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SUBCUTANEOUS ANCHOR ATTACHMENT INCREASES RETENTION OF RADIO TRANSMITTERS ON XANTUS' AND MARBLED MURRELETS

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Abstract.—We modified a subcutaneous anchor attachment and achieved transmitter retention times that exceeded those reported previously for other attachments used on alcids. Traditional suture and epoxy attachment methods were used on Xantus' Murrelets in 1995 and 1996, while the modified attachment was used for Xantus' Murrelets in 1996 and 1997 and Marbled Murrelets in 1997. Modifications included use of an inhalant anesthetic, placing the anchor in a more cranial position on the back, application of marine epoxy, and placement of a single subcutaneous non-absorbable suture at the caudal end of the radio to hold the radio in place initially. We located 22 of 56 (39%) Xantus' Murrelets radio-marked using suture and epoxy during aerial surveys in 1995 and 1996. Of birds radio-marked using the subcutaneous anchor attachment, we located 92 of 113 (81%) Xantus' Murrelets marked in 1996 and 1997 and all 28 (100%) Marbled Murrelets marked in 1997 during aerial surveys. The maximum confirmed duration for the subcutaneous anchor transmitter attachment was 51 d for Xantus' Murrelets and 78 d for Marbled Murrelets versus 41 d for the suture and epoxy attachment used on Xantus' Murrelets. Recapture rates of radio-marked Xantus' Murrelets were similar to recapture rates of unmarked Xantus' Murrelets. Our post-release observations indicated negligible short-term physical effects from the attachment procedure, while telemetry data and examination of recaptured murrelets indicated no evidence of infection or other long-term physical effects. Breeding behavior of some murrelets was not disrupted; however, further evaluation of potential effects of this attachment technique on breeding and behavior is needed.

CONECTOR SUBCUTÁNEO DE TIPO ANCLA AUMENTA LA RETENCIÓN DE RADIOTRANSMISORES EN *SYNTHLIBORAMPHUS HYPOLEUCUS* Y *BRACHYRAMPHUS MARMORATUS*

Sinopsis.—Modificamos un conector subcutáneo tipo ancla y obtuvimos retención del transmisor por tiempos que exceden los reportes previos para otros conectores usados en álcidos. Se usaron métodos tradicionales de sutura y de cola en *Synthliboramphus hypoleucus* en 1995 y en 1996, mientras que el accesorio modificado se utilizó en *Synthliboramphus hypoleucus* en 1996 y 1997, y en *Brachyramphus marmoratus* en 1997. Las modificaciones al accesorio de ancla incluyeron: 1) el uso de un anestésico inhalante, isoflurano, para facilitar la adhesión del radiotransmisor; 2) el colocar el ancla más hacia el cráneo en la región dorsal de las aves, en comparación con la localización más caudal del ancla en aves; 3) el uso de pegamentos marinos para fijar inicialmente el radiotransmisor en su lugar hasta que una reacción de tejido fibroso saludable fijara el ancla a las aves; y 4) la colocación de una sola sutura subcutánea no absorbable en el extremo caudal del radiotransmisor.

Localizamos 22 de 56 (39%) de los *Synthliboramphus hypoleucus* radio marcados con sutura y pegamentos durante los censos en 1995 y 1996. Con los radio transmisores fijados con el ancla subcutánea localizamos 92 de 113 (81%) de estas aves en 1996 y 1997 y todos los 28 (100%) *Brachyramphus marmoratus* marcados en 1997 en censos aéreos. La duración máxima confirmada para fijadores subcutáneos tipo ancla de transmisores fué 51 días en *Synthliboramphus hypoleucus* y 78 días en *Brachyramphus marmoratus,* contra 41 días del fijador de sutura y pega usado en *Synthliboramphus hypoleucus.* Las tasas de recaptura de *Synthliboramphus hypoleucus* marcados con radio transmisores fueron similares a las tasas de recaptura de la misma especie sin marcar. Nuestras observaciones post-liberación indican efectos fisicos de corto alcance neglegibles por el proceso de adhesión, mientras que los datos de telemetría y el exámen de las aves recapturadas no muestran evidencia de infección o de otro tipo de efecto físico de largo alcance. La conducta reproductiva de algunas aves no se afectó; sin embargo, se necesita una evaluación posterior de los efectos potenciales de esta técnica de adhesión en la reproducción.

Documenting individual movements, home ranges, and foraging ranges of alcids is critical for their proper conservation and management. Two species of murrelets found on the Pacific coast of North America, the Xantus' Murrelet (*Synthliboramphus hypoleucus*) and the Marbled Murrelet (*Brachyramphus marmoratus*), are of particular concern. Marbled Murrelets are federally classified as threatened under the U.S. Endangered Species Act, and Xantus' Murrelets may be considered for listing as threatened in the near future. The small populations of both of these species in California are vulnerable to various threats including loss of nesting habitat, environmental pollutants, native and introduced predators, fisheries impacts, ecotourism disturbances, and at-sea disturbances.

Successful radio telemetry studies require a transmitter attachment capable of providing adequate transmitter retention times without causing significant adverse effects to the study subject. Several transmitter attachment methods have been developed, including harnesses, adhesives, neck collars, sutures, and surgical implants (Kenow et al. 1997). These techniques have been used on a variety of birds, but alcids have posed particular problems because of the harsh marine conditions they inhabit, their sensitivity to handling, and their reaction to the attached transmitter. Radio telemetry studies of small alcids have been hampered by low transmitter retention times, radio failure, short transmission ranges, or adverse behavior (Hunt et al. 1979, Duncan and Gaston 1990, Quinlan and Hughes 1992, Ralph et al. 1992, Kuletz et al. 1995). As a result, few radio telemetry studies of small alcids have been attempted compared with other species such as waterfowl.

