Post-release Survival and Movement of Western Grebes (*Aechmophorus occidentalis*) Implanted with Intracoelomic Satellite Transmitters

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Abstract.—The main goal of this study was to gain knowledge on post-release survival and movement of Western Grebes (*Aechmophorus occidentalis*) using a modified technique for implanting satellite transmitters. This technique had improved post-surgical survival in an earlier study. Nine Western Grebes, implanted with intracoelomic (within the body cavity) satellite transmitters with percutaneous antennae, were released close to their capture site in San Francisco Bay, California, USA. Eight survived at least 25 days (average number of transmittal days was 140.8), while two had transmitters that provided data for greater than 1 year (436 and 454 days). The average cumulative distance recorded for all Western Grebes ($n = 9$) was 829 km with two round-trip movements documented. One individual Western Grebe traveled a cumulative round-trip distance of 2,144 km in July and November 2011, while another individual traveled a round-trip distance of 1,514 km between 8 and 14 December 2011. This study provides a step forward in testing implantable satellite transmitters in Western Grebes and highlights the need to further improve tracking methods, potentially improving our understanding of their population threats. *Received 5 February 2015, accepted 25 March 2015.*

Key words.—*Aechmophorus occidentalis*, migration, satellite transmitter, surgical implantation, Western Grebe.

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Over the past two decades, Western Grebe (*Aechmophorus occidentalis*) populations have been in decline along the west coast of North America (Ivey 2005; Anderson *et al.* 2009; Wilson *et al.* 2013). Multiple and synergistic factors have been hypothesized to explain this rangewide decline. One hypothesis is oil spill-related mortality of wintering adults (Carter *et al.* 2003; Hampton *et al.* 2003; Humple *et al.* 2011). Large spills off the western coasts of the USA have killed thousands of Western Grebes (Smail *et al.* 1972; Page *et al.* 1990; Carter 2003; Humple *et al.* 2011). For example, both the 2005 Ventura Oiled Bird Incident and the 2007 Cosco Busan oil spill resulted in heavy estimated mortality of Western and Clark's (*A. clarkia*) grebes (2,500 for Ventura Oiled Bird Incident, Humple *et al.* 2011; 1,071 for Cosco Busan oil spill, Cosco Busan Oil Spill Trustees 2012). Also, there is evidence that low volume oil spills regularly kill small numbers of wintering Western Grebes throughout their range (Speich and Wahl 1986; Henkel *et al.* 2014). According to stranding reports and rehabilitation records in California, USA, most Western and Clark's grebe mortality caused by oil injury (either via a declared spill, natural seep, or unknown source) occurs between November and February. One likely contributing factor in the susceptibility of *Aechmophorus* spp. to marine oil spills is the large percentage of adult Western and Clark's grebes that undergo simultaneous flight feather molt during the non-breeding season, when they are wintering along the Pacific coast of the USA (Humple *et al.* 2013).

Our understanding of potential factors contributing to the decline of Western Grebes is hampered by a lack of detailed information on migratory patterns and winter habitat use. Few data exist on winter movement patterns and migratory routes for these animals, yet data on migration and winter movement are needed to determine potential exposure to oil spills and to guide mitigation projects after spills. To date, movement data have only been available via band returns from rehabilitated oiled and non-oiled released birds (Humple and Holcomb 2014). External or internal telemetry devices and satellite transmitters can provide species' movement information; however, unlike several other marine bird species that are readily tracked, evidence from diving bird species (Calvo and Furness 1992; Withey *et al.* 2001; Ropert-Coudert *et al.* 2007) suggests that externally attached devices are not always well tolerated. Furthermore, pilot studies have suggested that surgical implantation of transmitters, while an improved alternative for some species not handling externally attached transmitters (Korschgen *et al.* 1996), is also challenging in Western Grebes. Previous attempts to use the Korschgen *et al.* (1996) procedure for transmitter implants in Western Grebes in 2004 and 2005 resulted in 100% mortality. A modification to this surgical technique (Gaydos *et al.* 2011) successfully reduced the immediate post-implantation mortality in a captive setting, but field survival was not assessed.

Our primary goal was to evaluate post-release survival of Western Grebes implanted with satellite transmitters, using the modified surgical technique described in Gaydos *et al.* (2011). A second goal was to gain new information on Western Grebe movements.

