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16. ABSTRACT During three nesting seasons a total of 102 marbled murrelets (<i>Brachyramphus marmoratus</i>) were captured on the ocean off northern California and had radio transmitters attached. Reproductive success varied between years, and the average reproductive success was 6.9-13.5%, depending on assumptions in the calculations. Most nest failures occurred early in incubation. Predation by corvids was implicated as a major source of nest failure. When nests were exposed to disturbance in form of sound from an operating chainsaw, neither incubating adults or chicks flushed from the nest. The proportion of resting behavior was significantly less when the saw was operating than before or after. Reproductive success was not reduced when nests were exposed to the sound disturbance. No correlation was found between nest success and distance from roads or trails. However, there was a potential for indirect effects of longer-term noise (greater than 15 minutes) due to potential attraction of corvids. Murrelets that were feeding chicks flew inland later in the morning than other inland flying murrelets. Only chick-feeding murrelets flew inland in the evening. Murrelets whose breeding attempts failed still continued to fly inland. At one nest equipped with a persistent video, murrelets nested at the same location on the platform for five years, but lost their eggs to Steller's Jays or Ravens in 3 of 5 years.		
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Movements, Nesting, and Response to Anthropogenic Disturbance of Marbled Murrelets (*Brachyramphus marmoratus*) in Redwood National and State Parks, California

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DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the state of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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CHAPTER 1

EVALUATION OF HUMAN-CAUSED DISTURBANCE ON THE BREEDING SUCCESS OF MARBLED MURRELETS (*BRACHYRAMPHUS MARMORATUS*) IN REDWOOD NATIONAL AND STATE PARKS, CALIFORNIA

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The influence of human disturbance on the nesting success of birds is well documented. Human disturbance can influence, either directly or indirectly, species richness as well as nesting success (Wright 1913, Van der Zande et al. 1980, Westmoreland and Best 1985, Gutzwiller et al. 1998, Fernandez-Juicic 2000). Among birds, ground-nesting seabirds including alcids appear to be especially sensitive to human disturbance (e.g. Burger 1981, Piatt et al. 1990, Gotmark 1992), particularly during the incubation period. For instance, disturbance during the incubation period may lead to temporary or prolonged desertion of eggs which results in increased hatch failure (Cairns 1980, Sealy 1984, Pierce and Simons 1986, Piatt. et al. 1990, Gotmark 1992), or predation on the eggs (Piatt et al. 1990).

Marbled Murrelets (*Brachyramphus marmoratus*), in contrast to other alcids, typically nest on large branches in old-growth coniferous forests (Nelson 1997). Nest branches are usually high above ground, often averaging 40+ m above ground (Hamer and Nelson 1995). Nesting at such heights may be sufficient to minimize or isolate the nest from the potential impact of ground disturbances (but see Hamer and Nelson 1998). Therefore, literature on the sources and effects of human-caused disturbance on ground nesting seabirds and other colonial waterbirds (Pierce and Simons 1986, Piatt et al. 1990; Lyngs 1994, Brown and Morris 1995, Burger and Gochfeld 1999, Carney and Sydeman 1999) are of limited relevance to Marbled Murrelets.

Over the last 30-50 years, Marbled Murrelet populations have declined as a result of habitat loss (see Perry 1995) resulting from the harvest of old growth coniferous forests (Carter and Erickson 1992, Rodway et al. 1992, Carter and Kuletz 1995, Kelson et al. 1995), as well as other anthropogenic disturbances (Carter and Sealy 1982, Sealy and Carter 1984, Carter and Morrison 1992). Consequently, the Marbled Murrelet was listed as endangered in

California in 1992 (Larsen 1991, Calif. Fish and Game Comm. 1992). Later, the populations in Washington, Oregon, and California all received federal listing as threatened (US Fish and Wildlife Service 1992) from the Endangered Species Act.

In accordance with the Endangered Species Act, the U.S. Fish and Wildlife Service constructed the Marbled Murrelet Recovery Plan (US Fish and Wildlife Service 1997) to promote the survival and recovery of Marbled Murrelet populations in California, Oregon and Washington. Several procedures have been implemented to reduce human-related disturbances at Marbled Murrelet nests, including: a) scheduling the timing of human-caused disturbances in nesting habitat to occur outside the breeding season, b) reducing the level of direct disturbance of nests by human presence during the breeding season, c) reducing the numbers of nest predators (i.e., mainly corvids) in areas with human disturbance during the breeding season, and d) reducing the unnatural attraction of predators to specific forest areas (with human disturbance) during the breeding season (U. S. Fish and Wildlife Service, 1997).

In northern California, the largest population segment of Marbled Murrelets is associated with Redwood National and State Parks (hereafter RNSP) in northern Humboldt County (Ralph and Miller 1995). As such, management in RNSP (Humboldt and Del Norte Counties, California), in accordance with the Marbled Murrelet Recovery Plan (U. S. Fish and Wildlife Service 1997) and Section 7 of the Endangered Species Act, has attempted to reduce human-caused disturbance in five categories: noise pollution; visual human disturbance; predator numbers to natural levels; predator attraction; and air pollution (RNSP General Management Plan 2000). To comply effectively with the Marbled Murrelet Recovery Plan (U. S. Fish and Wildlife 1997), management of RNSP needed to determine whether Marbled Murrelets on nests respond to human disturbance associated with the

maintenance and use of public trails, and any accompanying visual or auditory disturbance. If murrelets respond negatively (i.e. change in behavior, abandon egg or chick) to disturbances associated with the use and maintenance of trails, or disturbance from highway intrusions, then changes in park management and park use may be required. Further, the rate of disturbance on the productivity of Marbled Murrelets will allow informed decisions on priorities that effect conservation.

For several avian species, human activities can cause adult birds to leave their nests unattended, exposing eggs and chicks to nest predators and also expose adult birds to predation (Ellison and Cleary 1978, Fetterolf 1983, Hamer and Nelson 1998). This risk of predation to birds is exacerbated when noise pollution resulting from anthropogenic activities also attracts nest predators such as corvids (Gotmark 1992, Gutzwiller et al. 2002). Further, indirect consequences of disturbance can include increased time in vigilant behavior and higher levels of energy expenditure (Stillman and Goss-Custard 2002, Peters and Otis 2005).

Minimizing nest disturbance is a prudent conservation effort, especially for species at risk of extinction (Long and Ralph 1998). Although it is known that Marbled Murrelet adults and chicks can be disturbed by auditory and visual stimuli (Hamer and Nelson 1998), there is very little specific data available on the response of murrelets to anthropogenic disturbances. Most research in old-growth forests between 1987 and 2000 had not addressed directly the potential impacts of human-caused disturbance on breeding Marbled Murrelets (Nelson and Sealy 1995, Nelson 1997). Although murrelets have nested near campgrounds and other areas of high human use (e.g., near park amphitheaters), the success of these nests were not known (E. Burkett, pers. comm.). The lack of data relating nest success to anthropogenic

disturbance makes it difficult to develop appropriate protective measures that can improve the conservation of Marbled Murrelets.

The issue of human disturbance is compounded further by fragmentation of nesting habitat. Studies have shown that habitat fragmentation, and intrusions by roads and trails cause changes in the faunal community (Sakai 1988). For example, there can be an increase in the number of predators, such as Steller's Jay (*Cyanocitta stelleri*) that occur along forest edges (George and Brand 2002). The increase in the number of predators is thought to be responsible for the decrease in reproductive success for birds that occupy fragmented habitats (George and Brand 2002, Manolis et al. 2002). Further, reproductive success can be affected negatively by human disturbance associated with specific human intrusions such as trails or roads (Van der Zande 1980, Miller et al. 1998). Thus, habitat fragmentation results in loss of habitat and the edges associated with this fragmentation compound the negative impact of deterministic events (such as anthropogenic disturbance) in the remaining habitat.