We modified a subcutaneous anchor attachment developed for telemetry studies of ducklings and waterfowl (Mauser and Jarvis 1991, Pietz et al. 1995) to use in our studies of the distribution and movements of Xantus' Murrelets and Marbled Murrelets during breeding and post-breeding dispersal periods. Both murrelets are small (Xantus' Murrelets,

$\bar{x}$ = 165 g; Marbled Murrelets, $\bar{x}$ = 220 g), widely distributed, and found nesting in concealed sites in mostly inaccessible habitat (Sealy 1974, Binford et al. 1975, Murray et al. 1983, Hamer and Nelson 1995, Nelson and Hamer 1995). In this paper, we describe the effectiveness of a modified subcutaneous anchor attachment for Xantus' Murrelets and Marbled Murrelets and discuss the advantages and disadvantages of this radio-marking technique.

MATERIALS AND METHODS

Study area.—We captured and radio-marked 169 Xantus' Murrelets at Santa Barbara Island (33°30′N, 119°02′W), Santa Barbara County, California during April and May of 1995–1997. This small island (2.6 km^2) harbors the largest breeding colony of Xantus' Murrelets in California (Carter et al. 1992, Drost and Lewis 1995). We also captured and radio-marked 28 Marbled Murrelets in May, June, and August of 1997 at Año Nuevo Bay (37°06′N, 122°19′W), Santa Cruz County, California. A small breeding population of Marbled Murrelets (750–1400 birds) nests in old-growth forests along the central California coast, which is the southern extent of their breeding range in the northeast Pacific Ocean (Ralph and Miller 1995).

Capture.—During the breeding season, murrelets formed loose congregations at night where they were scattered singly or in small groups of up to five birds on the waters adjacent to breeding areas. We captured murrelets on the water from 4-m inflatable boats with high-intensity spotlights and dipnets (Whitworth et al. 1997a). After capture, murrelets were transported to a research vessel anchored a short distance away. Aboard the vessel, murrelets were weighed to the nearest 1 g with a 300-g spring scale and inspected for presence or absence of paired lateral brood patches on Xantus' Murrelets (Murray et al. 1983) or a single medial brood patch on Marbled Murrelets (Sealy 1974, Binford et al. 1975). A small subset of Xantus' Murrelets (n = 16) were captured by hand from nests on Santa Barbara Island for radio attachment in May 1996. Standard morphometric measurements were recorded, plumage photographs were taken, and blood samples collected from most radio-marked murrelets. All captured murrelets were banded with U.S. Fish and Wildlife Service stainless steel bands.

Materials.—We used 3.5-g radio transmitters (Model PD-2; Holohil Systems Ltd.©, Ontario, Canada) with 15-cm external whip antennas and front and rear suture channels for Xantus' Murrelets in all years of the study. Expected lifespan of the transmitters used on Xantus' Murrelets were 3 mo in 1995 and 6 wk in 1996 and 1997. We used 2.0-g transmitters (Model BD-2G, Holohil Systems Ltd.©, Ontario, Canada) with a 15-cm whip antenna, front and rear suture channels, and an expected 6-wk lifespan for Marbled Murrelets. We used larger radios on Xantus' Murrelets because a stronger signal was needed to track murrelets that forage and disperse widely from the colony, compared to Marbled Murrelets, which remain within a narrow coastal area in central California (Drost and Lewis

1995, Becker et al. 1997). Stainless-steel anchors (Advanced Telemetry Systems©, Isanti, Minnesota) were slightly flattened and attached to the bottom surface of the front end of the transmitter with Superglue® and finished with epoxy (Hysol Epoxi-Patch®, Dexter Corp., Seabrook, New Hampshire). The bottom of the radio was then sanded using 200-grain sandpaper to create a slightly roughed surface for better epoxy adhesion and to smooth protusions.

Anesthesia.—We administered an inhalation anesthetic (isoflurane) to facilitate handling and minimize the stress associated with the attachment procedure in 1996 and 1997. We sedated murrelets with a prototype field anesthesia system. Three to five isoflurane-soaked gauze sponges were placed in the 250-ml glass flask and sealed with a rubber stopper that had an influx and efflux port through which 1-cm diameter plastic tubing was passed. A battery-powered aquarium air pump forced ambient air into the flask and an unregulated amount of isoflurane gas vapor was carried to the anesthesia mask (a latex glove stretched over the open end of a 60-cc syringe case). The murrelets' bill was placed through a 3-mm hole in the glove. Murrelets were exposed to the anesthetic until they no longer had a palpebral or blinking reflex, showed signs of decreased muscle tone (no leg or wing withdrawal reflex), and developed slow, deep respiratory patterns. Most murrelets required anesthetic exposure for <30 s. We readministered the anesthetic if the murrelets woke from sedation during the procedure.

Suture and epoxy attachment.—In 1995 and April of 1996, we radiomarked 56 Xantus' Murrelets using the traditional suture and epoxy method (Martin and Bider 1978, Wheeler 1991). Front and rear suture placement techniques are similar to those described in the following section and are referred to as the "suture" method.

Subcutaneous anchor attachment.—We adapted the subcutaneous anchor attachment ("anchor" method) from Mauser and Jarvis (1991) to radio-mark Xantus' Murrelets (n = 113) in May of 1996 and April and May of 1997. All Marbled Murrelets captured in 1997 (n = 28) were radiomarked using the anchor method. Researchers handling murrelets wore latex gloves. One person held the murrelet while another performed the minor surgery. Needle holders and forceps used for the surgery and transmitter anchors were sterilized in Cidex© (Johnson and Johnson Hospital Services, New Brunswick, New Jersey) or Benz-all© (Xttrium Laboratories, Chicago, Illinois) for ≥15 min prior to use.