METHODS

Study Area

We captured Western Grebes (n = 9) from three locations in the northern region of San Francisco Bay, California, USA, on 7 and 9 December 2010 using a modified neutrally buoyant gill net technique (Breault and Cheng 1990). Based on plumage characteristics, we believed that all captured birds were after hatch year in age, although aging Western Grebes is intrinsically difficult (Pyle 2008; Humple *et al.* 2013). We determined the sex of the birds (Table 1) based on culmen length (La Porte *et al.* 2013) and obtained body weights at the time of capture and daily thereafter while in captivity.

On the day of capture, we transported all birds (placed inside plastic carriers on elevated net platforms) from the location of capture to a research facility about 120 km away. Birds were housed indoors in 3-m diameter freshwater rehabilitation pools with a depth of 1.3 m; pool water temperature and air temperature were maintained at 16 °C and 18 °C, respectively. We force-fed birds three to six whole, freshly thawed night smelt (*Spirinchus starksi*) or capelin (*Mallotus villosus*) twice daily (approximately 120 g total/bird/day). To prevent infection by the fungus *Aspergillus* sp., we administered oral itraconazole (15 mg/kg; Sporanox) at the time of capture and once daily until release. To manage pain associated with capture and surgery, we administered oral meloxicam (0.5 mg/kg; Metacam, Boehringer Ingelheim Vetmedica) upon capture and once daily until release. All birds received one dose of an oral multivitamin supplement (Sea Tabs) during the course of the trial.

While in captivity, we identified grebes individually with temporary plastic leg bands, which were replaced with permanent U.S. Geological Survey metal leg bands prior to release. Post-surgery birds were placed in carriers with a net bottom for 1-4 hr while they recovered from anesthesia. While in captivity birds were examined daily by a veterinarian and were kept in captivity for a total of up to 48 hr, after which they were released within 3 km of their capture location.

Clinical Pathology

On the day of capture and back at the facility, we collected a blood sample (up to 2.5 mL) from the jugular vein for the evaluation of blood parameters. Blood parameters examined were: corticosterone level, plasma protein electrophoresis profile, complete blood count (packed cell volume, total white blood cell count, white cell differential), and plasma chemistry. Plasma chemistry included fibrinogen, glucose, blood urea nitrogen, creatinine, sodium, potassium, total carbon dioxide, amylase, lipase, calcium, phosphorus, cholesterol, triglycerides, uric acid, aspartate aminotransferase, alanine aminotransferase, lactate dehydrogenase, creatine phosphokinase, and gamma-glutamyl transpeptidase. All clinical pathology was processed at a veterinary hospital and laboratory in California, USA.

We anesthetized all birds with 5% isoflurane via mask, maintained between 2-5% in 100% oxygen. Using a previously described procedure (Gaydos *et al.* 2011), we implanted birds with Argos Platform Terminal Transmitters (PTT; Argos 2013) with external percutaneous whip antennae. The basic surgical technique is described in detail in Gaydos *et al.* 2011; modifications included: 1) providing each bird with 30 cc of lactated ringer solution subcutaneously during surgical preparation; 2) administering meloxicam for pain; 3) not removing feathers at the incision site; 4) lateral offset-

Table 1. Transmission duration and ultimate disposition of Western Grebes (*Aechmophorus occidentalis*) implanted with intracoelomic satellite transmitters. Body mass = mass at time of capture (mean mass for males = 1,429 g, Range = 1,137-1,826; mean for females = 1,199 g, Range = 808-1,753; LaPorte *et al.* 2013); Δ Body Mass = change in body mass during captivity, not accounting for transmitter mass; Load Ratio = Platform Terminal Transmitter implant mass/body mass (at release) x 100.

Individual ID	Sex	Body Mass (g)	Δ Body Mass (g)	Load Ratio	Maximum No. Transmission Days	Total Cumulative Distance (km)	Final Status
97620	Male	1,134	+150	2.02	5	129.7	Mortality
97614	Female	1,225	-71	2.25	25	218.2	Mortality
97621	Male	1,435	+24	1.78	39	246.6	Mortality
97615	Unknown	1,025	+14	2.50	47	571.7	Undetermined
97618	Male	1,102	-13	2.39	68	295.6	Battery depletion or failure
97613	Male	1,385	-51	1.95	123	624.3	Mortality
97619	Unknown	1,190	-46	2.27	143	283.8	Battery depletion or failure
97617	Female	1,378	-34	1.95	436	2,940.4	Battery depletion
97622	Male	1,455	-1	1.79	454	2,143.6	Battery depletion