Greater knowledge of the behavioral responses of Marbled Murrelet adults and chicks to various forms of human disturbance or related predator actions, would allow managers to evaluate possible strategies to reduce certain types of human disturbance during the breeding season. Such strategies could allow for other park activities to occur without direct impacts to murrelets, and minimize the potential impact of predators on murrelet nest success. The purpose of our study was to examine the effect of human-related noise pollution, visual human disturbance, and their influence on predator attraction. Results from this study will also have useful insights for managers of road systems or other anthropogenic activities in similar old-growth forest settings.

METHODS

CAPTURE

We captured Marbled Murrelets in the coastal waters of northern California between Big Lagoon and Gold Bluffs Beach (N 41.186: W 124.135 and N 41.388: W 124.062, respectively; 2001 – 2003), and in Trinidad Bay (N 41.069: W 124.171; 2002). Capture occurred between 2100h and 0400h, using the night-lighting and dip net technique (Whitworth et al. 1997). Capture crews, equipped with high intensity spotlights and a long-handled dip net, searched near-shore waters (within 5 km of shore) in two 4.5-m inflatable boats. A third 4.5-m inflatable boat served as a transport boat, and a safety/backup boat. Captured Marbled Murrelets were transported, inside plastic tubs with lids, from the capture boat to a larger boat (or pier in Trinidad Bay) to collect data on morphology, attach radio-transmitters, and collect blood samples (hereafter handling process). Birds captured between Big Lagoon and Gold Bluffs Beach were processed on either the Humboldt State University research vessel *Coral Sea* (in 2001 - 2003), or a chartered 15-m fishing-trawler (in 2002 and 2003).

HANDLING PROCESS

We first examined murrelets for the presence of a brood patch. When present, brood patches were scored using the scale developed by Sealy (1974). Murrelets with a brood patch were examined using ultrasound to assess their reproductive status. In addition, we measured mass (g) using a 300-g Pesola spring scale, as well as bill length and depth (mm), and flattened wing chord length using dial calipers. Each murrelet was then banded with a U.S. Geological Survey stainless steel leg band. To each Marbled Murrelet captured, we attached a 2-g radio-transmitter with a unique frequency (Model BD-2G, Holohil Systems

Ltd., Ontario Canada) using a subcutaneous anchor (Mauser and Jarvis 1991), following the procedure described by Newman et al. (1999). A sub-sample of murrelets was sedated with Isoflurane prior to radio-attachment to assess the technique (Appendix A). Following attachment of the radio-transmitter we attempted to collect 1.5 - 2.0 ml of blood for analysis of reproductive hormones and for sex determination from genomic DNA using the methods outlined by Griffiths et al. (1996, 1998). After radio-attachment and blood collection, murrelets were returned to the plastic holding tubs for approximately 20 min, after which they were transported to their capture-site and hand-released onto the water. We observed the murrelets for normal behavior for approximately 30 seconds, or as deemed appropriate based on the behavior of the bird. All birds exhibited normal behavior (flying, diving, preening) when released.

LOCATION OF NEST TREES

Locations of radio-marked birds in forests (and at sea; Chapter 3) were determined from fixed-wing aircraft (Cessna 182 or 185). Aircraft were equipped with a receiver (model R4000, Advanced Telemetry Systems, Inc., Isanti, Minnesota) and either a 2-element H-antenna or a single-element omni-directional antenna. Locations of radio-marked Marbled Murrelets were established using a global positioning system (GPS) and aerial telemetry procedures (Gilmer et al., 1981, Whitworth et al. 2000a, b).

In 2001, the first aircraft flight occurred on 13 April (the morning after the first capture session) and the last flight occurred on 19 August. In 2002, the first flight occurred on 13 April and the last flight occurred on 28 August. In 2003, the first flight occurred on 17 April and the last flight occurred on 11 August. Flights were conducted between 0800h and

2030h. The departure time and length of the flight depended on the weather, location of birds, and number of birds to be located.

A bird detected inland after 0800h was considered to have initiated nesting. Once a potential nest initiation had been indicated by aircraft telemetry, we began a ground search for the nest tree using an ATS receiver (Model R4000) and a 2-element H-antenna (Model RA-2A, Telonics, Mesa, Arizona). When a tree or trees had been identified as a potential nest site we subsequently conducted early morning observational surveys (see Paton et al. 1990) to identify the specific nest tree used by the radio-marked Marbled Murrelet. A nest tree was identified when a murrelet was observed landing in a suspected nest tree, and the strength of the radio signal coincided with the arrival of a bird at that tree. An investigator then ascended an adjacent tree to confirm the location of the nest site.

HUMAN DISTURBANCE AT NEST TREES

Human disturbance within Marbled Murrelet nesting habitat can include human activity on trails and roads that intrude into nesting habitat. We assessed the effects, if any, of such human intrusions on Marbled Murrelet behavior and nesting success in several ways. Specifically, we examined the potential effects of auditory and visual stimuli from humans on the ground in proximity to nests, as well as proximity of nests to trails and roads, and to human activity on trails. Further, we used the height above ground as a measure of distance from the disturbance source.

Tree and Nest Height.--The extent to which ground sources of disturbance, such as trail users, influenced Marbled Murrelet nesting success may be related to nest-site and nest-tree characteristics and the exposure to visual stimuli. We measured tree height (m) and the height of the nest platform (m), after the breeding season, using a clinometer and

trigonometric equations (Van Pelt 2001). These heights were used as estimates of potential for disturbance from visual stimuli.

We also determined visibility to the ground from the nest platform by having a tree-climber at the nest site count the number of whole and partially (half) obscured 25 x 25-cm squares visible on a 100 x 50-cm board (Figure 1-1). This visibility board was held approximately 25 m from the base of the nest tree, and 0.5 m from the ground. We measured visibility at each of the four cardinal directions, and averaged the four measures of visibility for each nest tree. Visibility scores greater than 4 (max 8) indicate more open undergrowth and a more open canopy below the nest platform, whereas visibility scores less than 4 indicate more dense undergrowth and a more closed sub-canopy. Visibility from the nest platform was used as another estimate of potential for disturbance from visual stimuli.

Auditory Stimuli.--Marbled Murrelet nest site selection and nesting success may also be influenced by auditory stimuli associated with trail users or vehicular traffic on nearby roads. To determine if ambient sound levels influenced nest site selection, or hatching success by Marbled Murrelets, we recorded ambient sound levels at randomly chosen sites (2002, $n = 10$; 2003, $n = 12$) in RNSP that contained old-growth coniferous trees. Sound levels were measured using a calibrated, digital Type 1 sound level meter (Model 407750, Extech, Waltham, MA) on a tripod approximately 1 m from the ground (configured for 'A' weighting, fast response, with windscreen). Measurements were obtained at the sites in the absence of fog and with winds less than 5 m/sec (Hendricks 1998). At each site we measured sound levels five times, which were averaged for each site. We also recorded ambient sound levels at each nest site after the breeding season (2002 and 2003).

Proximity to Trails and Roads.--We examined the potential effects of trail users and vehicular traffic on Marbled Murrelet reproductive success by determining the proximity of nests to park trails and paved highways. We determined the distance of a nest tree to a trail or paved road using a Geographical Information System (ArcView ver 3.3; ESRI, Redlands, California). We plotted nest tree locations on a map of RNSP that included trails and roads (U. S. Fish and Wildlife Service, Arcata, California; Figure 1-2). Using the “Distance” tool in ArcView, we determined the distance of a nest site to the nearest trail (± 1 m) and nearest road (± 10 m). We compared the proximity to trails and roads between nests with successful hatching and nests that failed prior to hatching. We performed separate analyses for nest tree locations obtained only from aircraft telemetry (larger sample size), and for locations obtained for nest trees that were identified to the specific nest tree (exact locations). The latter, however, were also used in the experimental sessions (see below), and thus analyses may be biased by potential experimental error. We also caution that nest tree locations obtained by aircraft telemetry were only estimates (although unbiased relative to roads or trails).