We affixed the transmitter on the murrelet's dorsal midline at the small depression between the scapulae just caudal to where the vertebrae disappear from their superficial location and become more internal. Anatomically, this is dorsal to the junction of the cervical and thoracic vertebrae (Fig. 1). This attachment site resulted in the transmitter being covered by contour feathers to reduce drag. Additionally, the site was difficult for the bird to reach, making the radio less likely to be pulled off. The surgical attachment site (2.0 cm × 1.5 cm) was prepared by parting the feathers and wetting the skin and underlying feathers with

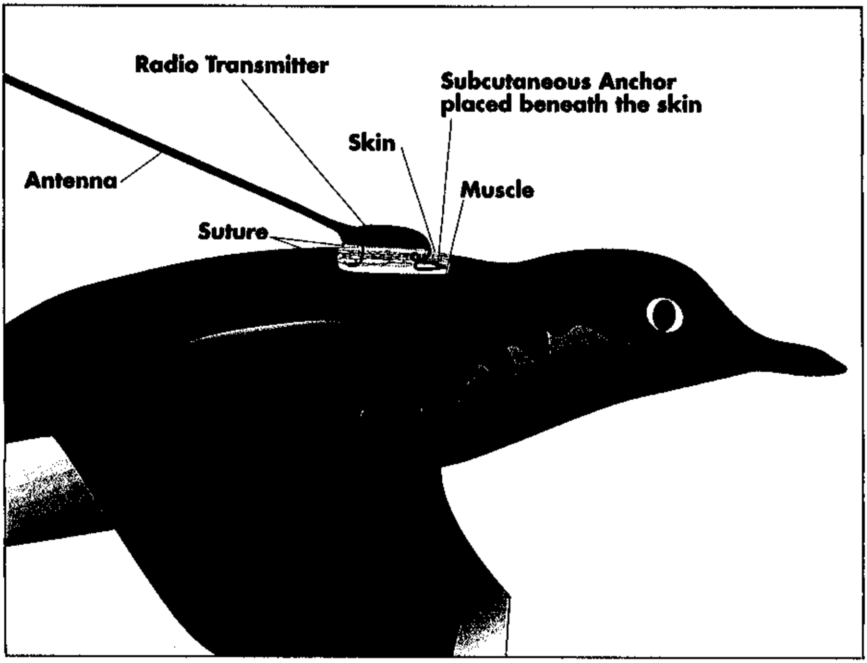

FIGURE 1. Location and placement of the subcutaneous anchor for radio-marking Xantus' and Marbled Murrelets.

isopropyl alcohol. We initially removed down feathers at the attachment site of 12 birds, but this was unnecessary in most cases. We pinched and lifted the skin at the attachment site and used a sterile 16-gauge × 1 inch (2.54 cm) hypodermic needle to puncture the skin, avoiding contact with underlying musculature, nerves, and blood vessels. The needle was left in place while the radio anchor was rinsed with sterile saline to remove the sterilization solution. Then the anchor was fed through the skin opening after removing the hypodermic needle. Once the entire anchor was beneath the skin layers (epidermis, dermis and hypodermis), it was rotated and situated with the head of the arrow pointing forward and the anchor flat on the murrelet's back (Fig. 1). A rear suture (2-0 Prolene© (non-absorbable, monofilament) Ethicon Inc., Somerville, New Jersey) was placed by laterally pinching the skin adjacent to the rear suture channel and passing a sterile 22-gauge × 1.5 inch (3.81 cm) hypodermic needle laterally through the skin fold. We threaded the suture through the needle from the sharp end and out the hub before the needle was withdrawn from the skin, leaving the subcutaneous suture in place parallel to the rear suture port of the radio. The suture was passed through the rear suture channel and a thin coat of marine epoxy (Marine epoxy #332©, Titan Corporation, Lynnwood, Washington) applied to the bottom of the transmitter prior to tying the suture with four surgical square knots.

Recovery.—Following radio attachment, we returned murrelets to holding boxes for 15–30 min to allow for anesthesia recovery and for curing of epoxy. Prior to release, murrelets were examined for alertness, normal palpebral reflexes, and normal muscle tone. Radio attachments were inspected and transmitter signals were tested before murrelets were released. We took murrelets several hundred meters from the research vessel before release. At release, we gently lofted birds into the air so they could fly away. Most birds flew out of sight upon release.

Tracking.—We tracked Xantus' Murrelets over a 2-mo period during the breeding season, April–June, 1995–1997. The two tracking methods included a remote receiving station on Santa Barbara Island and aerial surveys (Whitworth et al. 1997b). We conducted daily Marbled Murrelet aerial and land-based surveys over a four-month period from 9 May–19 Sep. 1997 (Burkett et al. 1998). We report mean tracking duration ($\bar{x} \pm$ SD) and maximum tracking duration for both attachment methods. We performed statistical tests for effects of species, year, and attachment method on tracking duration using Mann-Whitney U tests. We performed Yates corrected Chi-square tests (χ^2_c) for differences between recapture frequencies in our radio-marked and unmarked Xantus' Murrelet capture samples.

RESULTS

Transmitter attachment.—We marked 46 Xantus' Murrelets using the suture technique in 1995, and 10 in April 1996. We radio-marked a total of 113 Xantus' Murrelets (54 in 1996 and 59 in 1997) and 28 Marbled Murrelets in 1997 using the anchor technique. Total time in captivity, from capture to release, for Xantus' Murrelets marked with the anchor method averaged 61.3 ± 28.8 min in 1996 (n = 31) and 46.7 ± 10.3 min in 1997 (n = 47). We held Xantus' Murrelets marked with the suture method for 51.4 ± 26.7 min (n = 46) in 1995, and 42.1 ± 8.9 min (n = 8) in 1996. We required 72.3 ± 20.4 min (n = 28) to complete procedures on Marbled Murrelets.