ting of the body wall incision approximately 1 cm to the right of the midline; 5) application of a waterproof sealant to the antenna exit site; 6) application of a 1 cm^2 square piece of dry porcine small intestine submucosa (SIS; Vet BioSISt) placed over the base of the transmitter antenna prior to the antennae being put through the skin and coelomic davit (within the main body cavity next to the body wall); 7) application of absorbable cyanoacrylate tissue glue placed within the tissue layers to form a barrier between the body wall incision and the midline skin incision; and 8) holding the birds 24-48 hr post-surgery to ensure adequate waterproofing. Surgical procedures were similar for all birds, with the exception of one bird (band # 97617), in which the porcine SIS placed over the base of the transmitter antenna was inadvertently omitted. The average total anesthesia time was 68 min (SD = 17.5 min), and the average surgery duration was 42 min (SD = 17.4 min).

Transmitters

Each PTT weighed 26 g (14 mL volume, 45 x 16 x 34 mm, antenna length: 210 mm from where it protrudes from the PTT), representing 1.78-2.50% of adult body mass at the time of release (Table 1), and was equipped with a battery capable of 400 hr of transmission. Each PTT was programmed with a 6 hr on/19 hr off duty cycle for the first 25 cycles (26 days), then switched to 6 hr on/75 hr off for the remainder of the life of the battery, which was expected to last approximately 365 days. In addition to geographic location, each PTT transmitted internal body temperature and battery voltage.

We processed the locations of the PTTs using an algorithm based on the Kalman filtering approach, which provides a greater number of positions and has improved position accuracy compared to the least squares method (Argos 2013). We classified locations based on type of location, estimated error, and the number of messages received. Data of class type Z, A, B, 0 (> 1,500 m estimated location error, < four messages) were excluded from analyses because of poor location accuracy (Argos 2013). We also excluded the positions that were obvious errors (i.e., more than 300 km offshore), although these were uncommon. Raw data were further filtered to exclude post-mortem locations using our definition of mortality (a precipitous and permanent temperature drop to below what is considered normal for marine birds, set as 37.8 °C). We differentiated between potential mortality, as defined above, and battery depletion or failure (voltage < 3.73 volts). The total number of locations for all individuals was 4,002 before the filters were applied; of these, 1,629 met the accuracy criteria and were used in the final analysis. The average number of transmissions that met the accuracy criteria was 3.1 per individual per day (SD = 0.27, *n* = 9, Range = 2.6-3.4).

Analysis

For the four individuals that spent the most amount of time in the study area, we evaluated kernel density using a kernel density estimator that weighed locations according to a bivariate Gaussian distribution having a maximum at the location being processed (Seaman and Powell 1996). A matrix of the density estimates for each bird, reflecting the likelihood of that bird spending more time in a particular area, was then represented as a contour plot for each individual bird from the date of release to 21 March 2011.

We used Pearson Correlations to evaluate the relationships between the number of days of post-release transmission time and the mass at capture (as an index of body condition) (Schamber *et al.* 2009), complete blood count, and plasma chemistry values for each individual. With the exception of one individual (band # 97613), all birds were recorded as having a good body condition score (BCS = 4-5/9) at the time of intake. Bird # 97613 was recorded as a "slightly thin bird" with a BCS = 3/9.

To evaluate overall "survival" of instrumented grebes, we used a combination of suspected battery depletion or failure (as defined above) and suspected bird mortality (as defined above). All analyses were performed using Stata (StataCorp 2011) and MATLAB (MathWorks, Inc. 2012). *P*-values < 0.05 were considered statistically significant. Maps were produced using ArcGIS (Environmental Systems Research Institute 2011).

RESULTS

Survival Post-Surgery

Nine birds were successfully implanted with transmitters and subsequently released. Eight out of nine birds (89%) survived up to day 25 post-release (Table 1). Battery depletion or failure was suspected in two PTTs that ceased to transmit after a decline in voltage and cessation of transmission at days 68 and 143, while two birds survived until complete PTT battery depletion, transmitting for 436 and 454 days post-release (Table 1). Four grebes were categorized as 'mortalities' based on drop in temperature at days 5, 25, 39, and 123. The fate of one grebe (band # 97615) was undetermined, as both the battery voltage and temperature were within normal range when it abruptly ceased transmitting at day 47 post-release on the southern end of Monterey Bay (Fig. 1). Median transmission time was 68 days (Range = 5-454), at which time there was a post-release survival of 44% (this includes all birds that had a battery failure or depletion), and post-release survival was at least 22% at 454 days post-release.