Trail Activity.--In addition to proximity to a trail, potential disturbance may be a function of the amount of activity on a trail. To determine if the amount of trail activity influenced nesting success, we integrated trail activity (number of trail users per day) and trail proximity. We divided the distance from a nest to a trail by the average daily number of trail users. Trail user data were available for the four trails that were nearest to Marbled Murrelet nest trees. Activity on Redwood Creek Trail was measured in 2001 and 2002 using an active infrared beam. The raw data were divided by 2 to account for visitor entrance and exit. In 2003, trail activity was monitored using a magnetic car counter placed next to the

road leading to the trailhead. The numbers of cars were multiplied by a “persons per vehicle” summertime average of 2.7 persons per car and then divided by 2 (for entrance and exit). It was unknown how far visitors traveled on the trails. For purposes of categorizing trail activity, we counted the number of people using the trail as a relative measure of user activity.

At Lost Man Creek Trail, activity was measured by a magnetic car counter in the roadway just before the parking lot at the end of the road and manipulated as described above. At Orick Horse Trail, activity was measured using an active infrared beam and divided by 2. At Davison Grove Trail, activity was measured in 2003 by counting the number of trail users observed on a continuous recording video camera.

For each trail we averaged trail activity for all years and months, by day. To integrate trail activity and proximity to trail, we indexed trail activity by dividing the daily average trail users into the distance to nearest trail. The resulting number was then multiplied by 100 to yield a User Disturbance Index (UDI). Small UDI values are indicative of nest trees that are closer to trails with high trail activity, whereas larger UDI values are indicative of trees that are farther from high use trails, and thus should experience less disturbance.

Trail Activity and Murrelet Behavior.--In 2003 we placed a miniature video-camera (PC106C Weatherproof C-Mount Monochrome Video Camera, Supercircuits, Liberty Hill, TX), prior to nesting, at a nest site that was used in 2001 and 2002 (Appendix B). This nest tree was located 25 m from an adjacent trail. A second camera was directed towards this adjacent trail. Both the nest tree and trail cameras were linked, by cable, to a signal splitter (QS18 Mini 12/24 Volt Monochrome Quad Processor, Supercircuits, Liberty Hill, TX) located on the forest floor approximately 50 m from the base of the nest tree. The signal was

then routed to a time-lapse VCR (ST-960N, Supercircuits, Liberty Hill, TX). The resulting recording produced time synchronized images from the nest site and the trail. Videotapes were reviewed on another time-lapse VCR, equipped with slow-motion playback capability, connected to a monitor. We recorded the duration (± 1 sec) of all murrelet behaviors (each behavior category was mutually exclusive of other categories). For example, if a bird raised its head, and 5 seconds later raised its bill, timing of the head raised behavior stopped, regardless of whether or not the head continued to be raised, for the duration of the raised bill behavior.

To examine the effect, if any, of the presence of trail users on the behavior of Marbled Murrelet adults or chicks, we compared murrelet behavior before, during, and after trail users had passed by the nest tree. Each individual or group of individuals was considered a single disturbance event. For analyses, we set the disturbance period to include the 3-min period prior to the arrival of the trail user(s) and the 3-min period following the departure of the trail user(s) (Figure 1-3). The pre-disturbance period was the 6-min interval prior to the 6-min disturbance period. That is, between 9 and 3 min before the trail user(s) had been observed in front of the trail camera. Likewise, a 6-min post-disturbance period included the time interval between 3 and 9 min after the disturbance period (Figure 1-3). During each trail disturbance event, the behavior of the Marbled Murrelet adult or chick was recorded (± 1 sec). We calculated the proportion of time adults and chicks spent exhibiting each behavior for each time period (i.e. pre-disturbance, disturbance, post-disturbance).

EXPERIMENTAL TEST OF HUMAN DISTURBANCE

Experimental Disturbance of Adults and Chicks.--We assessed the effects, if any, of trail maintenance activities on the behavior and nesting success of Marbled Murrelets. We

experimentally examined the effects of human disturbance on Marbled Murrelet adults and chicks at the nest by exposing the nests to the sound of an operating chainsaw (Model 288, Husqvarna, Sweden).

Before starting the chainsaw, a crew of four to five people slowly walked to the nest tree while talking at a normal level, beginning a conversation at least 125 m from the nest tree, and continuing to within 25 m from the nest tree. Once at the site they continued talking at normal levels for the remainder of the protocol to test the effect of the operating chainsaw.

To test the effects of the operating chainsaw on the adult or chick, a tree-climber equipped with a video camera (PV-L681-VHS, Panasonic, Secaucus, NJ) ascended an adjacent tree to a position that allowed a view of the nest. A period 5 min after the climber was positioned in the tree allowed for the test bird to acclimate to the presence of the tree climber. Then video recording began for an initial 30-min pre-disturbance period. After the pre-disturbance period, the chainsaw was started and operated for a 15-min disturbance period. To mimic trail maintenance activities the chainsaw was operated alternately at full throttle, half throttle and at idle. The disturbance period was followed by a 30-min post-disturbance period with no chainsaw in operation. Videotapes were analyzed as described above for trail disturbance. For each bird we calculated the average proportion of time a behavior occurred during each of the periods (pre-disturbance period, disturbance period, and post-disturbance period). For the purposes of analysis we used only those behaviors where the total time the behavior was displayed made up greater than 1% of the total time of the disturbance period.

We also recorded sound levels (dB) at 3 m from the base of the nest tree during each experimental period, using equipment described previously. For each pre-disturbance,

disturbance, and post-disturbance periods, we repeated sound measurements five times and then averaged the observations for analysis.

Corvids.--During the experimental sessions, we attempted to assess corvid behavior and how human activity may alter the potential risk of predation on Marbled Murrelets. We conducted visual and auditory surveys during each of the pre-disturbance, disturbance, and post-disturbance periods, in 2002 and 2003. Visual surveys were conducted from a point 25 m from the nest tree. The observer recorded all visual observations, and attempted not to count the same individuals more than once (during each period). Auditory surveys were conducted at 75-100 m from the nest tree, and approximately 100-125 m from the operating chainsaw. This distance was used to minimize the effect of the operating chainsaw on the observers ability to detect a vocalizing corvid during the disturbance period. The observer recorded all auditory detections of corvids, but also made an effort not to count the same individuals more than once.

NESTING SUCCESS

We calculated three measures of nesting success. First we determined hatching success for control (all nests not exposed to experimental disturbance) and experimental nests. Experimental nests were selected based on our ability to exactly locate nests to conduct experiments. Aircraft telemetry and/or automated telemetry receiving stations (see Chapter 4) located near nests allowed us to detect the typical individual Marbled Murrelet incubation pattern (which consisted of alternating 24 h incubation bouts with 24 h bouts at sea). This allowed us to identify a successful or unsuccessful incubation period at a nest. If the radio-marked bird stopped the ritualized incubation pattern prematurely (complete incubation = 28 days), we considered the nest to have failed during incubation. We

considered hatching to be successful if the radio-marked bird maintained a pattern of alternating 24 h incubation bouts with 24 h bouts at sea for at least 27 days. We present hatching success as the number of eggs that hatched successfully as a proportion of the number of nesting attempts. Nesting attempts included re-nesting attempts (if after nest-failure, a bird was again detected inland, and sufficient time had elapsed for a new egg to be formed and laid, we considered this a re-nest; see Hébert et al. 2003).

Secondly, we determined fledging success for nests where hatching had been successful. Fledging success at exactly located nest sites was determined directly when a post-breeding season tree-climber found a full fecal cup impregnated with down feathers, or when video observation confirmed the fledging fate. For nest-sites that were not exactly located, we used data gathered from ground-based telemetry. We considered a chick to have fledged if the radio-marked bird was detected inland after 1800h, at least once, when the chick was at least 25 days old. Previous studies (Hébert et al. 2003) have determined that murrelets continue to visit nest sites even after nesting has failed (see Chapter 4, Appendix B). However, in such instances, visits to the nest site are limited to the early morning. Thus we used the above criterion to distinguish between murrelet visits to failed nest sites and visits for feeding chicks. Fledging success was the number of fledglings produced as a proportion of the number of eggs that successfully hatched.

