Final Report

The Effects of Petroleum Exposure and Rehabilitation on Post-release Survival, Behavior, and Blood Health Indices:

A Common Murre (*Uria aalge*) Case Study Following The *Stuyvesant* Petroleum Spill

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Abstract

In California, oiled wildlife care, as a component of oil spill response, is required by law, despite costs, success rates, or biological importance. However, further research is needed to evaluate the conservation implications of rehabilitation, especially as governments and resource agencies continue to struggle with management decisions pertaining to care of oil injured wildlife. To better understand the long-term effects of petroleum exposure and rehabilitation on Common Murres (*Uria aalge*), we conducted a post-release survival study following the September 1999 *Stuyvesant* oil spill in northern California. Oiled murres were rehabilitated according to Oiled Wildlife Care Network (OWCN) protocols at the Marine Wildlife Care Center at Humboldt State University in Arcata, California. Upon meeting release criteria, we monitored survival and behavior of 31 randomly selected oiled and rehabilitated (ORHB) murres and 25 non-oiled, non-rehabilitated (control) murres using frequent radio-telemetry surveys from aircraft. Blood samples obtained from all birds prior to release were evaluated in relation to subsequent survival.

Based on radio signal presence, ORHB murres had a much longer mean tracking duration (63 ± 8 days) compared to previous studies evaluating post-oil spill survival, but radio failure prevented measurement of long-term survival for most birds; 68% percent of ORHB murres survived for at least 80 days, 3 ORHB murres survived for at least 135 days, and 2 ORHB murres survived for at least 142 days. Higher survival percentages and improved survival duration indicated that recently developed (since1994) OWCN care techniques and facilities resulted in improved care and likely led to higher survival. However, ORHB murre survival was not equivalent to that of control murres. Survival analyses (which compared ORHB and control murre mortality incidence over the entire duration study) indicated that for each control murre that died, 4 ORHB murres were likely to die [Relative Risk = 4.03]. However, ORHB and

control murre mortality did not differ after day 34 of the study (ANCOVA, p=0.55) suggesting that the difference in survival between ORHB and control murres mostly occurred during the first 34 days after release. In total, 10 ORHB and 2 control murres died and 80% of the mortalities occurred between 15-40 days after release. If ORHB murres survived past 34 days, they survived comparably to non-oiled control murres, traveled similar distances from Humboldt Bay to the north and south, stayed at similar distances from shore, and utilized similar areas as control murres. This suggested that if murres survived, their at-sea distribution, mobility, navigation, and movements were not impaired.

Blood results differed between ORHB and control murres, and between ORHB murres that died and ORHB murres that survived. These findings indicated that inflammation and possibly infection secondary to petroleum exposure, captivity, and/or handling contributed to post-release mortality. From a clinical perspective, only pre-release fibrinogen concentration differed significantly between ORHB murres that survived and ORHB murres that died. However, based on survival analyses, lower total inorganic phosphorous concentration, higher creatine kinase activity, and higher fibrinogen concentration were associated with decreased survival by 1.7, 2.4, and 3.0 times respectively. These findings suggest that current OWCN release criteria may be further optimized by including these blood parameters in health assessments prior to releasing oil injured wildlife.

While survival of ORHB murres was still somewhat lower than that of control murres, no previous studies have documented comparable survival rates, survival duration, and customary or normal behavior in oiled and rehabilitated Common Murres. Longer documented survival (45-145d) likely indicates greater potential for even longer survival and breeding of ORHB murres suggesting that oiled wildlife care may have biological importance and conservation implications in the future.

Introduction

Since 1999, five major oil spills in France, Germany, South Africa, Spain, and the United States have resulted in the need for biomedical care of more than 50,000 birds and actual losses in the hundreds of thousands of seabirds (J. Holcomb, pers. comm., IFAW unpubl. data). As impacts of large oil spills gain notoriety worldwide, many governmental agencies and conservation organizations must evaluate the effectiveness of rehabilitation efforts.

Oiled seabird rehabilitation has traditionally been viewed as an ineffective restoration technique by many wildlife and conservation biologists due to: 1) the low percentage of total oiled seabirds recovered alive and low percentage of these birds suitable for rehabilitation; 2) poor survival of oiled birds during captive care; 3) documented deaths or return to shore of some rehabilitated birds shortly after release; 4) evidence of altered behavior during breeding season and little direct evidence of successful reproduction by rehabilitated birds after release; and 5) evidence of oil damage to organ systems from petroleum exposure (Anderson et al. 1996, Anderson et al. 1999, Camphuysen et al. 1997, Fry and Addiego 1987, Fry and Lowenstine 1985, Golightly et al. 2002, Newman et al. 1999a, Sharp 1996, Wernham et al. 1997). In addition, high costs have been associated with effective oiled seabird care, and some have argued that these funds could potentially be spent more effectively on other forms of seabird restoration after the oil spill response (Estes 1998, Jessup 1998, Newman 1995).

Oiled seabird rehabilitation has occurred over the past 5 decades throughout the world, primarily for humanitarian reasons. Through these numerous efforts, improvements have been made in captive care and rehabilitation techniques. To date, most research has been focused on rehabilitation techniques (Newman et al. 2003) as the task of determining the long-term fate and breeding outcomes of rehabilitated birds has been difficult and costly to undertake. However, it

is becoming increasingly important to determine whether oiled wildlife rehabilitation can be considered a tool for mitigating effects of oil spills, and ultimately, a biologically viable option for seabird restoration (Anderson et al. 1999, Golightly et al. 2002, Newman et al. 1999a).

In the northern Pacific and Atlantic Oceans, the Common Murre, (*Uria aalge*) (hereafter referred to as "murre") has been oiled in large numbers and represents a large portion of the birds impacted by marine oil spills (Ainley et al. 2002, Carter 2003, Carter et al. 2001, Evans and Nettleship 1985, OWCN Legislative Report 2002). Efforts to rehabilitate oiled murres in the 1980's and early 1990's resulted in short survival times (estimated average of 10-29 days) following release and survival to one year was estimated to rarely (0-0.6 %) occur (Camphuysen et al. 1997, Sharp 1996, Wernham et al. 1997). These results suggested that in both Europe and North America, efforts to care for oiled murres had not resulted in the release of healthy, viable murres. Challenges associated with murre rehabilitation are that they readily stress during handling, they are prone to captive care or husbandry problems including keel lesions, stifle, hock or foot abrasions, and bacterial or fungal infections (Tseng 1999), and as a colonial species, they should be housed in groups to accommodate their highly social nature. This in turn, creates a situation in which infectious diseases can spread and result in mass mortality (Bicknell et al. 1971, Friend and Trainer 1969), especially when murres are densely housed in rehabilitation pens or recovery pools.

In contrast, Western Gulls (*Larus occidentalis*) are a more captivity and handling tolerant species suggesting that successful rehabilitation would be more likely in this species compared to murres. Following the 1997 *Torch/Platform Irene Pipeline* spill in southern California, oiled and rehabilitated Western Gulls had equivalent long-term survival and utilized similar area as non-oiled control gulls (Golightly et al. 2002). This was the first demonstration of successful long-

term survival following oil exposure, rehabilitation, and release using modern rehabilitation techniques in California (OWCN 1998, Mazet et al. 2002, Newman et al. 2003). The question of effectiveness in a potentially more sensitive species such as the murre remained to be determined.

In central California, the murre population had also declined significantly between 1980 and 1990 due mainly to mortality in gill nets and oil spills (Carter 2003, Carter et al. 2001, Takekawa et al. 1990). While showing signs of recovery in the 1990's, this population has been continually affected by both acute and chronic petroleum exposure (Carter et al. 2001). In fact, murres were the species most frequently recovered during California oil spills between 1996 and 2004 (OWCN Legislative Report 2002, Ziccardi et al. 2004). Thus, we identified the study of murre survival following release from oiled wildlife care facilities as an important way to determine whether current rehabilitation efforts were efficacious given that; 1) previous studies on Western Gulls were successful, 2) recent attempts were being made to improve and standardize oiled wildlife care in California, 3) physical structures and personnel infrastructure existed in California, and 4) murre populations were undergoing chronic impacts due to the persistent nature of oil spills and fisheries practices in the central California.