At the time of release, three birds had gained weight during captivity and six had lost weight (Table 1). There was no significant difference in the number of days the PTT transmitted and release weight ($F_{1,7} = 2.24$, $r^2 = 0.242$, $n = 9$, $P > 0.05$) or in body mass at release between the birds that are suspected to have died and those whose battery failed or was depleted ($t_8 = 0.818$, $n = 9$, $P > 0.05$). Of the four heaviest birds, two (one male and one female) transmitted the greatest number of days post-release (over 400 days). However, based on the PTT temperature sensor readings, the other two heaviest birds (both males) are suspected to have died by days 39 and 123 (Table 1).

Movement Patterns

In general, post-release movement of the grebes showed birds remained within the study area for the majority of the tracking period. Some grebes demonstrated use of a wide geographic area (e.g., band # 97613 and # 97615; Fig. 2A, 2B), while others used only a very small area (e.g., band # 97617 and # 97622; Fig. 2C, 2D). In general, however, there were distinct regions that were used more intensively within San Francisco Bay, primarily in the north-central portion (Figs. 2C and 3).

Of the nine released birds, only three left the San Francisco Bay area during the study period. Grebe # 97615 left San Francisco Bay between 25 and 28 January 2011 and traveled 572 km south to Monterey Bay (Table 1; Fig. 1), where transmission ceased at 47 days post-release. Grebe # 97622 remained within San Francisco Bay through the first winter, then departed northward between 10 and 13 July 2011. This individual first stopped at Clear Lake, California, between 10 and 13 July 2011 and then flew to Drew's Reservoir, Oregon, between 14 and 17 July 2011, continuing on to Upper Klamath Lake, Oregon, between 18 and 20 July 2011 (Fig. 1). During this migration, the bird covered 1,620 km in approximately 10 days. The individual remained at Upper Klamath Lake for just over 3 months, returning to San Francisco Bay between 1 and 4 November 2011 for a total round-trip distance of 2,144 km (Table 1). Grebe # 97617 remained in San Francis-