Finally, we determined overall reproductive success, calculated as the number of chicks fledged per nesting attempt. Given that we could not determine the outcome of some nests due to failure of the radio-transmitter or insufficient radio-telemetry data, we calculated minimum reproductive success (known outcomes only) and maximum reproductive success (we assumed nests of unknown fates were all successful).

STATISTICAL ANALYSES

All statistical analyses were performed using SPSS software (ver. 11.5, SPSS corp, Chicago, IL). We used logistic regression to determine if nest tree/nest platform height, visibility, and ambient sound levels influenced hatching success. We used logistic regression to determine if the User Disturbance Index influenced hatching success. Finally, to determine if ambient sound levels influenced nest-site selection we compared average sound levels at the random sites with ambient sound levels recorded at the nest sites using 2-tailed t-tests. To minimize pseudo-replication issues, we averaged the daily proportion of time a murrelet exhibited each behavior when multiple disturbance events occurred on the same day.

We compared the proportion of time each behavior occurred within each period and between periods (i.e. pre-disturbance, disturbance, post-disturbance) with analysis of variance, to examine the potential effects of experimental disturbance on murrelet adults and chicks. When analysis of variance indicated a significant effect, we made a post-hoc analysis using a Least Significant Difference (LSD) multi-comparison test to determine which periods were different. We also used bivariate correlation analysis (Pearson's 2-tailed) to determine if the proportion of time a behavior was displayed was correlated with nest and platform height, and visibility from the nest platform. We compared corvid numbers between periods using a χ^2 analysis. Given that the duration of the disturbance period was half as long as that of the pre and post-disturbance periods, expected values for the χ^2 analyses were adjusted accordingly. Finally, Fisher's Exact Test was used to compare hatching and fledging success between control and experimental nests.

RESULTS

CAPTURE AND HANDLING PROCESS

A total of 102 Marbled Murrelets were captured and had radio transmitters attached during the three years. In 2001 we captured Marbled Murrelets in coastal waters adjacent to RNSP, primarily between Big Lagoon and Gold Bluffs Beach, California (Table 1-1). In 2002 we captured Marbled Murrelets near Trinidad Bay and in coastal waters between Big Lagoon and Gold Bluffs Beach, California. In 2003 we captured murrelets in coastal waters between Big Lagoon and Gold Bluffs Beach, California.

We measured mass, culmen length, bill depth, flat-wing chord, and brood patch score of Marbled Murrelets during the handling process of captured murrelets in 2001, 2002, and 2003 (Table 1-2). Handling of birds averaged approximately one hour (Table 1-2).

EFFECTS OF HUMAN DISTURBANCE AT NEST TREES

Tree and Nest Height.--Tree and nest heights could only be calculated for nests whose location was exactly known. In 2001, the one tree that was exactly located was 87 m tall, and the nest platform was 73 m high. This nest successfully fledged. In 2002, the mean height of trees with nests that successfully hatched was 57.1 ± 7.5 ($\bar{x} \pm \text{SE}$) m ($n = 5$) compared to 65.9 m ($n = 1$) for the tree with a nest that did not successfully hatch. Height of nests that successfully hatched was 47.6 ± 4.5 m ($n = 5$) compared to 34.3 m ($n = 1$) for the nest that did not successfully hatch. In 2003, the height of the tree with the nest that successfully hatched was 56.6 m ($n = 1$) compared to 50.8 ± 9.2 ($n = 2$) for nests that did not successfully hatch ($n = 2$). The height of the nest that successfully hatched was 44.6 m, and the height of nests that did not successfully hatch was 47.1 ± 7.9 m ($n = 2$).

When the data were combined across years, the height of trees with nests that successfully hatched (61 ± 7 m, $n=7$) was similar to that of trees with nests that did not successfully hatch (56 ± 7 m, $n=3$; Logistic Regression, $P > 0.60$). Nest height for nests that successfully hatched (51 ± 5 m; $n=7$) was similar to that of nests that did not successfully hatch (43 ± 6 , $n=3$; Logistic Regression, $P > 0.3$). Tree and nest height were not statistically significant between years ($P > 0.1$ for both comparisons).

Mean visibility to the ground from nest platforms, when the data were combined across years, was 1.3 ± 0.5 squares ($n=10$). Nests that successfully hatched tended to have a lower mean visibility to the ground compared to nests that did not successfully hatch, but this difference was not statistically significant (Logistic Regression; $P > 0.4$; Table 1-3).

Auditory Stimuli.--Ambient sound levels at randomly chosen sites in RNSP averaged 40.9 ± 0.9 dB ($n=10$) in 2002, and 43.3 ± 1.6 dB ($n=12$) in 2003. The mean ambient sound level at nest sites was 44.4 dB ($n=1$) in 2001, 44.8 ± 2.2 dB ($n=6$) in 2002, and 46.0 ± 5.6 dB ($n=3$) in 2003. When the data were combined across years, mean ambient sound levels at random sites in the park (42.2 ± 0.9 dB; $n=22$) were similar to those recorded at nest sites (46.6 ± 2.4 dB, $n=10$, ANOVA, $P > 0.9$). Sound levels at nests that successfully hatched were similar to sound levels at nests that did not successfully hatch (Logistic Regression, $P > 0.3$; Table 1-3).

Proximity to Trails and Roads-Aircraft Telemetry.--In 2001, five nests were initiated, based on nest tree locations derived from aircraft telemetry. Nests that successfully hatched averaged slightly more distant from the nearest trail than nests that did not successfully hatch (Table 1-4). Conversely, nests that successfully hatched were slightly closer to the nearest paved road than nests that did not successfully hatch (Table 1-4).

In 2002, 19 nests were initiated. Data for one bird were omitted due to transmitter failure during the incubation period. Nests that successfully hatched averaged a greater distance from trails than nests that did not successfully hatch (Table 1-4). Nests that successfully hatched and those that did not successfully hatch were similar distances from the nearest paved road (Table 1-4).

In 2003, eight nests were initiated. The single nest that successfully hatched was a similar distance from the nearest trail as nests that did not successfully hatch (Table 1-4). The nest that successfully hatched was further from the nearest paved road than those that did not successfully hatch (Table 1-4). When all nests in all years were combined, neither distance to nearest trail nor distance to nearest paved road was a significant predictor of hatching success (Table 1-3).

In 2001, the User Disturbance Index was 1.4 ± 0.9 ($n = 3$) for nests that successfully hatched compared to 0.5 ± 0.3 ($n = 2$) for nests that did not successfully hatch. In 2002, nests that successfully hatched had a User Disturbance Index of 1.7 ± 0.5 ($n = 6$) compared to 3.7 ± 3.0 ($n = 9$) for nests that did not successfully hatch. In 2003, the User Disturbance Index for the nest that successfully hatched was 0.5 ($n = 1$), and 15.7 ± 15.3 ($n = 4$) for the nests that did not successfully hatch. When the data were combined across years, User Disturbance Index was not a significant predictor of hatching success (Table 1-3).

Proximity to Trails and Roads-Ground Telemetry (Exact Locations).--In 2001 only one nest tree was exactly located. The chick at this nest was exposed to the sound of an operating chainsaw when it was 28 days old and fledged two days later. This nest-tree was closer to the nearest trail than it was to the nearest paved road (Table 1-4).

In 2002, six nest trees were exactly located. The five nests that successfully hatched were farther from the nearest trail than the single nest that did not successfully hatch (Table 1-4). Nests that successfully hatched were closer to the nearest paved road, than the nest that did not successfully hatch (Table 1-4).