Following the 1999 *Stuyvesant* intermediate fuel oil spill in northern California, we evaluated survival and behavior of oiled and rehabilitated (hereafter "ORHB") murres using radio-marked individuals. To assist interpretation of results, we also evaluated survival and behavior in free ranging, non-oiled, non-rehabilitated murres (hereafter "control murres"). To assess consistency in the two groups' behavior, we determined whether ORHB and control murres had similar spatial extent and similar movements following release. We anticipated that survival might not be equivalent between ORHB and control murres, so we also evaluated the

potential physiological differences that might exist between surviving and non-surviving rehabilitated murres. Consequently, we collected blood samples prior to release to determine whether there were detectable differences in blood health indices. We also assessed whether blood health indices could be used as predictors of survival or mortality in ORHB murres.

Materials and Methods

Study Group Sampling, Capture, Radio Marking, and Morphometrics

On 6 September 1999, at least 9,000 liters of intermediate fuel oil (IFO 180) was spilled adjacent to the mouth of Humboldt Bay (40º 45.8'N, 124º 14.1'W) on the northern California coast. Oil contaminated wildlife were recovered between 8–11 September from the beaches north (40º 47.4'N, 124º 12.4'W) and south (40º 44.4'N, 124º 14.4'W) of the entrance to Humboldt Bay. Birds were collected primarily by staff of OSPR and OWCN organizations including the Marine Wildlife Care Center at Humboldt State University (HSU) and International Bird Rescue Research Center with the assistance of U.S. Fish and Wildlife Service and California Department of State Parks and Recreation. A total of 644 live birds (550 murres) were rehabilitated using to OWCN protocols (OWCN 1998) at the Marine Wildlife Care Center, an oiled wildlife care facility located at HSU, in Arcata, California (approximately 7 km from the initial oil spill site).

Juvenile murres that hatched in 1999 were excluded from the study because: a) we could not determine if they all were fully independent of parental care when oiled, which might contribute to death after release; b) high juvenile mortality occurs in murres (before and after parental independence) which would complicate measurement of post-release survival, especially with small sample sizes of radio-marked birds; and c) inclusion of differing

proportions of juvenile birds would affect which control birds would be need to be captured as controls to match the cohort of birds used in the study. Thirty-one oiled after-hatching-year (AHY) murres (based on mottled head plumage and flightless primary molt [see Nevins and Carter 2003]) were randomly selected for the study after being rehabilitated for 17-21 days and meeting the following criteria; body mass was within 10% of intake mass, plumage was waterproof while birds swam in recovery pools, blood results included a packed cell volume (PCV) greater than 35% and total solids greater than 3.0 mg/dl, and birds consistently exhibited normal foraging, preening, and social behaviors (OWCN 1998). Prior to release, each rehabilitated murre was fitted with a stainless steel federal leg band and 3 plastic color coded bands, morphological measurements were taken, and molt was assessed. Blood samples (3 ml) were collected aseptically from the medial metatarsal vein and an 8.5 g ATS radio-transmitter (Model 2040, Advanced Telemetry Systems, Isanti, MN) equipped with a mortality sensor was attached to each bird using the subcutaneous anchor method (Newman et al. 1999b). After oil cleanup operations had ceased and no oil was observed in the ocean at or near the spill site, all rehabilitated murres were released inside Humboldt Bay (40º 46.4'N, 124º 13.5'W) approximately 2 km northeast of the original spill site and on the inside of the breakwater.

Between 24 and 31 days after the oil spill, 25 non-oiled free ranging adult murres were captured using the night-lighting technique (Whitworth et al. 1997). These murres were captured between within 10 km of shore between Trinidad Head (41º 03' 6.34N, 124º 09' 1.50W) and the mouth of the Mad River (40º 57' 22.30N, 124º 07' 42.58W) on 30 September or 6 and 7 October, or between Crescent City Harbor (41º 44' 35.05N, 124º 11' 26.36W) and the mouth of the Klamath River (41º 32' 50.94N, 124º 05' 2.22W) on 2 or 3 October. These individuals had no evidence of oiling based on visual inspection, waterproofing, buoyancy, and body condition.

All control murres were undergoing primary molt and were flightless, similar to ORHB murres in captivity. Control murres were transported in plastic pet carriers to Marine Wildlife Care Center at HSU and thoroughly examined a second time to confirm that they were not oiled. Each control murre was then processed similar to rehabilitated murres in that each bird was banded, measured, radio marked, bled, and equipped with radio-transmitters (identical model, size and weight as rehabilitated murres). Birds were tube fed isotonic fluids for hydration after blood samples were collected. All control murres were released near their respective capture locations at Trinidad Head or Crescent City Harbor within 24 hours of capture. No oil was observed in the ocean at or near these release sites.

Telemetry Flights and Bird Locations

Aircraft with wing-mounted antennae were used to locate murres twice per week from October through December 1999 and once per week from January to March 2000. Flights were conducted between Monterey Bay, California (36º 36.4'N, 121º 53.5'W) and the Oregon-Washington border (41º 59.9'N, 124º 12.6'W) with the aircraft traveling 8 km offshore in one direction then returning 30-40 km offshore in the other direction. Radios could be detected 33-50 km from the aircraft as it flew at 450 m above sea level. Bird locations were recorded by the biologist pilot using a global positioning system. Radio-marked birds were considered dead if a radio emitted the encoded mortality signal associated with no movement for 2 consecutive flights. However, if no signal was detected for 3 consecutive flights, the radio-marked bird was considered missing. Missing birds were not assumed to be dead because the radios could have expired before the expected radio lifespan due to early battery failure or other signal transmission problems (Ackerman et al. 2003, Golightly et al. 2002). If a radio signal was absent in a single

survey and detected in a subsequent survey, the bird was considered alive in all surveys. If individual birds were not located for 2 consecutive flights, a larger geographic region was searched during the subsequent flight. Extensive air surveys eventually encompassed a large portion of the winter range for murres breeding on northern California island colonies. Radio tracking flights ranged from Los Angeles, California (35º 56.2'N, 118º 26.4'W) to southern Vancouver Island, British Columbia (50º 02.6'N, 125º 15.3'W). The northern-most portion of the winter range for northern California murres including Juan de Fuca Strait, Puget Sound, Straits of Georgia, and northern Vancouver Island (Manuwal and Carter 2001) were not searched.

We were not able to visually identify radio-marked murres from the aircraft, but recorded locations were estimated based on the loudest, strongest radio signal and aircraft circling to locate the strongest signal. When mortality signals were detected, a ground team was deployed to attempt to recover the carcass and radio. We calculated the total numbers of active radios in each study group for each aerial survey, during the time when radio signals were disappearing. This provided us with a cumulative disappearance rate for ORHB and control groups. We hypothesized that if greater undetected mortality was occurring in ORHB murres during the time frame in which radio batteries were failing, we would detect these mortalities by a significantly higher disappearance rate. We conducted a piece-wise regression so we could analyze comparable post-release periods and then tested for differences using analysis of covariance (SPSS Inc. 1993).