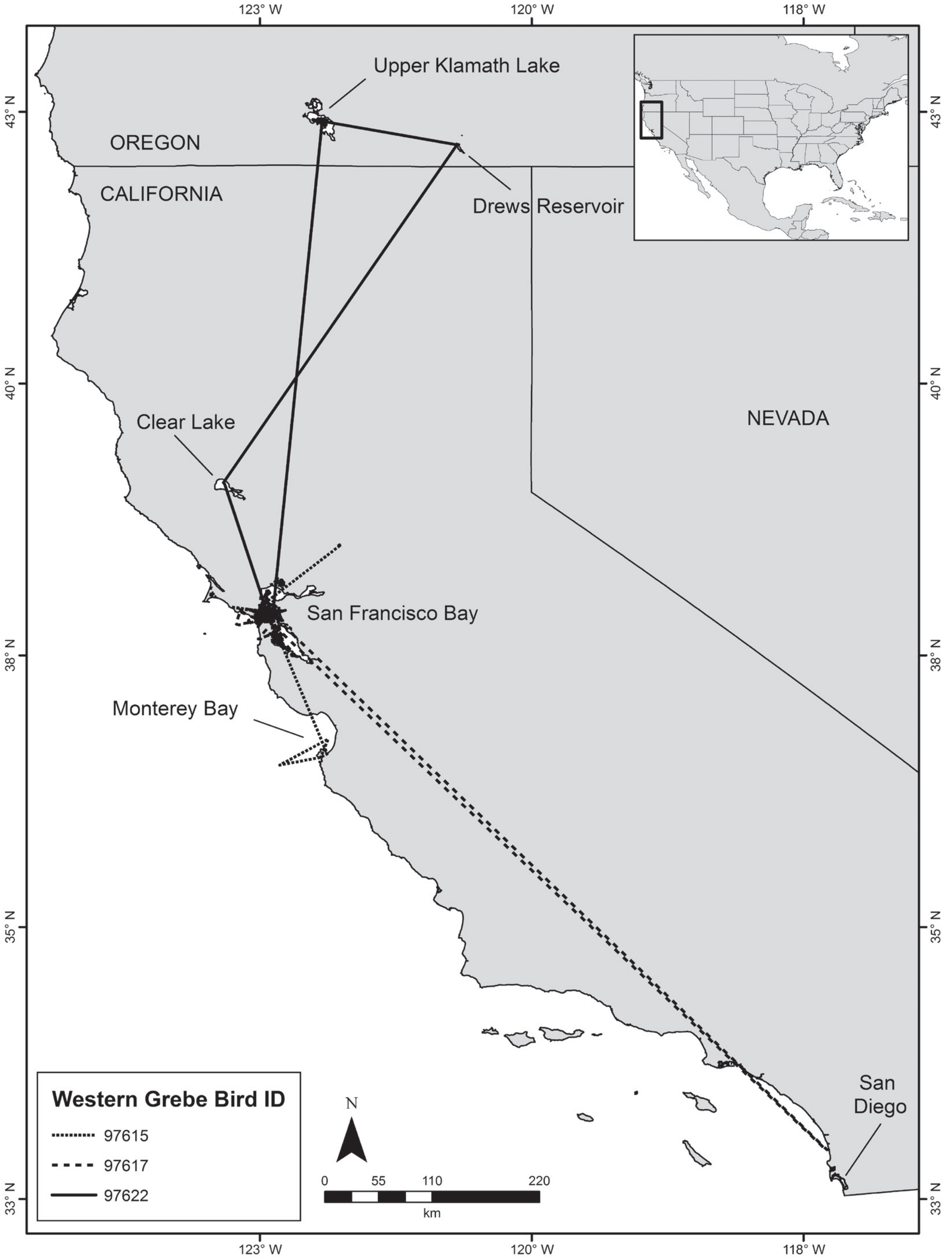

Figure 1. Migration tracks of Western Grebes ($n = 3$) implanted with intracoelomic satellite transmitters. Individual # 97615 migrated from late January, # 97617 migrated between 8 and 14 December 2011, and # 97622 migrated from mid-July to early November 2011.

co Bay through the first winter, spring, and summer (2010/2011). Between 8 and 10 December 2011 (almost exactly 1 year post-release), this individual traveled south to San Diego Bay, California (Fig. 1), then returned to San Francisco Bay between 10 and 14 De-