In 2003, we exactly located three nest trees. The single nest-tree that successfully hatched was much closer to the nearest trail and to the nearest paved road than the nest-trees that did not successfully hatch (Table 1-4). When exact nest locations were used and the data were combined across years, distance from the nearest trail and distance from the nearest paved road were not significant predictors of hatching success (Table 1-3).

Trail Activity.--Based on user activity at four trails (Table 1-5), we were able to examine murrelet response to trail activity. Incubating adult murrelets at the one nest for which we were able to measure responses to trail activity, were exposed to 11 instances of trail activity on five separate days. Adult murrelets exhibited six different behaviors (Table 1-6). Only two of these behaviors (rest, turn head) were exhibited at least 1% of the time during trail disturbance. On average, the adult murrelets spent significantly more time at rest than any other behavior during the pre-disturbance period (95%, $t = 18.3$, $df = 8$, $P < 0.001$), the disturbance period (99%, $t = 105.7$, $df = 8$, $P < 0.001$), and the post-disturbance period (98%, $t = 53.9$, $df = 8$, $P < 0.001$). Also, the proportion of time the incubating adults spent at rest was similar ($P > 0.2$) before, during, and after trail activity (Table 1-7).

For the chick in the same nest described above, 47 instances of trail activity were used for the analysis and they occurred on 19 different days. The chick exhibited nine different behaviors (Table 1-6), of which three (rest, preen, shuffle) were exhibited at least 1% of the time when the trail was used by people. For the pre-disturbance, disturbance, and

post-disturbance periods the proportion of time the chick exhibited each behavior was significantly different (ANOVA, $F_{2,54} = 130.7$, $P < 0.001$; ANOVA, $F_{2,54} = 99.7$, $P < 0.001$; ANOVA, $F_{2,54} = 82.4$, $P < 0.001$; respectively). Specifically, the chick spent more time at rest compared to other behaviors during the pre-disturbance, disturbance, and post-disturbance periods (LSD, $P < 0.001$; LSD, $P < 0.001$; LSD, $P < 0.001$; respectively; Table 1-8). The proportion of time the chick spent at rest was similar ($P > 0.9$) for the periods before, during and after the presence of trail users (Table 1-8).

EXPERIMENTAL HUMAN DISTURBANCE

For all years combined, a total of 18 experimental sessions were conducted, all of which occurred between 1500h and 1900h. At four different nests, seven adults were tested in 2002, of which, video-recordings from a disturbance period for one adult from 2002 were not sufficiently clear to allow accurate data collection. Another six adults from three different nests were tested in 2003. In 2001, one chick was tested, three chicks were tested in 2002, and another chick was tested in 2003. Video-recordings from the disturbance period for the chick from 2003 were not sufficiently clear to allow accurate data collection. None of the adults or chicks flushed during the disturbance periods. Overall, 24 different behaviors were identified, 11 of which were observed both in chicks and adults, three only in adults, and 10 only in chicks (Table 1-9).

Sound Levels During Experimental Sessions.--Ambient sound levels recorded during the pre-disturbance and post-disturbance periods of experimental sessions on Marbled Murrelet adults and chicks were less than 50 dB ('session low'; Table 1-10). During the disturbance period, sound levels exceeded 65 dB when the chainsaw was at full throttle ('session high'; Table 1-10).

During the 2002 and 2003 experimental sessions on adults, the mean sound levels during the pre and post-disturbance period at the base of nest trees were similar (ANOVA, $P > 0.4$; ANOVA, $P > 0.3$; respectively) to those recorded at random sites in the park (Table 1-10). When the data were combined across years, with year and site (base of nest tree vs. random sites) as variables, mean ambient sound levels recorded during the pre and post-disturbance periods were similar to those recorded at random sites in the park (ANOVA, $P > 0.3$).

In 2002 and 2003 sound levels during the pre-disturbance, disturbance, and post-disturbance periods differed significantly ($F_{2,15} = 38.3$, $P < 0.001$; $F_{2,15} = 107$, $P < 0.001$; respectively; Table 1-10). Sound levels recorded in both 2002 and 2003, at the base of the nest tree were significantly higher during the disturbance period when the chainsaw was running compared to the pre (LSD, $P < 0.001$; LSD, $P < 0.001$; respectively) and post-disturbance periods (LSD, $P < 0.001$; LSD, $P < 0.001$; respectively; Table 1-10). When the data are combined across years, ambient sound levels at the base of the nest tree differed significantly between the pre-disturbance, disturbance, and post-disturbance periods (2-Factor ANOVA; Experimental Period, $F_{2,30} = 109.0$, $P < 0.001$; Year, $F_{1,30} = 6.2$, $P < 0.02$). Sound levels during the disturbance period were significantly higher than those recorded during the pre-disturbance period (LSD, $P < 0.001$) and the post-disturbance period (LSD, $P < 0.001$; Table 1-10). Sound levels also differed between the disturbance period in 2002 and the disturbance period in 2003 (ANOVA, $F_{1,10} = 8.6$, $P = 0.02$; Table 1-10).

For disturbance experiments on chicks, which only occurred in 2002, sound levels during the pre and post-disturbance periods were significantly different from and significantly higher than sound levels recorded at random sites in the park (ANOVA, $F_{2,15} =$

6.5, $P < 0.01$; LSD, $P < 0.05$ for both comparisons; respectively; Table 1-10). Sound levels were also significantly different between disturbance periods (ANOVA, $F_{2,9} = 48.7$, $P < 0.001$). Sound levels during the disturbance period were significantly higher compared to the pre-disturbance period (LSD, $P < 0.05$) and the post-disturbance period (LSD, $P < 0.05$; Table 1-10).

Experimental Disturbance of Adults.--In 2002, the average day into incubation that the adults were tested was 16 d (range 5 – 24 days). We identified five behaviors that represented $> 1\%$ of the time during the experimental period (rest, raise head, turn head, bill up, and tail pump). Tail pumping was not detected in 2003, and thus was not included in subsequent analyses. Overall, the behaviors included in the analyses represented 95% of the proportion of recorded time during the pre-disturbance period, 96% for the disturbance period, and 95% for the post-disturbance period (Table 1-11).

In 2002, during the pre and post-disturbance periods, adults spent a significantly different proportion of time in each behavior (ANOVA, $F_{3,20} = 471$, $P < 0.001$; ANOVA, $F_{3,20} = 1396$, $P < 0.001$; respectively) and adults spent more time at rest than any other behavior during the pre and post-disturbance periods (LSD, $P < 0.001$ for both periods; for all comparisons; Table 1-11). During the disturbance period, adults spent a statistically similar proportion of time displaying each behavior (ANOVA, $P = 0.19$).

Between experimental periods in 2002, there were significant differences in the amount of time adults spent at rest (ANOVA, $F_{2,15} = 8.52$, $P = 0.003$). They spent more time at rest during the pre and post-disturbance periods compared to the disturbance period (LSD, $P < 0.05$ for both comparisons; Table 1-11). Also, there was a tendency for the proportion of time adults spent with their heads raised to vary between experimental periods

(ANOVA, $F_{2,15} = 3.16$, $P = 0.07$), and they spent less time with their heads raised during the pre and post-disturbance periods compared to the disturbance period (LSD, $P < 0.05$ for both comparisons; Table 1-11).

In 2003, the average day into incubation that the adults were tested was 18 d (range 10 – 22 days). We identified four behaviors that represented $> 1\%$ of the time during the experimental period and were thus included in the analyses (rest, raise head, turn head, and bill up). These behaviors represented 95 % of the proportion of recorded time during the pre-disturbance period, 96% for the disturbance period, and 95% for the post-disturbance period (Table 1-11).