We used the minimum convex polygon area-estimator (MCP) with the Telem computer program (K. McKelvey, United States Forest Service, Pacific Southwest Research Station, Arcata, California) to characterize the area used by radio-marked murres. Boundaries of each

MCP were drawn on maps using ArcInfo and ArcView (Environmental Systems Research Institute Inc. 1999). The Mann-Whitney U Rank Sum Test was used to test for differences in size of areas used by the ORHB and control groups (SPSS Inc. 1993). We also tested whether distances of birds from shore differed between groups. Because movements and distributions are strongly affected by the shoreline (predominately north and south in the study area), we also compared distances traveled north from the release site, distances traveled south from the release site, and the total distance from the northern most location to the southern most direction for ORHB and control murres.

Hematologic and Biochemical Blood Analyses

Prior to release, all murres (ORHB and control) were blood sampled (3 ml) from the medial metatarsal vein using a 3cc syringe and 23g butterfly needle. A 0.5 ml aliquot of blood was placed in EDTA Microtainer tube™ (Becton-Dickinson and Co., Franklin Lakes, New Jersey, USA) and refrigerated immediately. Hematologic testing was performed at the Veterinary Medical Teaching Hospital, School of Veterinary Medicine, University of California, in Davis California within 72 hours of collection. Packed cell volume or hematocrit (Hct) was determined by microhematocrit centrifugation (Jain 1986); erythrocytes (RBC) were counted using the RBC Unopette™ (Becton Dickinson and Co., Cockeysville, Maryland, USA) technique (Campbell 1995); hemoglobin (Hb) concentration was measured by a cyanmethemoglobin method following lysate centrifugation (Zinkl 1986); and fibrinogen concentration was determined by heat precipitation (Duncan et al. 1994). Mean corpuscular hemoglobin concentration (MCHC) was calculated (Hb concentration x 100 / PCV). Wright-Giemsa stained blood smears were examined for red blood cell (RBC) morphology, presence of

RBC parasites and to perform differential white blood cell counts (bands, heterophils, lymphocytes, monocytes, eosinophils and basophils). White blood cell counts (WBC) were performed using the modified Natt-Herrick's technique (Zinkl 1986).

Remaining blood was placed in serum separator tubes™ (Becton-Dickinson and Co., Franklin Lakes, New Jersey, USA), refrigerated, and centrifuged for 15 minutes at 3500 rpm using a Triac Centrifuge™ (Clay Adams, Sparks, Maryland, USA) within 6 hours of collection. Disposable polyethylene pipettes were used to pipette sera from the separator tubes into plastic 1.5 ml micro-cryovials (Out Patient Services, Petaluma, California, USA). Samples were frozen (-40º C) until biochemical analysis to determine activity levels of alkaline phosphatase (Alk Phos), aspartate amino transferase (AST), creatine kinase (CK), and lactate dehydrogenase (LDH) and concentrations of albumin, globulin, total protein (TP), cholesterol, blood urea nitrogen (BUN), glucose, calcium (Ca), inorganic phosphorus (P), total carbon dioxide (TCO_2), chloride (Cl), potassium (K), sodium (Na) and uric acid (UA). Anion gap was also calculated (Duncan et al. 1994).

Means for hematologic or biochemical blood parameters were compared between ORHB murres and control murres at the time of release as well as between ORHB murres that survived and ORHB murres that died (2-tailed t-tests, SPSS 1999; Levene's test for equality of variance; alpha = 0.05). A Chi-Square test (SPSS 1999) for differences in survival among ORHB and control groups was performed and relative risk was calculated (EpiInfo 1993). Kaplan-Meier Survival Analysis (SPSS 1999) was performed to determine if survival curves differed significantly between ORHB and control murres. Murres not available to follow-up due to loss of radio signal were included in the survival analysis for the time that they were known to be

alive. For blood parameters known to be biologically correlated, only one parameter was selected for evaluation in the Kaplan-Meier Survival Analysis.

A Cox Proportional Hazard Model was used to determine the hazard function (Cox and Oakes 1984, SPSS 1999) or likelihood of survival based on statistically significant hematologic and biochemical blood parameters. The Cox Proportional Hazard Survival Model considers the outcome, time to death or loss to follow up, as a function of the best predictors via a modified form of logistic regression (Cox and Oakes 1984, Hosmer and Lemeshow 1989). This method evaluates each blood parameter as a predictor of how long the murre survived before it died. The survival model included the data on individuals that were prematurely lost during the telemetry period (i.e. it includes individuals that survived a portion of the study period but whose radios failed early; these cases would have been excluded in logistic regression because data were not binomial).

Results

Survival, Behavior, and Movements

Mean duration of a radio signal persistence (including murres that ultimately died) was 63 ± 8 days ($\bar{x}$ ± SE) for ORHB murres and 76 ± 8 days for control murres. These means were not significantly different (P = 0.253). One radio operated for as long as 142 days for an ORHB murre and 137 days for a control murre.

In total, 12 murre transmitter signals indicated probable mortality; 10 were ORHB birds and 2 were control birds (Table 1). Calculations of survival through time (Figure 1) used information from all aerial surveys and the cumulative survival rate for ORHB murres was significantly different from control murres (Log rank test statistic 5.05, P = 0.03).

Survival analyses, which utilized the Chi square statistic, compared mortality (indicated by a radio transmitter mortality signals from ORHB and control murres), demonstrated that ORHB murres were four times more likely to die than control murres (Relative Risk = 4.03, P = 0.03). Thus, given sample sizes of 31 ORHB and 25 control murres, one would expect 4 ORHB to die for every one control murre that dies.

Radios began to disappear either due to transmitter-battery failure or mortality 3 days after release for ORHB birds. With the exception of one known control bird mortality at day 7, no control birds disappeared during the first 34 days after release. After day 34, the slopes of the lines generated from radio disappearances rates did not differ (ANCOVA, p=0.55) between ORHB and control murres.

Carcasses from 4 dead murres were recovered while the locations of all 12 dead murres were identified (Table 1). For all ORHB murres that died, the mean days to death (as defined by radio signals) was 34 days and ranged from 15-87 days after release (Table 1). Six of the 10 ORHB mortalities occurred within the first month after release. Mean days to death (as defined by a radio signals) for control murres was 49 days and ranged from 7-91 days after release (Table 1). Carcasses quickly decomposed, and necropsy to evaluate tissues for pathological processes was not attempted upon recovery due to advanced autolysis.

Regardless of whether birds that died were included or excluded in the analyses, size of area utilized by ORHB and control murres did not differ significantly (Table 2). The average distances of bird locations from shore, distances traveled in a northern direction from the release site, distances traveled in a southern direction from the release site, and total distances from north to south in the MCP did not differ ($P \leq 0.05$) between ORHB and control murres (Table 2). Individuals that traveled the furthest north were a control bird recorded 5 km offshore and 25 km

N of Coos Bay, Oregon (43º 34' 41"N, 124 17' 30W), and an ORHB bird recorded 22 km offshore between Aberdeen, Washington and Astoria, Oregon, next to the mouth of the Columbia River (46º 45' 21N, 124º 21' 59W). Individuals that traveled the furthest south were a control bird recorded in Monterey Bay, 25 km offshore between Marina and Watsonville (36º 48' 25N, 122 04' 36"W), and an ORHB bird that was recorded 22 km offshore and 20 km SW of San Francisco (37º 46' 52N, 122 45' 25"W).

Hematologic and Biochemical Blood Testing

Pre-release blood results differed significantly ($P \leq 0.05$) between ORHB and control murres for 18 of 31 measured blood parameters (Table 3). Oiled and rehabilitated murres had a lower mean RBC, concentrations of Hb, MCHC, Na, K, Cl, P, and activity levels for AST, CK, and LDH than control murres. Conversely, ORHB murres had higher mean concentrations of fibrinogen, TCO_2, UA, Ca, glucose, albumin, BUN, and cholesterol than control murres (Table 3). For ORHB murres, 3 of 29 blood parameters differed significantly ($P \leq 0.05$) between survivors and murres that died (Table 4) while 6 additional parameters differed at a significance level of ($P \leq 0.1$). Surviving ORHB murres had slightly higher mean concentrations of Na, Cl, P, albumin and AP activity levels. Oiled and rehabilitated murres that died had higher mean concentrations of fibrinogen, counts of WBC, bands, and monocytes, as well as CK activity (Table 4). Blood parameter measurements associated with decreased survival in ORHB murres included increasing CK activity ($P = 0.01$, $ß = 0.008$), increasing fibrinogen concentration ($P = 0.02$, $ß = 0.004$) and decreasing P concentration ($P = 0.05$, $ß = – 0.602$).