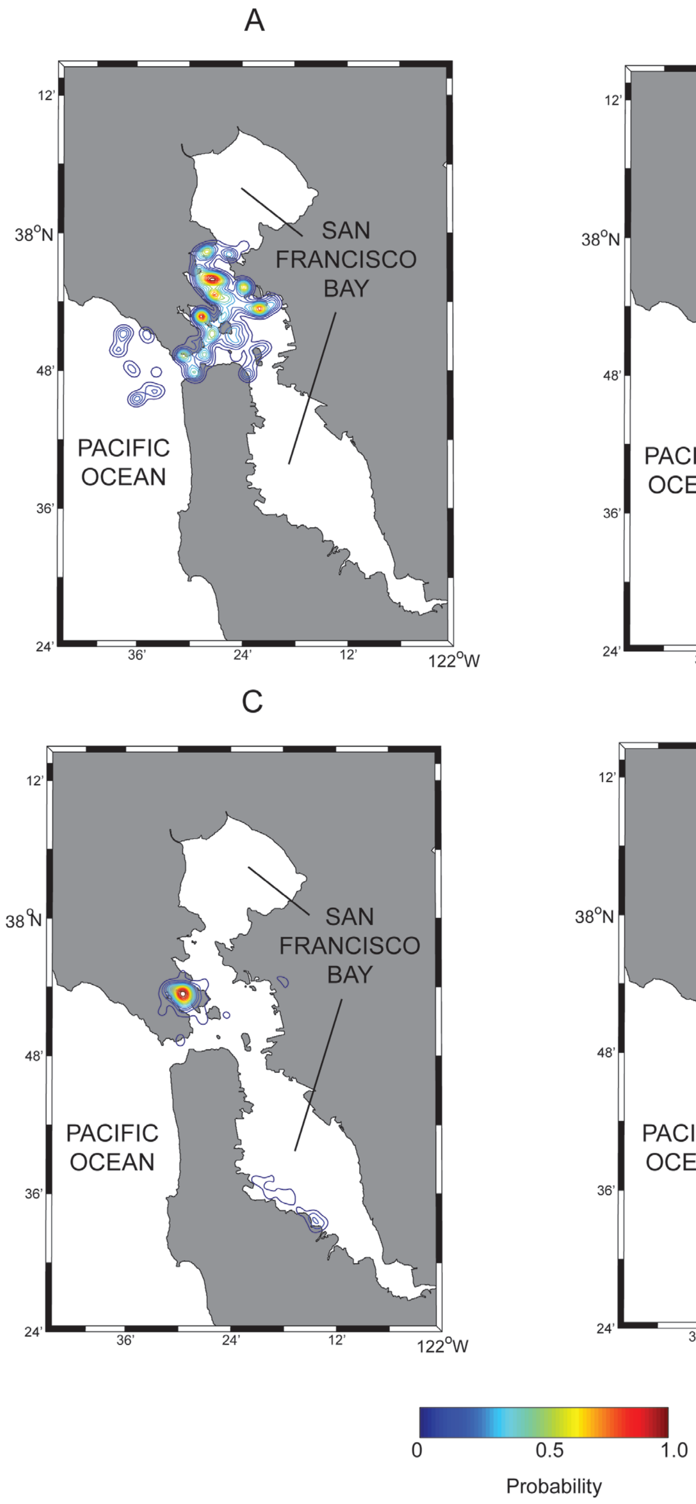

Figure 2. Kernel density estimator overlaid on a representative subset of maps of the study area for Western Grebes ($n = 4$) implanted with intracoelomic satellite transmitters during the first winter. The probability bar represents the kernel estimation, contoured at intervals of 15 units. Probability that the bird spent more time in a particular area increases as density approaches one.