Efficiency of tracking and duration of radio attachment.—We located a higher proportion of the radio-marked Xantus' Murrelets in each successive year of the study. However, statistical comparisons may have been confounded by differences in survey intensity among years. Differences in environmental variables among years, which affected murrelet distributions and therefore our ability to locate marked birds, also may have confounded comparisons. We located only 14 of 46 (30%) Xantus' Murrelets marked with the suture method in 1995, but 8 of 10 (80%) in April 1996. We located 37 of 54 (69%), and 55 of 59 (93%) of Xantus' Murrelets with anchor attachments during aerial surveys in 1996 and 1997, respectively. All 28 (100%) radio-marked Marbled Murrelets were located by both aerial and ground-tracking in 1997. We obtained 512 Xantus' Murrelet aerial locations and 1293 Marbled Murrelet aerial locations during the years of these studies. The mean duration of tracking increased for Xantus' Murrelets each successive year as marking techniques changed. The mean duration of tracking for the anchor method (14.7 ± 13.6 d) was twice as long ($Z = 4.19$, $P \leq 0.0001$) as that of the suture method (6.8 ± 9.8 d). Marbled Murrelets marked with the anchor method were tracked longer (45.1 ± 15.3 d) than Xantus' Murrelets ($Z = 6.34$, $P \leq 0.0001$).

Maximum confirmed duration for the suture attachment was 41 d. In 1997, we recaptured three Xantus' Murrelets marked using the suture method in 1995. None of the three still had transmitters attached. Two of these Xantus' Murrelets were never located during aerial surveys in 1995, while the third was located three times over 13 days. None showed adverse physiological effects from the marking procedure.

The maximum confirmed duration for the anchor method, as determined from telemetry data, was 51 d for Xantus' Murrelets and 78 d for Marbled Murrelets. However, we discovered a Xantus' Murrelet with a transmitter attached 340 d after radio-marking. We captured this murrelet and radio-marked it from the nest on 5 May 1996 at Santa Barbara Island, then re-sighted it on 10 Apr. 1997, incubating eggs in the same nest crevice. One Marbled Murrelet, radio-marked on 11 May 1997, was recaptured 86 d later, on 5 Aug. 1997, with the nonfunctional transmitter still attached. We tracked another Marbled Murrelet for 34 d before the signal was lost, then recaptured it without the transmitter 88 d after marking. A Marbled Murrelet radio-marked on 10 Jun. 1997 was recaptured on 23 May 1998 (Burkett et al. 1999) without the radio attached and only a minor fibrous tissue reaction or scar was present under the skin at the previous radio attachment site.

Although the recapture rates for radio-marked Xantus' Murrelets was low (4.5%), we recaptured five of the 110 Xantus' Murrelets we marked in 1995 and 1996. This was not significantly different ($\chi^2_c = 0.47$, $P = 0.49$) than the recapture rate (6.6%) of our total capture sample of non-radio-marked Xantus' Murrelets during those years. Two of the 28 Marbled Murrelets (7%) radio-marked in May and June 1997 were recaptured during a total of six capture nights later that season. One radio-marked Marbled Murrelet was recaptured in May of 1998.

DISCUSSION

Radio-marking murrelets using the subcutaneous anchor attachment proved to be both a reliable and practical method of transmitter attachment. We achieved mean and maximum transmitter retention times that exceeded retention times reported for all other radio-marking studies on murrelets.

Handling times.—Our handling times compare favorably with those reported for similar techniques on other alcids (Burns et al. 1994). Wanless et al. (1985) concluded that minimizing the handling time during radio attachment procedures improved the post-release responses of radio-marked Common Murres (*Uria aalge*). We estimate the radio attachment procedure alone required 5–15 min to complete, but because of concurrent tasks (e.g., morphometric measurements, photographs, and blood sampling), many murrelets were held longer than required for radio-marking alone. Additionally, we tended to release murrelets in groups so that one release trip could be made to release 2–4 birds. Limiting concurrent work would have decreased handling times. A small sample of Xantus' Murrelets (n = 5) captured from nests, sedated, and radio-marked in 1996 required only 12.6 ± 2.0 min from capture to replacement on the nest. Nest-trapped Xantus' Murrelets were not subject to transport, holding for anesthesia recovery, epoxy curing, or additional measurements and sampling.

Anesthesia.—Stress associated with capture and handling of wild birds has been documented in a variety of species (LeMaho et al. 1992, Smith et al. 1994, Marra et al. 1995) including Xantus' Murrelets (Newman et al. 1997). To prevent additional stress to murrelets, we sedated birds with an anesthetic, worked in a quiet environment, covered the bird's head to decrease visual stimulation, and wrapped each bird in a thin towel to limit struggling.

Despite problems reported when anesthetics were used on Marbled Murrelets (Quinlan and Hughes 1992, Burns et al. 1994), we found that careful monitoring of birds sedated with isoflurane was not only safe, but also facilitated radio attachment by decreasing struggling. Other benefits of isoflurane use for murrelet radio attachments in the field included easy administration, a wide safety margin, a rapid recovery rate (<10 min), and no lingering effects of anesthesia on reflexes, attitude, vigor, respiration, or body temperature. Furthermore, isoflurane likely decreased pain and stress associated with radio attachment.