In 2003, during the pre and post-disturbance periods, adults spent a significantly different proportion of time performing each behavior (ANOVA, $F_{3,20} = 32.9$, $P < 0.001$; ANOVA, $F_{3,20} = 609$, $P < 0.001$; respectively). They spent more time at rest than any other behavior during the pre and post-disturbance periods (LSD, $P < 0.001$; for all comparisons; Table 1-11). During the disturbance period, there was a tendency for adults to spend a different proportion of time displaying each behavior (ANOVA, $F_{3,20} = 2.2$, $P = 0.12$). Adults spent a significantly greater proportion of time at rest than performing ‘Turn Head’ or ‘Raise Head’ (LSD, $P < 0.03$; Table 1-11). There was also a tendency for adults to spend more time at rest compared to ‘Bill Up’, and this difference approached significance (LSD, $P = 0.08$).

Between experimental periods in 2003, there was a significant difference in the amount of time adults spent at rest (ANOVA, $F_{2,15} = 4.2$, $P = 0.03$). They spent more time at rest during the pre and post-disturbance periods compared to the disturbance period (LSD,

$P < 0.03$ for both comparisons; Table 1-11). All other behaviors lacked any statistical trends between the different experimental periods.

When the data were combined across years, within the pre-disturbance, disturbance, and post-disturbance periods, adults spent a significantly different amount of time exhibiting each behavior (ANOVA, $F_{3,40} = 1978$, $P < 0.001$; ANOVA, $F_{3,40} = 3.9$, $P < 0.05$; ANOVA, $F_{3,40} = 1691$, $P < 0.001$; respectively; Table 1-12). During the pre-disturbance period, adults spent significantly more time at rest compared to other behaviors (LSD, $P < 0.001$ for all comparisons). During the disturbance period, adults spent significantly more time at rest compared to 'Bill Up' (LSD, $P < 0.01$), and 'Turn Head' (LSD, $P < 0.001$). There was also a tendency for adults to spend more time at rest compared to the proportion of time they exhibited 'Raise Head' (LSD, $P = 0.076$; Table 1-12). During the post-disturbance period, adults spent significantly more time at rest compared to Bill Up and Turn Head (LSD, $P < 0.001$ for both comparisons). However, the amount of time spent at rest was similar to the amount of time spent with Head Raised (LSD, $P > 0.10$; Table 1-12).

Between experimental periods, adults spent a significantly different proportion of time at rest (ANOVA, $F_{2,30} = 11.9$, $P < 0.001$; Table 1-12). This difference resulted from adults spending significantly less time at rest during the disturbance period compared to the pre-disturbance period (LSD, $P < 0.001$) and the post-disturbance period (LSD, $P < 0.001$). There was also a significant difference between experimental periods in the proportion of time adults spent displaying 'Raise Head' (ANOVA, $F_{2,30} = 5.5$, $P = 0.01$). Adults spent a significantly greater proportion of time performing 'Raise Head' during the disturbance period compared to the pre and post-disturbance periods (LSD, $P < 0.01$ for both comparisons).

Finally, we also stratified behavior for male and female adult murrelets during the disturbance periods to examine differences by gender (Table 1-13). Both male and females spent a similar proportion of time performing each behavior during each of the experimental periods ($P > 0.10$ for all comparisons).

Experimental Disturbance of Chicks.--The four chicks used in the analyses were approximately 12, 20, 24, and 28 days of age. Of the 22 behaviors exhibited by chicks (Table 1-6), only six were displayed more than 1% of the time during the experimental periods. The six behaviors represented 95 % of the proportion of recorded time during the pre-disturbance period, 96% for the disturbance period, and 95% for the post-disturbance period (Table 1-14).

During the pre-disturbance, disturbance, and post-disturbance periods, chicks spent a significantly different proportion of time in each behavior (ANOVA, $F_{5,18} = 42.4$, $P < 0.001$; ANOVA, $F_{5,18} = 6.3$, $P < 0.001$; ANOVA, $F_{5,18} = 471.8$, $P < 0.001$; respectively), spending a significantly greater proportion of time at rest than any other behavior (LSD, $P < 0.001$; LSD, $P < 0.001$; LSD, $P < 0.001$; respectively; Table 1-14). Comparisons between other behaviors were not significantly different. Between the three periods, there was no difference in the amount of time chicks spent at rest ($P > 0.5$; Table 1-14).

In 2002 and 2003, the proportion of time adults spent at rest was not correlated with visibility from the nest ($r = 0.33$, $n = 6$, $P = 0.53$ for both years), or with nest height ($r = 0.39$, $n = 6$, $P = 0.44$ for both years). The proportion of time each chick spent at rest during the disturbance period was not correlated with average visibility from the nest site ($r = -0.60$, $n = 4$, $P > 0.40$) or with nest height ($r = 0.83$, $n = 4$, $P > 0.15$).

Corvids.--We detected four species of corvids during the visual and auditory surveys: Common Raven (*Corvus corax*), American Crow (*C. brachyrhynchos*), Stellar's Jay and Gray Jay (*Perisoreus canadensis*). During the adult disturbance periods, when the data were combined across years, there were fewer visual detections of corvids during the pre-disturbance and disturbance periods compared to the post-disturbance period, but this difference was not significant ($P > 0.20$; Table 1-15). The number of auditory detections of corvids also did not significantly differ between the pre-disturbance, disturbance and post-disturbance periods ($P = 0.22$; Table 1-15).

NESTING SUCCESS

Control Nests.--Six nesting attempts in 2001 (including a re-nesting attempt) were assigned to the control group to determine hatching success. Of these, three failed during the incubation period. Hatching success, for these six nesting attempts was 50%. In 2002, 17 nesting attempts were assigned to the control group, including one re-nesting attempt (see Chapter 2). One radio-marked murrelet tending a control nest was known to have lost its transmitter during incubation, and was thus excluded from the analysis. Hatching success for the remaining nesting attempts was 43.7% (7/16). In 2003, eight nesting attempts were assigned to the control group, including one re-nesting attempt (see Chapter 2). Hatching success at these nests was 25% (2/8).

When the data were combined across years, there were a total of 30 nesting attempts classified as controls for determining hatching success. Excluding one egg, for which the fate was unknown, hatching success for the three years was 40% (12/30).

For five control nests that successfully hatched between 2001 and 2003, fledging success was 40% (2/5). If nests with unknown outcomes were considered as successful and included as controls, maximum fledging success for nine nests would have been 56% (5/9).

Experimental Nests.--Adult Marbled Murrelets were exposed to the sound of an operating chainsaw in 2002 (four nesting attempts) and 2003 (both adults of each of three nesting attempts). Hatching was successful at three (75%) of these nesting attempts in 2002. In 2003 hatching success could not be determined at one of the experimental nests. Hatching success at the remaining two nesting attempts was 50%. For both years combined, hatching success at nests where the adults were exposed to the sound of an operating chainsaw was 66.7% (4/6).

Using only data for 2002 and 2003, hatching success at control nests (9/23; 39.1%) was similar to hatching success at experimental disturbance nests (4/6; 66.7%) (FEPT = 0.36).

All seven nests that were tended by adults exposed to the sound of an operating chainsaw failed to produce a fledging. Conversely, all three nests where only the chick was tested produced a fledging. Overall reproductive success at nests where the adults or chicks were exposed to the sound of an operating chainsaw was 30% (3/10).

When control and experimental nests were compared over both years, control nests were successful at fledging a chick in 9.5% (2/21) of the attempts, whereas nests where either the adult(s) and/or chick were exposed to an operating chainsaw were successful at fledging a chick in 30% (3/10) of the attempts. This difference was not statistically significant (Fisher's Exact Test, $P > 0.3$).

In our design, experimental nests were designated later in the incubation period than control nests. To avoid any potential bias associated with temporal variations in hatching success (see Chapter 2), we stratified data from the last 12 days of the incubation period for control nests for comparison with experimental nests. Thus a revised hatching success at control nests with known outcomes was 69.1% (9/13) compared to experimental nests that were 67% successful (4/6; Fisher's Exact Test, $P = 1.0$). At control nests that hatched a chick, the fledging success was 33.3% (2/6) (excluding nests with unknown outcomes). Finally, if we included nests with unknown outcomes into these previous data we can calculate a minimum success by assuming all unknown outcomes were failures or a maximum by assuming all unknown nests were successful. Minimum nesting success at control nests was then 25% (2/8) and maximum nesting success was then 50% (4/8). Fledging success at control nests (with known outcomes) and experimental nests was not significantly different (Fisher's Exact Test, $P = 1$). Maximum fledging success (includes nests with unknown outcomes as successful) at control nests was also not significantly different from fledging success at experimental nests (Fisher's Exact Test, $P = 0.1$).