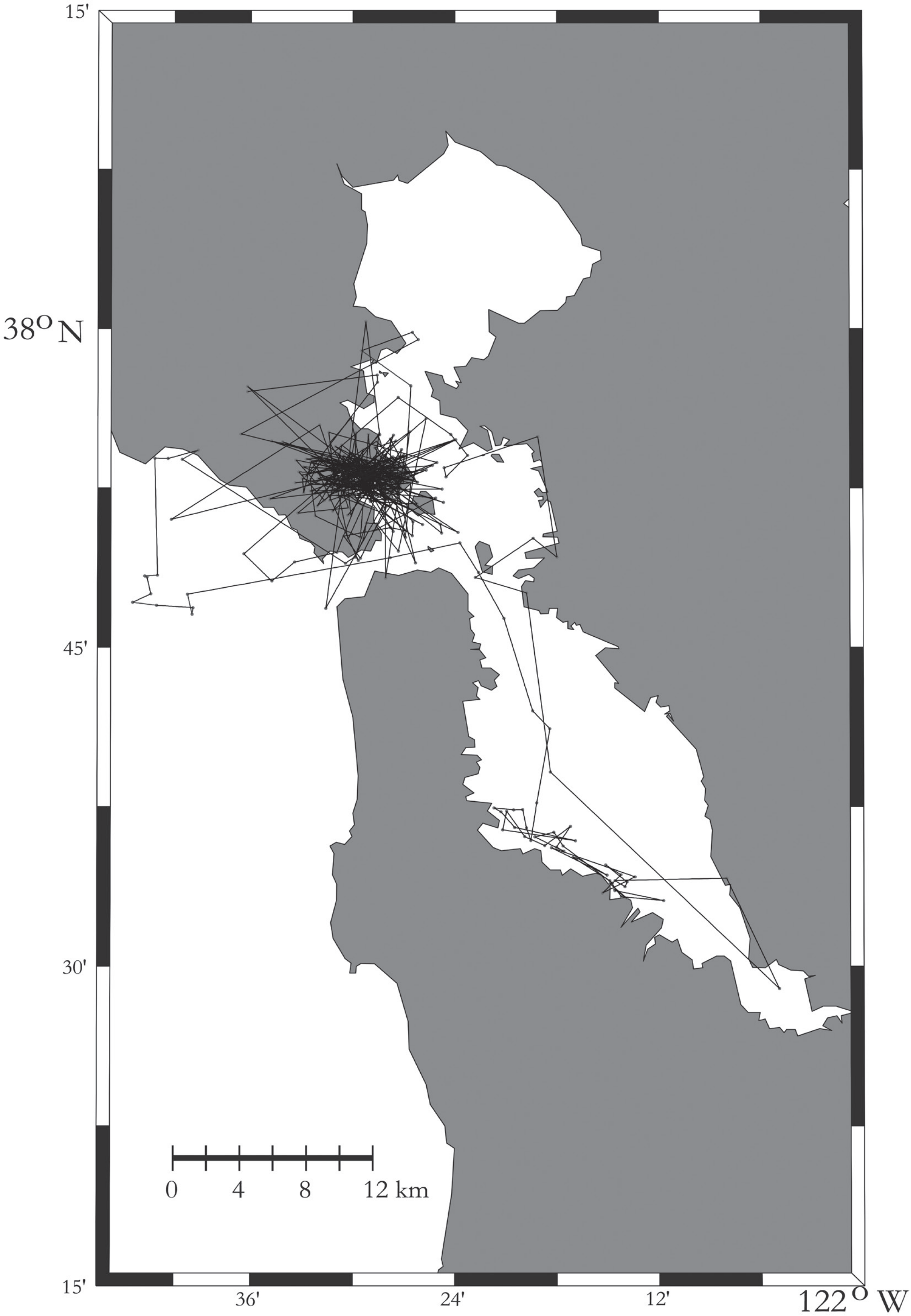

Figure 3. Example of track lines for one of the Western Grebes (# 97617) implanted with an intracoelomic satellite transmitter, showing extent and complexity of movement within San Francisco Bay, California, and corresponding with Fig. 2C.

cember 2011 for a total round-trip distance of 1,514 km. Post migration to San Diego, transmission continued for 65 days in San Francisco Bay and ceased on day 436 post-release (total cumulative distance was 2,940 km; Table 1), possibly from battery depletion rather than bird mortality.

DISCUSSION

This is the first study, to our knowledge, where one complete round-trip migration of a Western Grebe, from a wintering location to a breeding site and back to a wintering location, was recorded. Compared to the previous two studies of surgically implanting transmitters in healthy Western Grebes (with 100% mortality in the first study, and in the second a reported median survival time of 4 days, range of 1-29 days in 10 implanted birds; Gaydos *et al.* 2011), our 89% survival by day 25 and median survival time of 68 days (representing a 44% survival by this date), and survival of two individuals for over 1 year (22% survival) until batteries became depleted, is a significant improvement over previous efforts. Specific causes of post-release mortality in the implanted grebes were not determined, as none of the birds that died could be recovered.

In the immediate post-release period for all such studies, there are numerous manifestations of the detrimental effects of capture, transport, surgery, and housing that can contribute to mortality. Here, the individual that died 5 days post-release was completing wing molt at the time of capture; the physiological and energetic demands of molting could have affected survival. Remigial molt is relatively common during the fall and winter for non-breeding grebes (Humple *et al.* 2013) and, although capture was timed to avoid molting, retrospectively it may have been prudent to exclude this bird from the study or to time capture at a different time of year. Also, if the individuals in our study were young birds, they may have been less likely to survive because of natural processes. On the other hand, if the individuals in our study were adults, one would expect a higher survival rate in adult birds; therefore, our overall 88% mortality rate in just over 1 year implies that transmitter effect may play a significant role. The delayed release of the study birds may have also had an impact on survival, as other studies suggest a decrease in survival rate associated with delayed release (Richardson *et al.* 2013). Most studies using implanted transmitters have immediately released birds following recovery from surgery. An alternate explanation is that delayed release may have improved survival of the study birds, as there are potential benefits to holding birds post-surgery, such as providing food while the bird regains complete waterproofing (Gaydos *et al.* 2011; De La Cruz *et al.* 2013).

Mortality prior to day 25 is likely to be directly attributable to capture stress and surgical complications (Sexson *et al.* 2014). All eight birds surviving at least 25 days engaged in post-release movements, which would not be expected of severely debilitated animals. In previous work, Western Grebes implanted with satellite transmitters by the same technique had regained waterproofing and healed the celiotomy surgical incision by postoperative day nine (Gaydos *et al.* 2011). Ultimately, it is likely that some interactive effect between stress, altered thermoregulation, behavior, nutrition, and immune function was the cause of death for those birds surviving past day 25. Possible contributing factors of mortality for those birds include chronic low-grade infection, impaired waterproofing at the incision or antennae exit site, increased energy requirements due to transmitter weight, and antenna drag, and these factors may have important impacts upon critical behaviors such as ambulation, predator-evasion, preening, foraging, and inter- and intraspecific interactions. Studies in other diving species suggest that birds carrying devices, such as internal or external data loggers and radio or satellite transmitters, have altered behavior and/or survival (Boyd and Schneider 2000; Hatch *et al.* 2000; Latty *et al.* 2010; Fast *et al.* 2011). While a previous Western Grebe study (Gaydos *et al.* 2011) showed that surgically implanted birds spent a significantly greater time preening tail feathers vs. the control animals, the present study did not evaluate the behavioral impacts of the presence of the transmitter and/or external antenna. Behaviors unable to be duplicated in a captive environment (e.g., deep diving, escape from predators) cannot be assessed, and it may be these behaviors, in addition to the extra time spent preening, that are of greater importance to grebe survival after release.