Discussion

Telemetry, Movements, and Survival

Understanding the efficacy of rehabilitation is fundamental to improving management of wildlife populations injured in petroleum spills. To date, oiled wildlife care has been conducted as a humanitarian or legally mandated activity. In most cases, post-release survival studies are not undertaken, and are not considered to be a standard part of a spill response. Information from post-release survival studies can determine whether rehabilitation has biological relevance, a justification for conducting spill response which has not been accepted by either rehabilitators or biologists.

In our study, radios from ORHB murres were active for a mean of 63 ± 8 days indicating that at a minimum, we can confirm that rehabilitated murres survived for at least 2 months with the loss of radio signal transmission being the factor that limited knowledge of the extent of survival. Based on presence of radio signals, we confirmed that 3 ORHB murres survived for at least 135 days and 2 ORHB murres survived at least 142 days establishing unprecedented murre survival durations. In Britain and Ireland, Wernham et al. (1997) reported that 83% of oiled and rehabilitated murres died within 30 days after release and only 3 in 100 murres survived 60 days after release from rehabilitation. Sharp (1996) reported that 87% of murres rehabilitated in North America between 1969 and 1994 died within 20 days after release from rehabilitation with mean survival being less than 10 days.

Assuming that birds with active radio signals were live murres, our study also confirmed that a high percentage survived to 30 and 60 days after release demonstrating significantly better results than reported elsewhere. Thirty days after release, 6 ORHB murres had died, 4 were no longer transmitting signals, and 21 were alive based on radio signal transmission. Best and worst

case scenarios were that 25 (81%) or 21 (68%) of the ORHB murres were alive at 30 days. At 60 days after release, 9 ORHB murres had died, 8 were no longer transmitting signals, and 14 were alive based on the presence of radio signals. Best and worst case scenarios were that 22 (71%) or 14 (45%) of the ORHB murres were alive at 60 days. We have no reason to believe that most ORHB (or control) murres died shortly after the radios stopped transmitting signals. Only highly unlikely events (e.g., radio loss at sea due to immediate carcass sinking or through predation) could account for loss of radio signals at bird death. Worst-case scenarios are extremely unlikely because after 34 days, we statistically demonstrated that there were no differences in radio disappearance rates for ORHB and control murres. Furthermore, if missing birds were truly dead, by the end of the study all birds from both study groups would have been dead and this result was highly improbable. Therefore, we concluded that we did not miss mortalities in either study group and that missing birds were not transmitting radio signals due to early radio battery expiration or transmission problems such as antenna failure.

Reasons for short signal transmission durations were unknown during the study but a concurrent captive murre telemetry study at the Alaska Sealife Center (Seward, Alaska), provided possible explanations. Identical transmitters (Model 2040 Advanced Telemetry Systems, Isanti, Minnesota) were attached to 13 captive murres using the subcutaneous anchor method, and 9 (69%) damaged (i.e. broke antennae) or removed their radios before the conclusion of the captive study (275 days). Mean attachment duration and signal transmission time for those 9 birds was 76 ± 50 days ranging from 7-157 days (S. H. Newman, unpublished data). This was very similar to the radio loss rate in the free ranging oiled murre survival study.

We believe that improved OWCN protocols were the primary reason for higher survival of released birds including rapid capture and removal of birds from the environment and not

releasing birds that were unhealthy and did not meet OWCN pre-release criteria (OWCN 1998). Other factors that may have contributed to greater murre survival in this study included the time of year of the study was conducted and the exclusion of juveniles with lower natural survival rates in this study. More stringent pre-release criteria required that oil cleaned murres had a mass within 10% of intake mass (929 ± 88 g) emphasizing the importance of nutritional intake to maintain mass or regaining mass lost during the rehabilitation process. The emphasis on nutrition ensured that physiologic and metabolic processes were not limited by poor nutrition or inadequate weight gain meaning that birds were released in condition comparable to free ranging murres (930 ± 56 g; Newman and Zinkl 1998). Moreover, maintaining body mass guaranteed that catabolism (muscle breakdown and associated negative metabolic processes) had not contributed to the demise of birds undergoing rehabilitation. More progressive euthanasia criteria for oiled murres with Hct less than 10% and TS less than 0.5 mg/dl also ensured that weaker birds did not go through the rehabilitation process. More rigorous release criteria (Hct greater than 35% and TS greater than 3.0 mg/dl) ensured that the cohort of birds released from care was reasonably healthy and those birds with a lower likelihood of surviving were not released.

The time of year of this study may also have been important but this could not be confirmed. Murres became oiled in early September when they were undergoing flightless pre-basic molt which likely occurs when prey resources are abundant and available. Upon release, high prey availability may have assisted survival of birds during the critical period of readjustment to existence in the wild.

Our exclusion of juveniles from the study likely caused a slight increase in average post-rehabilitation survival rates compared to other studies. Based on banding studies, mean annual

survival rates of adult murres (e.g., 87-94%) are typically greater than for immatures less than 5 years of age, especially juveniles (e.g., 17-36%; Hudson 1985, Sydeman 1993). We do not think this was a serious problem for determining average post-rehabilitation survival for murres affected by the *Stuyvesant* oil spill. When the spill occurred, adults, sub-adults and juveniles from colonies in northern California had finished colony attendance and most or all of the birds present at sea in the spill zone in September likely belonged to these colonies (Manuwal and Carter 2001). Juveniles likely comprise less than 15% of the murre population at this time of year, assuming no differential dispersal or exposure to oiling between age classes within the spill zone and significant chick mortality occurring shortly after colony departure before September (Bayer et al. 1991, Nevins and Carter 2003). However, different age-related patterns of occurrence and potential for capture, rehabilitation, and release in other populations, spills, or times of year may result in a larger proportion of juveniles contributing to lower post-rehabilitation survival rates in samples studied.

A final factor that may explain minor differences in survival is that this study used radio telemetry, a technique that allows for direct monitoring of individual survival rather than estimating overall survival using mark-recapture techniques based on recoveries of less than 0.05% of banded birds (Sharp 1996). In particular, increased survival rates from telemetry data may have resulted because mark-recapture estimates are sensitive to extremely low rates of band recovered birds.

Survival of ORHB murres was higher than demonstrated in previous studies. Utilizing data for the entire study period, survival analysis demonstrated that ORHB murres were 4 times more likely to die than control murres. Mortalities of ORHB murres (n = 4) outnumbered control bird mortalities (n = 1; Table 1). Closer examination of the mortality patterns based on

the slopes of the lines generated by radio loss rates demonstrated that lower survival rates of ORHB murres occurred during the first 34 days after release. After day 34, the rate of radio disappearances did not differ between study groups.

Based on the pattern of mortality described by Sharp (1996), we expected that a large number of ORHB murres might have died within 10 days following release from rehabilitation. This was not the case in our study as the first ORHB murre mortality occurred 15 days after release and no additional ORHB murres beached themselves within 2 weeks of release as was described by Sharp (1996). We believe that the acute mortality Sharp reported (1996) was likely due to waterproofing deficiencies. Recent improvements in washing and rinsing techniques (Holcomb and Russel 2003) likely explain why waterproofing played no role in morbidity or mortality of birds from this study.