Previous telemetry studies on alcids.—Most recent attempts to radio-mark alcids have involved the use of adhesives or suture-adhesive combinations to secure the transmitter. Different types of glue or epoxy have been used to attach transmitters to Marbled Murrelet adults and chicks (Quinlan and Hughes 1992, Kuletz et al. 1995, Kuletz and Marks 1997), Common Murres, Atlantic Puffins (*Fratercula arctica*), Razorbills (*Alca torda*) (Wanless et al. 1985, 1988a,b), and Ancient Murrelet (*Synthliboramphus antiquus*) adults and chicks (Duncan and Gaston 1990). Suture-epoxy combinations have been used with limited success on Xantus' and Marbled Murrelets (Burns et al. 1994, this study) However, the adhesive-only and suture-epoxy attachments, with maximum confirmed duration of 22 and 41 d, respectively (Quinlan and Hughes 1992, this study), were not as durable as the anchor technique.

Attempts to radio-mark alcids with other transmitter attachment methods have proven disruptive. Stainless steel or surgical gut harnesses enclosed in plastic tubing appeared to disrupt the normal behavior of Xantus' Murrelets (Hunt et al. 1979). Marbled Murrelets fitted with harnesses of polyethylene tubing died soon after release and murrelets with surgically implanted transmitters responded poorly to the anesthetic and never behaved normally after release (Quinlan and Hughes 1992). Common Murres and Thick-billed Murres (*Uria lomvia*) equipped with coelomic cavity satellite implants experienced high mortality and low breeding success (Meyers and Hatch 1997).

Physiological effects of radio attachment on marked murrelets.—Previous physiological problems that may have affected the health of radio-marked birds include heat loss associated with the anchor attachment (Bakken et al. 1996, Kenow et al. 1997) and infections at the anchor attachment site (Bakken et al. 1996). To prevent heat loss, we did not remove or trim feathers at the radio attachment site. Examination of recaptured Xantus' and Marbled Murrelets indicated that infections were not present. Furthermore, blood tests, physical examinations, and necropsy findings from 75 American Coots (*Fulica americana*) radio-marked using the anchor attachment and monitored for 4 mo also showed no infections (Newman, unpubl. data). A fibrous tissue reaction had occurred at the anchor implantation site, which stabilized the radio even if the sutures had pulled out through the skin.

Physical effects of radio attachment on marked murrelets.—Our post-release observations and telemetry data indicate that attached transmitters did not interfere with murrelets' physical capacities. All released murrelets were capable of making a full range of wing movements. Tracking showed that some Xantus' Murrelets moved long distances (>100 km) in a relatively short time period (4–10 h) and several Xantus' Murrelets traveled over 1000 km in 30 d or more (Whitworth et al. 1997b).

At Año Nuevo Bay, California, Marbled Murrelets tend to forage nearshore and maintain a relatively local distribution (Carter and Sealy 1990, Strachan et al. 1995, Becker et al. 1997, Beissinger and Becker 1998). Individual movements were not expected to be as extensive as those for Xantus' Murrelets. Still, Marbled Murrelets dispersed far to the north (224 km) and south (181 km) from Pt. Año Nuevo (Burkett et al. 1998) and birds continued to navigate inland to forest nest locations (Big Basin Redwoods State Park and surrounding habitat). These observations suggest that radio-marking had minimal, if any, detrimental effects on the ability of marked individuals to fly.

We have no evidence that depredation of radio-marked murrelets was unusually severe. Had dead or weakened radio-marked murrelets been scavenged or preyed upon by avian predators, we should have detected transmitter signals from roost or nest sites (Quinlan and Hughes 1992, Burns et al. 1994). We found one functional Marbled Murrelet transmitter under a known Peregrine Falcon (*Falco peregrinus*) eyrie. One Xantus' Murrelet signal was detected repeatedly on Anacapa Island, a known Peregrine Falcon breeding site, and may have been preyed upon. Although Western Gulls (*Larus occidentalis*) are abundant on Santa Barbara Island, California and are known to prey upon Xantus' Murrelets (Oades 1974; P. Martin, pers. comm.), Marbled Murrelets (Nelson 1997), and other small alcids, we found no depredated murrelets near their nests.

Behavioral effects of radio-marking on murrelets.—Disruption of normal behavior following radio-marking may be subtle and difficult to detect. Based on the absence of brood patches, 85.8% of radio-marked Xantus'

Murrelets captured at-sea were not incubating when captured (Whitworth et al., in press). Therefore, radio-marked Xantus' Murrelets likely represented mostly sub-adult, non-breeding individuals or adult individuals which were socially congregating prior to breeding. Although radio-marking may precipitate early dispersal, nest abandonment, or colony avoidance by murrelets, these effects were not documented in birds captured at-sea.

We were able to confirm successfully hatched eggs for only one of our 16 nest-captured Xantus' Murrelets. We found depredated or abandoned eggs in seven nests, but were unable to confirm the fate of eight nests, although we suspect two of these may have hatched. Telemetry data indicated that marking effects were not always immediate. If birds were going to abandon nests, we expected this to occur immediately after birds were placed back on their nests. Surprisingly, only four Xantus' Murrelets departed within 30 min of replacement on the nest. Six radio-marked murrelets and the mates of two marked murrelets were found on nests for between 1–24 d after marking. Wanless et al. (1985, 1988a) found that marking Common Murres late in the incubation period or during the chick period reduced the detrimental effects of radio-marking. We intended to mark nest-captured Xantus' Murrelets at hatch, however, a relatively late nesting season in 1996, a small sample of monitored nests, and infrequent trips to Santa Barbara Island precluded marking at the end of incubation.