DISCUSSION

Many studies have examined the effects of human disturbance on avian productivity (see reviews by Burger 1981, Gotmark 1992, Carney and Sydeman 1999). Human disturbance can have a negative effect on reproductive success, either as a direct consequence on the behavior of the birds (see review by Burger 1981), or indirectly by increasing the risk of predation by conspecifics (e.g. Fetterolf 1983, Brown and Morris 1995) or by other species (Kury and Gochfield 1975, Anderson and Keith 1980). Of all the taxa for which human disturbance has been documented to reduce reproductive success (Bart 1977,

Anderson and Keith 1980, Cairns 1980, Ollason and Dunnet 1980, Gotmark and Ahlund 1984, White and Thurow 1985, Knapton et al. 2000), ground nesting colonial birds and alcids appear to be especially susceptible to nest failure (Gotmark 1992; but see Fraser et al. 1999). For example, studies on Ancient Murrelets (*Synthliboramphus antiquus*; Sealy 1976), Least Auklets (*Aethia pusilla*; Piatt et al. 1990), and Atlantic Puffins (*Fratercula arctica*; Rodway et al. 1996) show that nest visits by researchers, particularly early in incubation, often lead to nest desertion.

Unlike other alcids, however, Marbled Murrelets are not ground or burrow nesters, but rather are arboreal nesters, nesting in the upper canopy of old-growth coniferous forests (Nelson 1997). Thus, insights gained in other studies of the effects of human visitation to nest sites may not provide insight into the impacts of disturbance on Marbled Murrelets in coastal California. Our goal was to provide insight into the ways in which human activity affects Marbled Murrelets.

EFFECTS OF HUMAN DISTURBANCE AT NEST TREES

Proximity to Trails and Roads.--Trail users in recreational settings can cause adults and young of several avian species to flush (Gutzwiller et al. 1997, Miller et al. 1998, Swarthout and Steidl 2001), influence courtship patterns (Miller et al. 1998) and nesting success (White and Thurow 1985). Increased disturbance caused by trail users or roads may influence avian nesting success. Avian species richness and reproductive success can be influenced by the level of pedestrian activity (Van der Zande and Vos 1984, Fernandez-Juric 2000). Unlike these studies, we did not detect any case where Marbled Murrelets flushed, nor did we detect a statistically significant relationship between Marbled Murrelet nesting success and proximity to trails or roads.

Using nest locations determined from aircraft and from exactly located nests verified with ground telemetry for comparison of hatching success, it was determined that nests that successfully hatched young were located at similar distances from trails and roads as nests that did not hatch young. Singer et al. (1995) reported similar findings, observing separate nesting attempts by Marbled Murrelets; he reported that a nest in a tree immediately adjacent to a trail and a nest in a tree 69 m from a paved road both produced hatching.

Noise levels associated with highway traffic differ with the type of highway surface (Hanson et al. 2004), and thus may have different disturbance effects on nesting murrelets. However, a recent study detected a difference of only 4 dB between various road surface types (Hansen et al. 2004). Also, sound intensity generated by tires on paved road surface diminishes by 6 dB at a distance of only 10 – 20 m. In our study area, the sound disturbance was generated mostly by larger trucks using engine-retarder brakes to reduced their speeds, the noise associated with the condition of the road (shaking of load), and engine sounds. Thus we concluded that road-surface type did not affect the level of noise disturbance experienced by nesting murrelets. However, the amount of traffic is greater during the breeding season with the influx of tourists (especially along Highway 101), and this may create greater variation in disturbance than the road surface type. Finally, it is possible that we were unable to detect an effect of highway-related noise and murrelet nesting success because the murrelets avoid nesting sites closer to the highways. We caution that our assessment of highway noise cannot be extrapolated to other sites without careful consideration of all variables affecting noise transmission, because local topographic characteristics may alter the intensity of noise disturbance arising from vehicular traffic (Hanson et al. 2004).

It is important to note that road density was relatively low within the study area. Highway 101 was the only contiguous north-south route and carried a variety of traffic, including logging trucks and tourist vehicles. Traffic volume was greatest coincidental with murrelet nesting. Results were probably representative of roads in and around RNSP, but should be applied cautiously in areas with differing terrain or traffic volume.

Trails and roads represent both a source of disturbance and potential changes in “edge” habitat or fragmentation. More edge can cause failed nests that result from higher predation (Robinson et al. 1995, George and Brand 2002, Manolis et al. 2002). The relationship between proximity to edge and Marbled Murrelet nesting success are unclear. Bradley (2002) did not detect a relationship between murrelet nesting success and proximity to an edge. Unlike our study, Bradley (2002) used natural edges (creek, etc) in addition to roads and trails. Conversely, Nelson and Hamer (1995) observed that successful nests were located farther from unnatural forest edges than were unsuccessful nests. However, they also reported that one Marbled Murrelet pair that nested in a tree less than 10 m from a paved highway and produced a fledgling.

Trail activity could cause disturbance to murrelets in at least four ways. First, the activity on the trail could induce a change in the behavior of the murrelet at the nest, which could then attract a predator. Secondly, trail activity may attract (through noise, visual clues, or association with food) murrelet nest predators such as corvids, and thus increase the likelihood that the predator will find the murrelet nest. Third, trail activity may cause an incubating murrelet to flush from the nest, or perhaps even a chick to flush from the nest. Lastly, increased vigilance or non-resting behaviors can increase energetic expenditures or decrease food deliveries such that energetic costs exceed energy supply. Our data from a

single nest site in 2003 (see Table 1-7, 1-8) indicated that trail use does not appear to influence the behavior of murrelet adults or chicks on the nest. The amount of time murrelet adults and the chick spent at rest was similar for the periods before, during, and after trail users went past the nest tree. Our User Disturbance Index was actually higher for successful nests than it was for unsuccessful nests. That is, successful nests tended to be located in trees that were closer to trails with high trail activity compared to unsuccessful nests. Further, one of our nest sites was located in a tree that was 25 m from a trail, and less than 200 m from a highway with heavy traffic and has been used in five consecutive years (see Appendix B). This nest produced two fledglings (2001, 2003). However, two nesting attempts also failed due to predation by corvids (2002, 2004), and predation by corvids is suspected in the third failed nesting attempt (2005; see Appendix B, D). These observations might be explained by the fact that trails purposely exploit the most desirable (in human terms) old growth stands, and thus may be closer than random to trees most used by murrelets.

Finally, the lack of a relationship between distance to the nearest paved road and nesting success may be due to the scale of the distance measurement itself. The average distance to the nearest paved road for unsuccessful nests, based on aircraft locations, was approximately 1.6 km. These aircraft locations were potentially in error by 747 m (SD = 737; see Chapter 3). This error is many times greater than the 10 m distance for the successful nest observed by Hamer and Nelson (1998) in Washington. Thus, we may not have had the necessary resolution to detect differences in distance. However, our measurements of ambient sound levels at random sites in the park were similar to ambient sound levels recorded at the base of nest trees. Our results, and the observations made by

Hamer and Nelson (1998), suggest that in some instances vehicular traffic noise may have little or no effect on Marbled Murrelet nesting success.