It is well known that devices and antennae add drag and weight to flying and swimming birds (Wilson *et al.* 2004; Pennycuick *et al.* 2011), which may play a significant role in bird behavior and survival. Of the nine birds in our study, we suspected that at least four died; however, it is unknown what the mortality rate is for overwintering non-tagged grebes, so it is unknown whether this mortality is within the range of what would be expected if the birds did not have transmitters. Antenna drag may be more significant than transmitter mass in a diving-dependent bird like the Western Grebe because the increased density of water compared to air has a greater impact on swimming compared to flying birds (Wilson *et al.* 2004). While having an external antenna exiting perpendicular to the long axis of the body could have significantly impacted hydrodynamics (Pennycuick *et al.* 2011) and increased drag while diving (Wilson *et al.* 2004), similar techniques have been used successfully with both satellite and radio transmitters in other diving species such as Harlequin Ducks (*Histrionicus histrionicus*; Esler *et al.* 2000) and Pelagic Cormorants (*Phalacrocorax pelagicus*; Hatch *et al.* 2011). Even though we used flexible antennae to reduce potential negative effects, future work should investigate drag caused by the antenna at different angles (Wilson *et al.* 2004), as well as the possible "rudder effect" via the force exerted from the moment arm and the potential negative effect of the vibrations caused by antenna meta-stability in the water/air flow. However, optimal antenna angle and length are dictated by the wavelength of the transmitter and few modifications can be made. Spectacled Eiders (*Somateria fischeri*; Petersen *et al.* 1995) and Harlequin Ducks (Mulcahy and Esler 1999) equipped with implanted radio transmitters with percutaneous antennae similar to the devices used in our study have been successfully tracked long term. The investigation of alternative tracking methods may offer additional advantages over the technologies used in the present study. These include externally attached, smaller satellite transmitters, as well as devices shaped and placed to minimize turbulence and drag (Bannasch *et al.* 1994; Pennycuick *et al.* 2011). Iverson *et al.* (2006) found that there was no significant difference in Surf (*Melanitta perspicillata*) and White-winged (*M. fusca*) scoter survival between coelomically implanted and external radio transmitters, although there was a difference in radio retention. This should be taken into consideration when developing a study that uses radio or satellite transmitters.

Most of the implanted birds remained within San Francisco Bay for the duration of the winter. However, it is unknown whether the movement of these birds was affected by capture and implantation and/or the presence of the transmitter, or for a different reason. Two of the three birds that left the San Francisco Bay area went to other non-breeding sites, while one traveled to Clear Lake, California, and Upper Klamath Lake, Oregon, both well-documented breeding sites (La Porte *et al.* 2013). This long-distance movement from one wintering site to another within season may not necessarily be a transmitter effect, as this pattern of movement, based on band returns, has been recorded for other Western Grebes (Humple and Holcomb 2014). The small sample size warrants caution in interpreting these successful migrations, however, and multi-year data with larger sample sizes are needed. Humple (2009) and Wilson *et al.* (2013) suggest that Western Grebes have a high degree of plasticity in both summer breeding site and overwinter locations. Our work demonstrating the summer movement of a single bird to two known Western Grebe breeding sites may further support that Western Grebes can display breeding site plasticity and may explore several different breeding sites annually (Humple 2009). Alternatively, these sites may have simply been migratory stopovers, as this bird began migration late in the breeding season. The majority of Western Grebes migrate to breeding grounds between late April to early May, although they have been recorded nesting as late as early August (LaPorte *et al.* 2013); therefore, it is possible that this grebe attempted breeding while at Upper Klamath.

Improved techniques for tracking of Western Grebes are still needed to better understand breeding migration patterns, cross-seasonal connectivity, and summer and winter site philopatry. Results from this study suggest that the alterations made in the surgical procedures may have contributed to the higher survival rate post-release for the birds in this study as compared to those in prior pilot trials. While this research provides valuable knowledge on Western Grebe tolerance to implanted satellite transmitters as well as movements within San Francisco Bay and migratory paths, additional work is needed to explore ways to further improve the technique. In addition to addressing the efficacy of externally mounted transmitters as another option, future efforts with internally implanted transmitters should address antenna drag and design, as well as reducing impairment of waterproofing at the antennae exit site. Future tracking data can help to inform habitat protection and oil spill mitigation efforts, and ultimately aid in the recovery of Western Grebe populations.

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