In our study, 80% of mortalities occurred between 15-40 days after release. This was similar to Wernham et al. (1997) who found that 95% of mortalities were within 60 days. Our study differed from Wernham et al. (1997) in that a much higher percentage of murres survived. In fact, those ORHB murres that survived beyond 34 days survived comparably to non-oiled control murres suggesting that by day 34, they had adjusted to natural conditions, re-established physiological health in the wild, and probably capable of long term survival.

While survival for over 30-60 days was a good indicator of potential long-term survival, we also examined the at-sea distribution and movements of ORHB murres to look for signs of possible impairment in winter foraging or dispersal behavior, prior to loss of radio signals. We used movements and areas utilized to assess behavior relative to controls. In previous studies on American Coots (*Fulica americana*) and Brown Pelicans (*Pelecanus occidentalis californicus*) after oil exposure and rehabilitation, behavioral abnormalities occurred after release (Anderson et

al. 1996, 1999). Oiled and rehabilitated coots had different time budgets and atypical preening behaviors compared to control coots (Anderson et al. 1999, Newman et al. 1999a). Most pelicans did not return to breeding colonies the year after release from oil spill rehabilitation, or they exhibited other atypical breeding behavior. Unfortunately, breeding effort could not be evaluated for seasons due to radio battery expiration (Anderson et al. 1996). In contrast, ORHB and control Western Gulls (*Larus occidentalis*) used similar areas and both groups similarly shifted area use based on season (Golightly et al. 2002). Results for murre behaviors were similar to the gulls in that the overall size of area utilized did not differ between ORHB and control murres, even when the calculated area used included ORHB murres that died. Analogous distances were traveled and similar coastal areas were used by ORHB and control murres (Table 2). Most murres stayed near shore adjacent to Humboldt and Del Norte Counties or in southern Oregon, during October and November while they completed pre-basic molt and redeveloped flight capacity. This was consistent with habitat used by murres that are year-round residents and remain near colonies with little dispersal (Manuwal and Carter 2001).

Two months after release, 4 control murres moved south of San Francisco into Monterey Bay (approximately 800 km south of the release site), 1 ORHB murre moved to Washington state (approximately 1000 km north of the release site) while the majority of murres stayed in northern California and the area around the California-Oregon border (approximately 200-225 km from the release site). At three months after release, 4 ORHB murres and 2 control murres had moved to the Point Reyes National Seashore area, 1 control murre was near Devil's Slide Rock on the San Mateo coast, and 1 control murre was in Monterey Bay. The small numbers of murres that made long-distance movements to the north or south indicated that some northern California murres undergo wider dispersal during the non-breeding season.

Based on area used, movement distances, and movement directions, we concluded that surviving ORHB murres were not impaired in terms of winter foraging and dispersal behavior. This finding was especially interesting given that ORHB murres became oiled during pre-basic molt and upon release from rehabilitation, had additional metabolic demands coinciding with completion of feather growth. Despite the increased metabolic demand, good environmental conditions probably provided adequate nutritional support for murres to molt and start winter movements.

Long-distance movements to central California (adjacent to Point Reyes Headlands, Devil's Slide Rock Complex) may have reflected either: a) southern dispersal of some birds from northern California colonies in the non-breeding season; or b) return of some birds back to central California colonies where they had previously dispersed from once breeding season and pre-basic molt were completed. In the former case, observations of radio-marked murres near central California colonies probably only reflects foraging behavior. In the latter case, these birds may have been associated with or even visiting breeding colonies in central California, but were only detected foraging near colonies during telemetry flights. Since we did not detect any murres on colonies and low attendance at colonies occurs from October to January, we could not further associate murres with colonies. Unfortunately, radio batteries expired well before the April-August 2000 breeding season making it impossible to evaluate whether ORHB or control murres attempted to breed the year after release. Other studies have occasionally documented murres breeding and fledging chicks after oiling and rehabilitation but most post-release breeding success has been associated with for South African penguins (*Spheniscus demersus*; Crawford et al. 1998, Goldsworthy et al. 1998, Harris and Wanless 1997, Morant et al. 1981).

In California, during the 2001-2002 S.*S. Jacob Luckenbach* spill response, the OWCN captured an oiled adult murre at Monterey State Beach on 17 December 2001, rehabilitated this bird, and released it, 3 January 2002. This individual was first observed back at the Upper Upper Colony on southeast Farallon Island (37° 41' N, 123° 00' W), San Francisco County, California on 16 April 2002 when the first nest check was conducted. In all likelihood, this murre returned to the colony earlier in the season, before being observed. This individual was first observed incubating an egg on 20 May 2002 which was not the exact lay date, but the first day that egg was observed. A chick hatched and was first observed on 22 June 2002. Chick provisioning occurred for 8 days followed by the chick disappearing from the nest on 24 June 2002. The chick was too young at this point in time to have fledged and the chick was never seen at the nest after 24 June. This is the first documented case of an oiled and rehabilitated murre successfully nesting and laying an egg following a California oil spill response. This murre exhibited typical murre behavior only 3.5 months after release from oil exposure and rehabilitation by returning to the breeding colony as did other murres preparing for breeding season. By 4.5 months after release from rehabilitation, this murre was physiologically and behaviorally capable of breeding, egg laying, incubating an egg, and nesting. Based on these findings from this one individual, and the fact that our study demonstrated that after 34 days ORHB murres had similar survival and behavior as control murres, it is not unreasonable to assume that additional rehabilitated murres could have returned to breeding colonies, reproduced successfully, and contributed to murre populations. While the fate of the murre chick hatched from the oiled and rehabilitated murre remains unknown, Western gulls (*Larus occidentalis*) are known predators of murre chicks (PRBO unpubl. data) and this chick could have been depredated at some point during parental provisioning. Alternatively, some murres may return to breeding colonies, breed, incubate eggs,

and fail to fledge chicks due to unidentified long term effects of oil exposure and rehabilitation. This explanation seems less likely and would be the first documented case of a new mechanism of toxicity resulting in breeding failure as other research has demonstrated that brown pelicans failed to breed for behavioral reasons (Anderson et al. 1996) and South African Penguins that returned to colonies after oiling and rehabilitation failed to produce eggs (Ryan et al. 2003, Whittington et al. 2003). Additional research is needed to assess to fully understand potential effects of oiling and rehabilitation on breeding success of oiled wildlife but in the case of murres, our study results and anecdotal information about a chick successfully hatching from an oiled and rehabilitated bird months after being released suggests that there may be biological merit to these activities.

Hematologic and Biochemical Blood Testing

The combined physiological effects of petroleum and rehabilitation on marine birds is still largely unknown (Jessup and Leighton 1996) and the causes of death after release of oiled and rehabilitated birds are not well understood (Anderson et al. 1999, Newman et al. 1999a, 1999c). None the less, we know that rehabilitation can be quite stressful and inhalation, dermal contact, or ingestion of oil can result in toxicity. In our study, we observed mortality in ORHB murres from 15-87 days after release. While the cause of death makes no difference from a population standpoint, from a toxicological perspective, birds that died 15 days after release may be undergoing different pathophysiological processes than birds that died at 87 days. For this reason, we decided to evaluate pre-release blood health indices coupled with telemetry survival information. This provided an excellent opportunity to evaluate potential causes of morbidity and mortality of oil injured murres. Complete blood counts and biochemical profiles provided

important information about white and red blood cells, concentrations of proteins and electrolytes, and activity levels of enzymes making it possible to evaluate the health of organs, (liver, kidney, bone marrow, etc.), immunocompetence, and physiological homeostasis.

Blood-based health indices differed significantly between ORHB and control murres for many parameters (Table 3). Elevations of several electrolytes (Na, Cl, and K) and increased activity levels of CK, AST, and LDH in control murres were most likely due to dehydration and muscle exertion associated with capture and holding prior to blood sampling and radio attachment (Duncan et al. 1994, Newman and Zinkl 1998). However, other blood parameters that differed slightly between ORHB and control murres may be of greater importance.