In contrast to Xantus' Murrelets, 64% of radio-marked Marbled Murrelets (all captured at sea) had fully vascularized brood patches suggesting that these birds were either within days of egg laying or were actively incubating eggs. Tracking of individual Marbled Murrelets occurred on almost a daily basis, thus the 24-h incubation shift was monitored, along with at-sea locations, and diving or foraging behavior on non-incubation days (Burkett et al. 1998). Tracking results suggested that breeding behavior, nest initiation, and foraging patterns were not significantly disrupted by the anchor attachment method for at least 5 of 18 individuals (28%) known to be reproductively active, however, nest success may have been affected. More conclusive findings about the lack of effects of the anchor attachment on nesting and breeding behavior were documented from 40 radio-marked Marbled Murrelets in Desolation Sound, British Columbia where 23 nests were found and overall fecundity was 29% (Cooke et al. 1999).

Although nests failed for all five Marbled Murrelets which were tracked to inland nesting sites, at-sea surveys near Año Nuevo in 1997 found low juvenile to adult ratios (<0.02) suggesting that few nests were successful that year (Beissinger and Becker 1998). Furthermore, the effects of the 1997–1998 El Niño may have also contributed to poor nest success of murrelets. Radio attachment cannot be ruled out as a contributing factor, but we believe that birds would not have initiated nesting or continued to nest after radio attachment if the attachment and handling had led to the failure. It is possible that radio attachment, leading to increased preening rates during incubation, contributed to increased nest depredation which is a known cause of nest failure for Marbled Murrelets (Nelson and Hamer 1995). After capture, the five birds maintained a routine attendance behavior for a mean of 8.8 ± 7.8 d before nest failure. Although some birds with brood patches were never documented nesting, we do not know if their nests had already failed by the time of capture (Burkett et al. 1998), if they had abandoned their nests after marking, or if they were not nesting, despite having fully vascularized brood patches. In contrast, 15 nesting Cassin's auklets radio-marked using the anchor attachment did not abandon their nests at Prince Island, California in 1999 (U.S. Geological Survey, unpubl. data). These results, and findings from Cooke et al. (1999) suggest that for certain species under specific conditions the anchor attachment can be performed without disruption of nest attendance and parental care of chicks.

Explanations for unlocated murrelets.—All Marbled Murrelets we radio-marked were located over a period of at least 10 d by aerial survey or ground tracking, but most (62.5%) Xantus' Murrelets with the suture-epoxy method, and some (29.6%) Xantus' Murrelets marked with the anchor method were not located during aerial surveys. Differing at-sea distributions between these two species in California may explain much of this disparity. Marbled Murrelets in central California are inshore feeders and tend to stay within 2 km of the coast (Becker et al. 1997). This aspect of their at-sea ecology facilitates telemetry studies by limiting the at-sea survey area to a narrow coastal strip.

In contrast, Xantus' Murrelets dispersed widely through out the Southern California Bight (Whitworth et al. 1997b), resulting in an enormous survey area. Xantus' Murrelets are known to range far offshore, well outside the confines of our survey area (Briggs et al. 1987, Karnovsky et al. 1995). We believe that many radio-marked Xantus' Murrelets quickly dispersed out of the Southern California Bight, especially in 1995. Some radio-marked Xantus' Murrelets were not located for extended periods of up to 3 wk before being relocated, often far offshore. Because the immediate area around Santa Barbara Island was searched thoroughly on most aerial surveys, these murrelets must have returned to the study area, after dispersing to areas farther from the colony. We also suspect that some of the radios attached on Xantus' Murrelets in 1995 and 1996 using the suture method detached soon after release. Moreover, radio failure following attachment was also possible and this may further explain not locating some proportion of radio-marked murrelets.

Our results suggest that loss of lighter transmitters (2–3.5 g) attached with subcutaneous anchors was less severe than studies on Northern Shovelers (*Anas clypeata*) in which almost half the birds shed transmitters within 30 d of attachment (Zimmer 1997). Verifying the durability of a transmitter or the longevity of an attachment technique for any free ranging bird, especially a marine bird, is difficult. Failed transmitters or transmitters that detach at-sea would be undetectable. However, three Xantus' Murrelets marked in 1995 (suture-epoxy) and recaptured in 1997 indicated that murrelets not located after marking did not die, but that either the radios detached, failed, or murrelets had dispersed outside the tracking area.

We recommend the subcutaneous anchor attachment technique to researchers interested in pursuing telemetry studies of alcids. Direct observations and telemetry data suggests that the anchor method results in no physical impairment to murrelets. Data from these studies also suggests that breeding behavior for some murrelets was not disrupted, however, data from other alcid studies (Marbled Murrelets in Canada and Cassin's Auklets in California) definitively shows that this attachment method does not effect nesting and reproduction in these cases. Further evaluation of potential effects of this attachment technique is necessary before definitive conclusions are drawn.

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LITERATURE CITED

BAKKEN, G. S., P. S. REYNOLDS, K. P. KENOW, C. E. KORSCHGEN, AND A. F. BOYSEN. 1996. Thermoregulatory effects of radiotelemetry transmitters on mallard ducklings. J. Wildlife Manage. 60:669–678.

BECKER, B. H., S. R. BEISSINGER, AND H. R. CARTER. 1997. At-sea density monitoring of Marbled Murrelets in central California: methodological considerations. Condor 99:743–755.

BEISSINGER, S. R., AND B. H. BECKER. 1998. Marbled Murrelet studies in the Monterey Bay National Marine Sanctuary: monitoring temporal and spatial patterns from 1995–1997. Final Report, David and Lucile Packard Foundation, Monterey, California.

