for studying the long-term effects of oiling on free-ranging wildlife (Helm et al., 2015). Aside from improving immediate survival rates, post-spill rehabilitation efforts aim to enable processed individuals to eventually resume normal foraging and migratory behavior (Mazet et al., 2002). Long-term changes in movement or energy use following exposure, rehabilitation, and release could reduce body condition, limit mobility of individuals between less-suitable and more-suitable habitats, and adversely affect individuals' capacity to meet the energetic requirements of breeding. There is a need to understand post-rehabilitation movement patterns, habitat use, and breeding over the long term in order to accurately incorporate rehabilitated individuals into estimates of population parameters (Lander et al., 2002). Moreover, given the time, money, and personnel power invested in post-spill wildlife rehabilitation efforts, there is considerable interest in assessing the long-term effectiveness of returning affected individuals to breeding populations (Pyke and Szabo, 2017).

Seabirds are among the most frequently affected wildlife from marine oil spills and, since they spend time above water, some of the easiest to follow post-release (Haney et al., 2017). Previous studies have provided data on seabird survival following oil exposure and rehabilitation (e.g. Sharp, 1996; Anderson et al., 1996; Wernham et al., 1997; Anderson et al., 2000; Golightly et al., 2002; Dunne and Miller, 2007). However, data assessing changes in movement patterns, which require more intensive re-sighting and observation of individuals post-release, have been limited. Band-resighting studies (e.g., Selman et al., 2012) have given some insight into post-release movements of oiled and rehabilitated seabirds, but are limited by lack of comparative baseline or control data and the need to re-encounter individuals moving long distances in inaccessible marine and coastal environments. Anderson et al. (1996) used radio-telemetry to compare post-release movement patterns of rehabilitated California brown pelicans (*Pelecanus occidentalis californicus*) with those of non-oiled controls, and found that the oiled group associated less with breeding colonies than did control individuals, although movement patterns appeared similar between groups. In a similar telemetry study of western gulls (*Larus occidentalis*) Golightly et al. (2002) compared movement patterns among individuals that had been oiled and rehabilitated, non-oiled individuals that had undergone rehabilitation, and non-oiled, non-rehabilitated individuals. The study found similar home range sizes in all three groups, although transmitter duration did not permit comparisons of breeding behavior. Newman et al. (2004) also recorded comparable migration patterns and use areas between oiled, rehabilitated common murres (*Uria aalge*) and wild-caught controls. These three studies compared movement patterns at broad spatial and temporal scales, but short transmitter life and infrequent detections limited their ability to assess fine-scale movement patterns and habitat characteristics.

To address these knowledge gaps, we used bird-borne GPS telemetry to assess the movement patterns of California brown pelicans following oil exposure, cleaning, and rehabilitation. We compared rehabilitated individuals to a control group of non-oiled, wild-caught pelicans from the same region to determine how and whether movements and habitat use following rehabilitation differed from those of non-affected individuals. Given the well-documented negative effects of oil exposure on energetic performance, we expected to see reduced mobility in the oiled group compared to the control group, characterized by shorter distances traveled and decreased ability to select optimal habitats, as well as reduced breeding success. The goals of our work were to improve understanding of the effects of oil exposure on individual fitness and to assess the utility of cleaning and rehabilitation for returning affected individuals to breeding populations.

2. Methods

2.1. Transmitter deployment

Our study was conducted following the Refugio Oil Spill, which occurred in Santa Barbara County, California (USA) on 19 May 2015. The spill, which resulted from a corroded pipeline, released a total of 2934 barrels of crude oil, of which 500 barrels reached the Pacific Ocean (U.S. Department of Transportation Pipeline Hazardous Materials Safety Administration, 2016) and affected at least 20 km of coastline (National Oceanic and Atmospheric Administration Damage Assessment, 2015). In the 37 days following the spill, a total of 267 oiled birds (64 live and 203 dead) and 168 oiled mammals (62 live and 106 dead) were recovered along approximately 130 km of coastline, from Gaviota (34.46°N, −120.21°W) to Point Mugu (34.08°N, −119.06°W). Of these recovered live animals, 46 birds and 23 mammals were rehabilitated and released. Brown pelicans were the most collected avian species (47 live and 26 dead individuals, or 27% of all birds recovered).

Forty-three live oiled pelicans were admitted to the Los Angeles Oiled Bird Care and Education Center in San Pedro, California following the Refugio Oil Spill. Of these, 20 adult birds were assessed as healthy based on physical examination, complete blood count, chemistry panel, and protein electrophoresis, and 12 individuals from the pool of healthy adults were randomly selected for attachment of bird-borne transmitters (oiled and rehabilitated group; hereafter, OAR). OAR pelicans remained in captivity for an average of 19 (± 7) days (Table 1). Transmitters (65 g solar GPS-PTTs, GeoTrak Inc.) were attached using backpack-style Teflon ribbon harnesses intended to remain in place for the lifetime of the individual (Dunstan, 1972; Lamb et al., 2017a). To elevate the transmitters and prevent feathers from covering the solar panels and antenna (and hence negatively affecting solar charging and transmission), we mounted each device on a 6 mm thick neoprene pad that also extended 6 mm beyond the perimeter of the transmitter in all directions. OAR pelicans were given 24–48 h to acclimate to transmitters before being released near the sites where they were initially recovered. We observed elevated preening behavior during the initial 24 h immediately following transmitter attachment while birds were still being held in captivity; however, data collected from field studies

Table 1
Deployment periods and individual characteristics of tracked pelicans.

Individual	Capture date	Release date	Number of days tracked	Sex
Oiled and rehabilitated				
Z01	29 May	12 June	449	F
Z02	24 May	12 June	87	F
Z04	27 May	12 June	343	M
Z05	27 May	12 June	273	M
Z11	21 May	12 June	335	F
Z29	20 May	12 June	240	F
Z31	27 May	27 June	182	M
Z32	29 May	27 June	132	F
Z34	25 May	27 June	366	M
Z35	1 June	27 June	141	F
Z37	30 May	28 June	236	F
Z39	22 May	28 June	269	M
Control				
N10	07 July	07 July	215	F
N11	07 July	07 July	178	F
N12	07 July	07 July	707	F
N13	07 July	07 July	464	F
N15	08 July	08 July	187	M
N16	08 July	08 July	174	M
N17	08 July	08 July	279	U
NICK	08 July	08 July	154	M