While in most cases blood results that differed between ORHB and control murres were not significant from a clinical perspective (blood test results were within established reference ranges for murres (Newman and Zinkl 1998)), many subtle differences were statistically different suggesting that small distinctions in blood results may signify survival advantages or disadvantages to certain individuals, especially after oil exposure and rehabilitation. Just prior to being released, indices of renal function such as UA and BUN were slightly higher (but of statistical significance) in ORHB murres compared to control murres. As well, P was slightly lower in ORHB murres suggesting the possibility of minor renal insufficiency or subtle toxic renal effects from petroleum exposure. Other studies have clearly demonstrated that petroleum can cause renal toxicosis and histopathological damage to kidney cells (Khan and Ryan 1991, Jessup and Leighton 1996, Leighton 1991, Mazet et al. 2000). Renal tubular necrosis, a pathological finding in oil exposed seabirds, may result in permanent water balance and electrolyte stress (Fry and Lowenstine 1985). Although observed differences in blood parameter means were not large, greater differences in certain individuals may be indicative of subclinical

effects of petroleum exposure associated with early stages of renal insufficiency in ORHB murres, placing these individuals at a survival disadvantage.

Although the anemia of chronic disease (that existed during rehabilitation) resolved by the time ORHB birds were ready for release (Newman et al. 1999c), several red blood cell indices (RBC, Hb, and MCHC) were slightly lower on average in ORHB murres compared to control murres. Interestingly, while the RBC count differed on average by 300,000 red blood cells between ORHB and control murres, there was no statistical difference detected in the mean Hct of the 2 groups. This suggested that RBC may be a more sensitive indicator of red blood cells than Hct. During rehabilitation, Hct (and not RBC) was used repeatedly to determine health and establish whether birds should be euthanized at intake or during other stages of care, washed or provided additional supportive care, or ultimately released (Newman et al. 2003, OWCN 1998). Since the release of birds from rehabilitation is partially dependent on Hct measurements, if this test is less sensitive at detecting subtle differences in red blood cells, the cells responsible for carrying oxygen to cells, some birds that are physiologically not ready to survive in the wild may be release inadvertently. Murres with compromised oxygen carrying capacities would be less capable of flight and foraging dives, placing these individuals at a survival disadvantage. For these reasons, future oiled wildlife pre-release evaluations may benefit from using the more sensitive RBC count instead of Hct.

Fibrinogen concentration was significantly higher in ORHB murres at the time of release compared to control murres. The almost 200 mg/dl elevation in mean fibrinogen of ORHB birds may be attributable to inflammation from exposure to oil or inflammation associated with infectious agents (bacterial, viral or fungal). Since the WBC and differential cell counts did not differ between study groups, an infectious etiology was less probable; thus inflammation from

petroleum exposure likely persisted for 17-21 days. Other studies have suggested that external and internal inflammation has resulted from petroleum exposure (Jessup and Leighton 1996, Leighton 1991, Mazet et al. 2000, Newman et al. 1999a) in aquatic birds and mammals. This finding emphasizes the importance of evaluating rehabilitated animals for inflammatory proteins such as fibrinogen, prior to release. Birds released with chronic inflammatory processes would most likely have higher metabolic demands and be more susceptible to additional stressors such as infectious agents and limited food resources, to name a few.

We also wanted to determine whether ORHB murres that survived had different pre-release blood results compared to ORHB murres that died. We found that ORHB murres that died had a higher fibrinogen concentration, CK activity, WBC, and heterophil count and lower concentrations of Cl, P, albumin, cholesterol, and Alk Phos activity. Clinically, the elevated fibrinogen, WBC, and heterophil count suggested that inflammation, possibly coupled with infection, contributed to some mortality after release. This finding was similar to results from oiled and rehabilitated American Coots where an inflammatory response (infectious or non-septic) and decreased immune responsiveness contributed to mortality (Newman et al. 1999a). The effects of petroleum exposure and stress on the avian immune system have been extensively reviewed with immune suppression resulting from oil exposure (Briggs et al. 1996). Whether immune suppression played a role in murre mortality after release is uncertain, but a prolonged inflammation certainly could have contributed to mortality. Unfortunately, necropsies of carcasses shortly after death were not possible making it impossible to confirm the cause of death in ORHB murres.

Although inflammation is an important physiological response of animals exposed to oil, release criteria for oiled and rehabilitated animals does not directly evaluate the inflammatory

response. Current pre-release blood tests include measurement of TS (OWCN 1998)which provides a rough evaluation of the inflammatory response, but is primarily used to evaluate nutritional status and liver function. However, fibrinogen which is an acute phase protein and is a direct measure of inflammation is not currently used. Based on our results, future pre-release evaluations should include more extensive blood testing incorporating fibrinogen concentration, WBC and differential cell counts. This would minimize the chances of releasing birds with persistent inflammation or subclinical infections and likely result in fewer birds dyeing at 2-4 weeks after release, the time frame within which one would expect infections to become severe and potentially lethal.

The clinical relevance of differences in fibrinogen concentration between ORHB survivors and ORHB mortalities was clear compared to differences in CK and Alk Phos activity, or concentrations of Cl, P, albumin, cholesterol. However, the Cox Proportional Hazard Model determined the likelihood of survival based on statistical differences in blood results for ORHB murres. Concentrations of P and fibrinogen, and CK activity most accurately predicted survival duration for ORHB murres based on best-fit survival curves. If all else was equal, a murre with a P concentration of 3.0 mg/dl (mean for ORHB survivors) would have a survival advantage and be 1.7 times less likely to die compared to a murre with a phosphorus of 2.1 mg/dl (mean for ORHB mortalities). A murre with a fibrinogen concentration of 625 mg/dl (mean for ORHB mortalities) would be 3 times more likely to die compared to a murre with a fibrinogen of 350 mg/dl (mean for ORHB survivors). Finally, a murre with a CK activity of 309 IU/L (mean for ORHB mortalities) would be 2.4 times more likely to die compared to a murre with a CK activity of 197 IU/L (mean for ORHB survivors). A survival disadvantage would be even greater than

the individual risk factor if an individual ORHB murre had a low P, high fibrinogen, and high CK activity, or some combination of these differences.

Subtle, non-clinical differences in P concentrations and CK activity were measured in murres prior to release whereas differences in fibrinogen concentrations were of clinical significance and would have indicated that murres were not ready for release had this test been part of the pre-release evaluation. Concentrations of TS, glucose, and Hct are currently used to evaluate health of rehabilitated bird prior to release by the OWCN and while these parameters may be highly effective in determining which murres should be selected for rehabilitation and washing, we have demonstrate that they are not the best predictors of survival. More extensive blood testing prior to release should be directed at evaluating inflammation as well as the hepatic, renal, and immunologic status of birds, all of which have been previously identified as direct targets of petroleum exposure (Briggs et al. 1996, Leighton et al. 1991, Mazet et al. 2000, Newman et al. 1999a, 1999c). In future spill responses, more complete hematologic and biochemical analyses with protein electrophoresis (to include acute phase inflammatory proteins) should be used to evaluate health of pre-release murres and other similar seabirds to ensure that lingering effects of petroleum exposure, or captivity, treatment and husbandry associated problems are not limiting survival of oiled and rehabilitated birds upon release.

Conclusion

As our dependency on fossil fuels continues into the 21st century, oil spills will remain a significant threat to seabird populations and impacts may increase in relative importance. Seabird populations are declining worldwide from habitat loss, disturbance, introduced species, disease outbreaks, declines in prey diversity and abundance, fisheries impacts, and exposure to

pollutants. Ongoing efforts are being made in many of these areas to prevent impacts on seabird populations; however, science-driven professional oil spill response may ultimately provide an additional method to mitigate some associated anthropogenic damage. In California, due to legislation passed in the early and mid 1990s, the funding and infrastructure for wildlife spill response was established and new research in the area of post-release survival studies are enabling the OWCN to evaluate survival, behavior, and the cause of wildlife mortality following oil spills.