BINFORD, L. C., B. G. ELLIOT, AND S. W. SINGER. 1975. Discovery of a nest and the downy young of the Marbled Murrelet. Wilson Bull. 87:303–319.

BRIGGS, K. T., W. B. TYLER, D. B. LEWIS, AND D. R. CARLSON. 1987. Bird communities at sea off California: 1975 to 1983. Pp. 1–74, *in* F. A. Pitelka, ed. Bird communities at sea off California: 1975–1983. Studies in Avian Biology No. 11.

BURKETT, E. E., H. R. CARTER, J. Y. TAKEKAWA, S. H. NEWMAN, AND R. T. GOLIGHTLY. 1998. Movement patterns and habitat preferences of Marbled Murrelets in central California: a radio telemetry study. *In* Proceedings of the 25th Annual Pacific Seabird Group Meeting, January 21–25, Monterey, California.

———, ———, ———, ———, ———, AND J. L. LANSER. 1999. Marbled Murrelet radio telemetry in central California in 1997 and 1998: a reduced breeding effort in an El Niño year. *In* Proceedings of the 26th Annual Pacific Seabird Group Meeting, February 24–28, Blaine, Washington.

BURNS, R. A., L. M. PRESTASH, AND K. J. KULETZ. 1994. Pilot study on the capture and radio tagging of Murrelets in Prince William Sound, Alaska, July and August, 1993. Final Report, U.S. Fish and Wildlife Service, Anchorage, Alaska. Project #93051 B. *Exxon Valdez* Restoration Project.

CARTER, H. R., G. J. MCCHESNEY, D. L. JAQUES, C. S. STRONG, M. W. PARKER, J. E. TAKEKAWA, D. L. JORY, AND D. L. WHITWORTH. 1992. Breeding populations of seabirds in California, 1989–1991. Volume 1. Population estimates. Final Report, U.S. Fish and Wildlife Service, Northern Prairie Wildlife Research Center, Dixon, California.

CARTER, H. R., AND S. G. SEALY. 1990. Daily foraging behavior of Marbled Murrelets. Pp. 93–102, *in* S. G. Sealy, ed. Auks at sea. Studies in Avian Biology 14.

COOKE, F., L. W. LOUGHEED, G. KAISER, AND S. BOYD. 1999. Survival and fecundity of Marbled Murrelets at Desolation Sound, B. C. *In* Proceedings of the 26th Annual Pacific Seabird Group Meeting, February 24–28, Blaine, Washington.

DROST, C. A., AND D. B. LEWIS. 1995. Xantus' Murrelet (*Synthliboramphus hypoleucus*). No. 164 *in* A. Poole and F. Gill, eds. The birds of North America. Academy of Natural Sciences, Philadelphia and the American Ornithologists' Union, Washington, D.C.

DUNCAN, D. C., AND A. J. GASTON. 1990. Movements of Ancient Murrelet broods away from a colony. Pp. 109–113, *in* S. G. Sealy, ed. Auks at sea. Studies in Avian Biology 14.

HAMER, T. E., AND S. K. NELSON. 1995. Characteristics of Marbled Murrelet nest trees and nesting stands. Pp. 69–82, *In* C. J. Ralph, G. L. Hunt, Jr., M. G. Raphael, and J. F. Piatt, eds. Ecology and conservation of the Marbled Murrelet. U.S. Department of Agriculture, Forest Service, General Technical Report, PSW-GRT-152, Albany, California.

HUNT, G. L., JR., R. L. PITMAN, M. NAUGHTON, K. WINNETT, A. NEWMAN, P. R. KELLY, AND K. T. BRIGGS. 1979. Summary of marine mammal and seabird surveys of the Southern California Bight. Volume III—Investigator's Reports. Part III. Seabirds—Book II Reproductive ecology and foraging habits of breeding seabirds. Report for the U.S. Department of Interior, Bureau of Land Management by the Center for Coastal Marine Studies, University of California at Santa Cruz.

KARNOVSKY, N. J., D. G. AINLEY, N. NUR, AND L. B. SPEAR. 1995. Distribution, abundance and behavior of Xantus' Murrelets off northern California and southern Oregon. Abstract. Colonial Waterbird Society Bulletin 19:50.

KENOW, K. P., C. E. KORSCHGEN, F. J. DEIN, A. P. GENDRON-FITZPATRICK, AND E. F. ZUELKE. 1997. Evaluating the effects of telemetry transmitter attachment techniques on waterfowl: a review and recommendations. P. 41, *in* J. E. Austin and P. J. Pietz, eds. Forum on wildlife telemetry: innovations, evaluations and research needs. Snowmass, Colorado.

KULETZ, K. J., D. K. MARKS, R. A. BURNS, L. M. PRETASH, AND D. A. FLINT. 1995. Marbled Murrelet foraging patterns and a pilot productivity index for murrelets in Prince William Sound, Alaska. *Exxon Valdez* oil spill restoration project final report, Project 94102. U.S. Fish and Wildlife Service. Anchorage, Alaska.

———, AND ———. 1997. Post-fledging behavior of a radio-tagged juvenile Marbled Murrelet. J. Field Ornithol. 68:421–425.

LEMAHO, Y., H. KARMANN, D. BRIOT, Y. HANDRICH, J. P. ROBIN, E. MIOSKOWSKI, Y. CHEREL, AND J. FARINI. 1992. Stress in birds due to routine handling and a technique to avoid it. American Journal of Physiology 263:Part 2, R775–R781.

MARRA, P. P., K. T. LAMPE, AND B. L. TEFORD. 1995. Plasma corticosterone levels in two species of Zonotrichia sparrows under captive and free-living conditions. Wilson Bull. 107(2): 296–305.