We found that oiled and rehabilitated murres had a much longer mean survival than previous studies had reported; a higher percentage of murres survived for 30 and 60 days after release, 3 ORHB murres survived for at least 135 days, and an additional 2 ORHB murres survived at least 142 days. On the other hand, ORHB mortalities (n=10) outnumbered control mortalities (n = 2). There did not appear to be an acute post-release mortality period for at least 2 weeks, however, between 15-40 days post-release, 80% of ORHB mortalities occurred. If ORHB murres survived over 34 days, they survived comparably to a control murres, traveled similar distances along the coast, stayed at similar distances offshore, and utilized similar area sizes as control murres based on calculations of MCP's. Our findings suggest that surviving murres were not compromised in movement, mobility, or navigation. We presume that abnormalities in behavior would have compromised these parameters.

Multiple differences between ORHB and control murre pre-release blood health indices were documented. The physiological mechanisms leading to these differences were not understood for certain parameters, but for others such as higher fibrinogen concentration, UA, and BUN, biomedical explanations existed. From these findings, we concluded that inflammation, possible secondary infections from petroleum exposure and/or captivity, and

subtle compromise of renal function may have contributed to the demise of some murres after release.

From a clinical perspective, only the difference in fibrinogen concentration between ORHB murres that survived and those murres that died was significant, but based on survival analyses, a lower P concentration, higher CK activity, and higher fibrinogen concentration resulted in an increased risk (or lower likelihood of survival) by 1.7, 2.4, and 3 times respectively. This finding also suggested that current health indices evaluated prior to release (Hct, TS, and glucose concentration) may not be the most sensitive blood indices to measure; consequently, revised release criteria may be warranted.

Future research to evaluating long-term survival rates, behavior of released wildlife, and most importantly, breeding efforts and chick fledging rates is needed. Although oiled wildlife care has many political, social, ethical, economic, and conservation values in and of itself, it is only by documenting breeding success that we will know that these efforts have any direct biological value in helping maintain free ranging marine bird populations.

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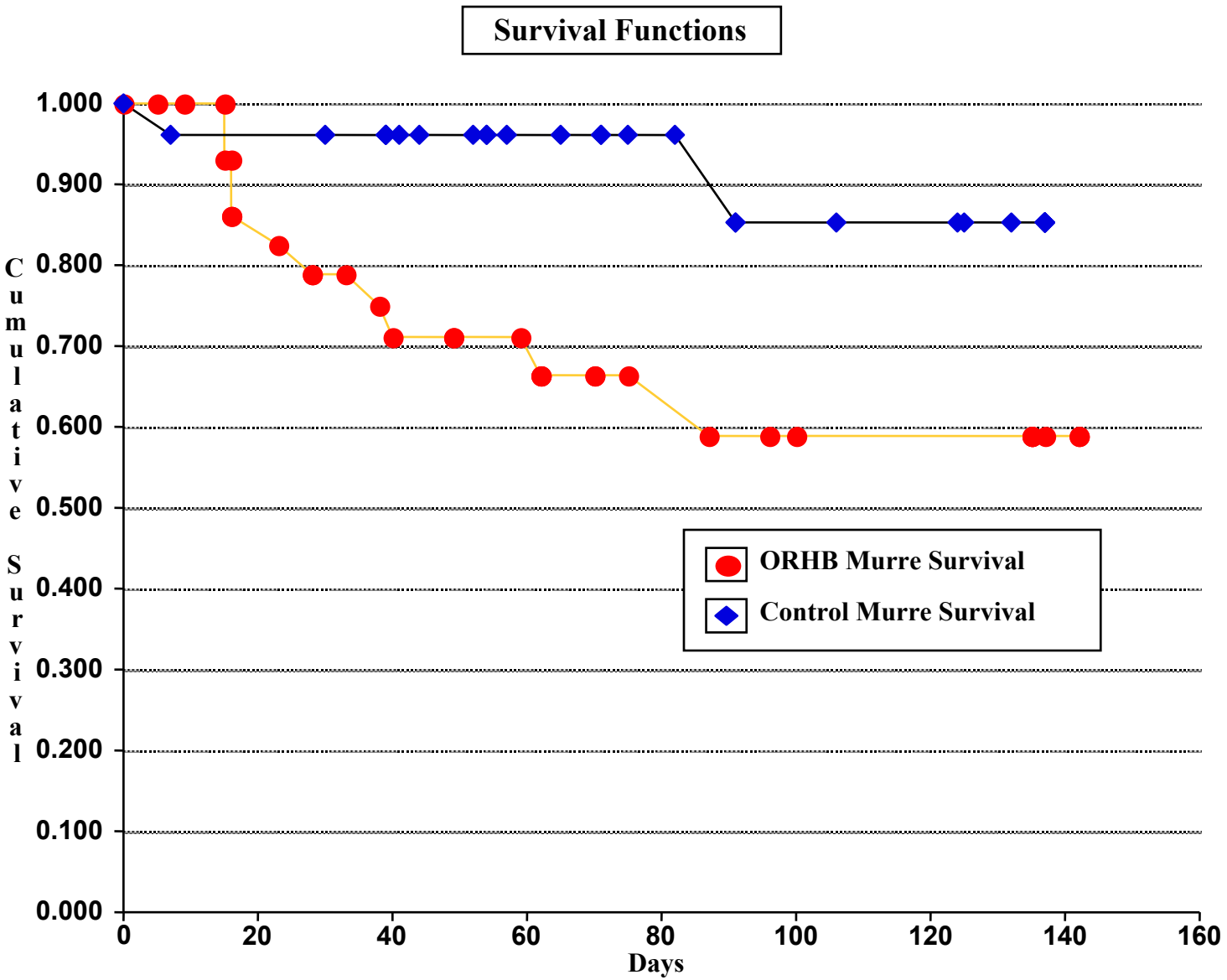

Figure1. Kaplan-Meier survival curves for oiled and rehabilitated murres and comparison murres. Oiled and rehabilitated murres and control murres differed with regard to survival function (P = 0.025).

Table 1: Recovery location for ORHB and comparison murres that died during radiotracking.

Frequency	ORHB or CON	Release Date	Mortality Signal Date	Days Alive	Carcass Recovered	Location
148.822	CON	10/1/1999	10/8/1999	7	10/8/1999	South Jetty of Humboldt Bay, CA
149.022	ORHB	9/28/1999	10/12/1999	15	10/12/1999	North Jetty, Manilla, CA
149.271	ORHB	9/28/1999	10/12/1999	15	10/16/1999	Trinidad Head, CA
148.638	ORHB	9/27/1999	10/12/1999	16	10/22/1999	Smith River
148.880	ORHB	9/27/1999	10/12/1999	16	No	North Jetty of Humboldt Bay, CA
148.373	ORHB	9/27/1999	10/19/1999	23	No	Punta Gorda, CA
149.043	ORHB	9/27/1999	10/24/1999	28	No	South Jetty of Humboldt Bay, CA
148.332	ORHB	9/27/1999	11/03/99	38	No	North Jetty of Humboldt Bay, CA
148.989	ORHB	9/27/1999	11/05/99	40	11/9/1999	Rocky Point, north of Trinidad, CA
148.294	ORHB	9/27/1999	11/27/1999	62	No	Cape Sebastion, OR
148.213	ORHB	9/27/1999	12/22/1999	87	No	Point Reyes, CA
148.065	CON	10/7/1999	1/5/2000	91	No	North Jetty of Humboldt Bay, CA

Table 2: Distances (mean ± SD) from release site travelled by ORHB and CON murres in the northly, southerly and combined directions.

Direction of Movement	Distances in kilometers ORHB murres	Non-oiled comparison murres	P value
Overall Area Utilized* (including mortalities)	2805 ± 3521	2792 ± 1702	0.22
Overall Area Utilized* (excluding mortalities)	3102 ± 2884	2859 ± 1707	0.83
Extent of movement (including mortalities)			
Maximum North	112 ± 126	136 ± 78	0.06
Maximum South	103 ± 140	121 ± 177	0.67
Total extent	214 ± 191	256 ± 160	0.12
Distance off shore	9 ± 1	11 ± 1	0.18
Extent of movement (excluding mortalities)			
Maximum North	133 ± 145	145 ± 74	0.12
Maximum South	128 ± 183	129 ± 149	0.82
Total extent	263 ± 200	273 ± 155	0.56
Distance off shore	10 ± 1	11 ± 1	0.44

* Overall area utilized was defined by utilizing the minimum convex polygon area estimator (MCP).

Table 3. Mean ± standard deviation of hematological and serum biochemical results which differed significantly between oiled and rehabilitated (ORHB) common murres (*Uria aalge*) and non-oiled control murres at the time of release.

Analyte	ORHB murres (N)	Control murres (N)	ORHB murres	Control murres	P Value
WBC (10^3/*u*l)	26	25	8,946 ± 4,793	8,638 ± 3,276	0.79
Bands (/*u*l)	26	25	0 ± 0	4 ± 21	0.33
Heterophils (/*u*l)	26	25	6,907 ± 4,181	6,221 ± 2,384	0.49
Lymphocytes (/*u*l)	26	25	823 ± 644	771 ± 731	0.79
Monocytes** (/*u*l)	26	25	334 ± 447	585 ± 488	0.06
Eosinophils (/*u*l)	26	25	635 ± 739	902 ± 890	0.25
Basophils (/*u*l)	26	25	247 ± 278	155 ± 325	0.28
RBC * (10^6 /*u*l)	26	25	2.60 ± 0.55	2.95 ± 0.63	0.04
Hb* (g/dl)	26	25	13.4 ± 2.5	15.3 ± 3.8	0.04
Hct (%)	26	25	51 ± 4	50 ± 6	0.49
MCHC* (g/dl)	26	25	26.4 ± 3.8	30.5 ± 6.5	0.01
Fibrinogen* (mg/dl)	26	25	435 ± 278	264 ± 132	0.00
Anion gap (mmol/L)	31	25	21 ± 3	21 ± 3	0.53
Sodium* (mmol/L)	31	25	150 ± 6	158 ± 2	0.00
Chloride* (mmol/L)	31	25	105 ± 6	116 ± 2	0.00
Potassium* (mmol/L)	31	25	2.6 ± 0.9	3.5 ± 0.9	0.00
Calcium* (mg/dl)	31	25	10.5 ± 1.1	9.6 ± 0.5	0.00
Phosphorus* (mg/dl)	31	25	2.7 ± 1.4	4.9 ± 1.2	0.00
TCO_3* (mmol/L)	31	25	27 ± 3	25 ± 4	0.02
Uric Acid* (md/dl)	31	25	12.8 ± 6.7	7.0 ± 2.3	0.00
Glucose* (mg/dl)	31	25	359 ± 52	333 ± 31	0.04
TP (g/dl)	31	25	4.5 ± 0.6	4.2 ± 0.8	0.20
Albumin* (g/dl)	31	25	1.4 ± 0.2	1.3 ± 0.1	0.020
Globulin (g/dl)	31	25	3.1 ± 0.6	2.9 ± 0.7	0.40
AST* (IU/L)	31	25	70 ± 36	100 ± 34	0.00
CK* (IU/L)	31	25	233 ± 140	631 ± 439	0.00
Alk Phos (IU/L)	31	25	40 ± 25	39 ± 63	0.93
LDH* (IU/L)	31	25	709 ± 264	1,176 ± 592	0.00
BUN* (mg/dl)	31	25	5.7 ± 1.7	3.6 ± 1.1	0.00
Cholesterol* (mg/dl)	31	25	425 ± 78	288 ± 49	0.00
Weight (g)	31	25	929 ± 88	930 ± 56	0.97

* Indicates that ORHB and control murres differed significantly ($P \leq 0.05$).

** Indicates that ORHB and control murres differed significantly ($P \leq 0.1$).

Table 4. Mean ± standard deviation of hematological and serum biochemical results which differed significantly between oiled and rehabilitated (ORHB) common murres (*Uria aalge*) that survived and ORHB murres that died.

Analyte	ORHB Survived (N)	ORHB Died (N)	ORHB Survived	ORHB Died	P Value
WBC **(10^3/*u*l)	18	8	7,850 ± 3,899	11,412 ± 5,925	0.08
Heterophils **(/*u*l)	18	8	5,870 ± 3,519	9,240 ± 4,833	0.06
Lymphocytes (/*u*l)	18	8	879 ± 579	696 ± 800	0.52
Monocytes (/*u*l)	18	8	208 ± 122	618 ± 738	0.16
Eosinophils (/*u*l)	18	8	634 ± 738	638 ± 792	0.99
Basophils (/*u*l)	18	8	205 ± 319	191 ± 240	0.90
RBC (10^6 /*u*l)	18	8	2.49 ± 0.43	2.86 ± 0.71	0.11
Hb (g/dl)	18	8	13.6 ± 2.3	12.9 ± 2.9	0.45
Hct (%)	18	8	51 ± 4	50 ± 4	0.76
MCHC (g/dl)	18	8	26.7 ± 3.1	25.5 ± 5.3	0.46
Fibrinogen * (mg/dl)	18	8	350 ± 266	625 ± 212	0.02
Anion gap (mmol/L)	21	10	21 ± 3	22 ± 3	0.60
Sodium (mmol/L)	21	10	152 ± 5	147 ± 7	0.60
Chloride * (mmol/L)	21	10	106 ± 5	101 ± 8	0.03
Potassium (mmol/L)	21	10	2.4 ± 1.0	2.9 ± 0.7	0.16
Calcium (mg/dl)	21	10	10.3 ± 1.0	10.8 ± 1.1	0.23
Phosphorus ** (mg/dl)	21	10	3.0 ± 1.4	2.1 ± 1.3	0.08
TCO_3 (mmol/L)	21	10	27 ± 3	27 ± 3	0.84
Uric Acid (md/dl)	21	10	12.6 ± 6.9	13.1 ± 6.6	0.85
Glucose (mg/dl)	21	10	351 ± 31	375 ± 81	0.40
TP (g/dl)	21	10	4.4 ± 0.7	4.6 ± 0.3	0.22
Albumin * (g/dl)	21	10	1.5 ± 0.1	1.3 ± 0.2	0.03
Globulin (g/dl)	21	10	3.0 ± 0.7	3.3 ± 0.4	0.13
AST (IU/L)	21	10	71 ± 36	67 ± 40	0.78
CK ** (IU/L)	21	10	197 ± 100	309 ± 182	0.10
Alk Phos ** (IU/L)	21	10	46 ± 28	29 ± 10	0.08
LDH (IU/L)	21	10	712 ± 261	701 ± 284	0.91
BUN (mg/dl)	21	10	5.7 ± 1.8	5.5 ± 1.7	0.76
Cholesterol ** (mg/dl)	21	10	441 ± 69	391 ± 89	0.10
Mass (g)	21	10	939 ± 86	909 ± 93	0.39

* Indicates that ORHB murres that survived and ORHB murres that died differed significantly ($P \leq 0.05$).

** Indicates that ORHB murres that survived and ORHB murres that died differed significantly ($P \leq 0.1$).