MARTIN, M. L., AND J. R. BIDER. 1978. Transmitter attachment for blackbirds. J. Wildlife Manage. 42:683–685.

MAUSER, D. M., AND R. L. JARVIS. 1991. Attaching radio transmitters to one-day-old Mallard ducklings. J. Wildlife Manage. 55:488–491.

MEYERS, P., AND S. HATCH. 1997. Assessment of implantable satellite transmitters for Common and Thick-billed Murres. Pacific Seabirds 24:19.

MURRAY, K. G., K. WINNETT-MURRAY, Z. A. EPPLEY, G. L. HUNT, JR., AND D. B. SCHWARTZ. 1983. Breeding biology of the Xantus' Murrelet. Condor 85:12–21.

NELSON, S. K., AND T. E. HAMER. 1995. Nesting biology and behavior of Marbled Murrelets. Pp. 57–67, *in* C. J. Ralph, G. L. Hunt, Jr., M. G. Raphael, and J. F. Piatt, eds. Ecology and conservation of the Marbled Murrelet. U.S. Department of Agriculture, Forest Service, General Technical Report, PSW-GTR-152. Albany, California.

———. 1997. Marbled murrelet (*Brachyramphus marmoratus*). No. 276. *In* A. Poole and F. Gill, eds. The birds of North America. Academy of Natural Sciences, Philadelphia and the American Ornithologists' Union, Washington, D.C.

NEWMAN, S. H., J. Y. TAKEKAWA, D. L. WHITWORTH, AND H. R. CARTER. 1997. Utilization of blood sampling to examine the stress response of Xantus' Murrelets (*Synthliboramphus hypoleucus*) to three different handling protocols. *in* Proceedings of The 24th Annual Pacific Seabird Group Meeting, Portland, Oregon.

OADES, R. D. 1974. Predation of Xantus' Murrelet by Western Gull. Condor 76:229.

PIETZ, P. J., D. A. BRANDT, G. L. KRAPU, AND D. A. BUHL. 1995. Modified transmitter attachment method for adult ducks. J. Field Ornithol. 66:408–417.

QUINLAN, S. E., AND J. H. HUGHES. 1992. Techniques for radio tagging of Marbled Murrelets. Pp. 117–121, *in* H. R. Carter and M. L. Morrison, eds. Status and conservation of the Marbled Murrelet in North America. Proceedings of the Western Foundation of Vertebrate Zoology 5.

RALPH, C. J., AND S. L. MILLER. 1995. Offshore population estimates of Marbled Murrelets in California. Pp. 353–360, *in* C. J. Ralph, G. L. Hunt, Jr., M. G. Raphael,and J. F. Piatt, eds. Ecology and conservation of the Marbled Murrelet. U.S. Department of Agriculture, Forest Service, General Technical Report, PSW-GTR-152. Albany, California.

———, ———, AND B. O'DONNEL. 1992. Capture and monitoring of foraging and breeding of the Marbled Murrelet in California during 1990. Interim Report: Technical Report 92.07, California Department of Fish and Game, Sacramento, California. 16 pp.

SEALY, S. G. 1974. Breeding phenology and clutch size in the Marbled Murrelet. Auk 91: 10–23.

SMITH, G. T., J. C. WINGFIELD, AND R. R. VEIT. 1994. Adrenocortical response to stress in the common diving petrel, *Pelecanoides urinatrix*. Physiological Zoology 67:526–537.

STRACHAN, G., M. MCALLISTER, AND C. J. RALPH. 1995. Marbled Murrelet at-sea and foraging behavior. Pp. 247–253, *in* C. J. Ralph, G. L. Hunt, Jr., M. G. Raphael, and J. F. Piatt, eds. Ecology and conservation of the Marbled Murrelet. U.S. Department of Agriculture, Forest Service, General Technical Report, PSW-GTR-152. Albany, California.

WANLESS, S. M., M. P. HARRIS, AND J. A. MORRIS. 1985. Radio-monitoring as a method for estimating time budgets of Guillemots *Uria aalge*. Bird Study 32:170–175.

———, ———, AND ———. 1988a. The effect of radio transmitters on the behavior of Common Murres and Razorbills during chick rearing. Condor 90:816–823.

———, J. A. MORRIS, AND M. P. HARRIS. 1988b. Diving behavior of guillemot *Uria aalge*, puffin *Fratercula arctica* and razorbill *Alca torda* as shown by radio telemetry. Journal Zoological Society of London 216:73–81.

WHEELER, W. E. 1991. Suture and glue attachment of radio transmitters on ducks. J. Field Ornithol. 62:271–278.

WHITWORTH, D. L., J. Y. TAKEKAWA, H. R. CARTER, AND WILLIAM R. MCIVER. 1997a. A night-lighting technique for at-sea capture of Xantus' Murrelets. Colonial Waterbirds 20:525–531.

———, ———, ———, S. H. NEWMAN, T. W. KEENEY, AND P. R. KELLY. 1997b. Foraging distribution and dispersal of Xantus' Murrelets in the Southern California Bight: 1995–

1997. Final Report, U.S. Geological Survey, Biological Resources Division, California Science Center, Vallejo and Dixon, California; Wildlife Health Center, University of California, Davis, California; Naval Air Weapons Station, Pt. Mugu, California; and California Department of Fish and Game, Office of Oil Spill Prevention and Response, Sacramento, California.

———, ———, ———, ———, ———, AND ———. *In press.* Distribution of Xantus' Murrelets *Synthiloboramphus hypoleucus* at sea in the Southern California Bight, 1995–1997. Ibis.

ZIMMER, J. M. 1997. Poor retention rates of 8-g anchor radio transmitters by Northern Shovelers. J. Field Ornithol. 68:526–529.

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