EXPERIMENTAL HUMAN DISTURBANCE

Experimental Disturbance of Adults and Chicks.--Flushing is a common response to human disturbance in many forest dwelling birds (e.g. Northern Spotted Owl, *Strix occidentalis lucida*; Swarthout and Steidl 2001). However, adult Marbled Murrelets exposed to an operating chainsaw did not flush from the nest. The cost of flight for Marbled Murrelets is relatively higher compared to other birds and flushing may not be an energetically viable response for incubating murrelets (Hull et al. 2001). Marbled Murrelets have evolved several mechanisms to avoid predation (Nelson 1997); they have cryptic coloration, are silent around the nest, minimize movement at the nest, and limit incubation exchanges and chick feeding to occur during twilight hours (Nelson 1997). Thus, flushing, as a result of a disturbance or activity on the ground, might not provide a benefit compared to the potential risks or costs.

The behavior of adult Marbled Murrelets at the nest did change when exposed to an operating chainsaw on the ground. During the pre and post-disturbance periods, adults spent significantly more time at rest than any other behavior (Table 1-12). However, during the disturbance period, adults spent more time in other behaviors than they did resting and spent significantly less time at rest (approximately half as much time resting). Conversely, there were increases in the proportion of time adults spent with their heads raised, and their bill up during the disturbance period, compared to the pre and post-disturbance periods. The relevance of behaviors such as, 'raised head' and 'bill up', are at present unknown, but may

be associated with vigilance behavior as these were seen immediately prior to video-recorded visits by a predator to a nesting adult (Appendix F).

When undisturbed (during the pre and post-disturbance periods) adult Marbled Murrelets spent 95% of their time at rest or near motionless. Remaining motionless combined with the marbled coloration of the dorsal plumage has been thought to represent an anti-predation strategy (Nelson 1997). Interestingly, Delaney et al. (1999) also observed a significant increase in head movements of adult Mexican Spotted Owls exposed to an operating chainsaw as compared to pre and post-disturbance periods. Delaney et al. (1999) interpreted these movements as alert responses resulting directly from the disturbance. As with Marbled Murrelet adults exposed to an operating chainsaw, adult Mexican Spotted Owls returned to pre-disturbance behavior within minutes of termination of the disturbance period. Together, these observations on adult Marbled Murrelets and Mexican Spotted Owls suggest that noise disturbance during 10 – 15 minute disturbance periods, at a distance > 25 m, does not induce long-term behavioral changes.

Chicks exposed to an operating chainsaw did not flush from the nest. Similarly, Swarthout and Steidl (2001) observed that juvenile Mexican Spotted Owls were less likely to flush compared to adult spotted owls. Nevertheless, Marbled Murrelet chicks did exhibit some behavioral responses to the operating chainsaw. Chicks, like adults, exhibited the ‘raised head’ and ‘bill up’ behaviors more commonly during the disturbance period, although compared to before or after, this relationship was not statistically significant. That both of these behaviors were exhibited by adults and chicks during the disturbance period, suggests that the ‘raised head’ and ‘bill up’ behaviors may be responses to the sound of the operating chainsaw.

Although no long term behaviors changed, it is possible that protracted anthropogenic noise might produce short term behaviors that have unknown consequences. There is potential that these behaviors could compromise the cryptic situation at the nest. If a murrelet responded to an inappropriate noise stimulus, this might facilitate observation by a predator and expose the nest at that, or a later time to predation. Additionally, the energetic cost of increased vigilance to protracted disturbance, or especially disturbances that occurred coincidental in time with food delivering could have negative consequences and needs further assessment. Additional flight time by adults delivering food would have significant energetic cost, as flight in birds is one of their most expensive endeavors (Tucker 1969).

NESTING SUCCESS

Hatching success at control nests in 2002 and 2003 (39.1%) tended to be lower compared to nests with experimental disturbance (66.7%). These results, however, were possibly biased by how nests were assigned to the experimental or control categories, and caution is necessary in their interpretation. Given the difficulty in finding nests, and the need to ensure adequate sample size for the experimental sessions, we had to assign all nests that were located to the exact tree to the experimental group. Consequently, if a nest failed prior to being found, it would have been assigned to the control group. Including only data for control nests that did not fail in the first two weeks, hatching success (69.2%; 9/13) was similar to that of experimental nests (66.7%).

Nests tended by adult murrelets that were exposed to an operating chainsaw did not fledge any young. The relationship, if any, between the disturbance periods during the incubation period, and fledging success was unclear. Overall reproductive success was similar for control (13%) and experimental nests (30%). In contrast to our study, a similar

study on the Mexican Spotted Owl by Delaney et al. (1999) did not detect a difference in the reproductive success of experimental nests (exposure to an operating chainsaw) and control nests. The contrast in results for murrelets and owls is likely due to the differences in biology. Adult murrelets, eggs, and chicks are all potential prey for a variety of predators (Nelson and Hamer 1995a). By contrast, the Mexican Spotted Owl may have fewer predators, and thus reproductive success is possibly not as influenced by predation, as it is in Marbled Murrelets.

Other studies of disturbance on alcids have noted that disturbance during the period that chicks are present is less likely to cause nesting failure (Rodway et al. 1996, and references therein). Our results were consistent with this finding. It must be cautioned, however, that we exposed chicks to an operating chainsaw in the late afternoon, when feedings were unlikely. Adult Marbled Murrelets typically feed their chicks in the early morning, and occasionally in the evening. Operating chainsaws while an adult approaches a nest to feed a chick may cause sufficient disturbance to result in abortion or delay of the feeding. The abortion of a single feeding trip could deprive the chick of 25-50% of its daily energy and water intake, which could potentially have a significant negative impact on fledging success.

CORVIDS

The relationship between human activities and predators, and their potential impact on murrelet nesting success was addressed by the Marbled Murrelet Recovery Plan (Section C, 1.4; 2.3.1; 3.1.3). Predators can be attracted to human presence and human-related noise (Miller et al. 1998), and human provisioning of artificial food resources (e.g., creating accessible garbage; Marzluff et al. 1994). These factors could lead to a local increase in

predator density (either absolute abundance or in concentration of activity), and increase the potential risk of murrelets being detected by predators. This in turn can alter the distribution of murrelets and other birds. In addition, there is evidence that forest fragmentation promotes increases in corvid densities (Andren 1992) which are known to prey on murrelet eggs and chicks (Singer et al. 1991, Nelson and Hamer 1995a, Appendix D). This is particularly relevant to murrelets that occupy fragmented old-growth forest habitats.

During the disturbance period the presence of corvids in the vicinity of the nest-tree did not change. Most of the corvids we observed were Steller's Jays, and these birds are territorial. Thus, although additional jays may have been attracted to the disturbance, territoriality may have prevented them from approaching the specific site. However, we must caution that we did not monitor jay behavior. Only short term changes could have been detected. Further, it is unlikely that our methodology could have detected alterations in behavior of predators during disturbance that might increase risk (e.g. greater likelihood of a predator detecting a murrelet).

CONCLUSION

There may be both proximate and ultimate effects of human disturbance on Marbled Murrelet nesting success. Disturbance resulting from proximity to a trail or road, or the activity associated with such intrusions appears to be negligible, at least in RNSP. Mitigation in the form of reducing access to trails within the parks appears unwarranted at the level of trail use which occurred in 2001-2003. However, given the established link between human use of trails and campgrounds, increases in campground use or trail use might affect corvid densities (George and Brand 2002), and we encourage continued efforts to reduce anthropogenic support of corvid populations.

Adult murrelets exposed to the sound of an operating chainsaw altered their behavior, usually extending their necks and raising their heads. Although hatching success was relatively high (71.4%) compared to control nests (40%), many adult murrelets exposed to an operating chainsaw ultimately experienced complete nest failure. Marbled Murrelet chicks exposed to the sound of an operating chainsaw also altered their behavior, in a manner similar to that of adult murrelets. However, fledging was still 100% at nests where only the chicks were exposed to the sound of an operating chainsaw. Based on these results, we recommend avoiding extended disturbance to incubating (see Chapter 2 on chronology of nesting) Marbled Murrelet adults and any disturbance to chicks at the time of food delivery, either early morning or late evening when feeding is most likely (P. N. Hébert and R. T. Golightly, unpublished data; Nelson 1997).

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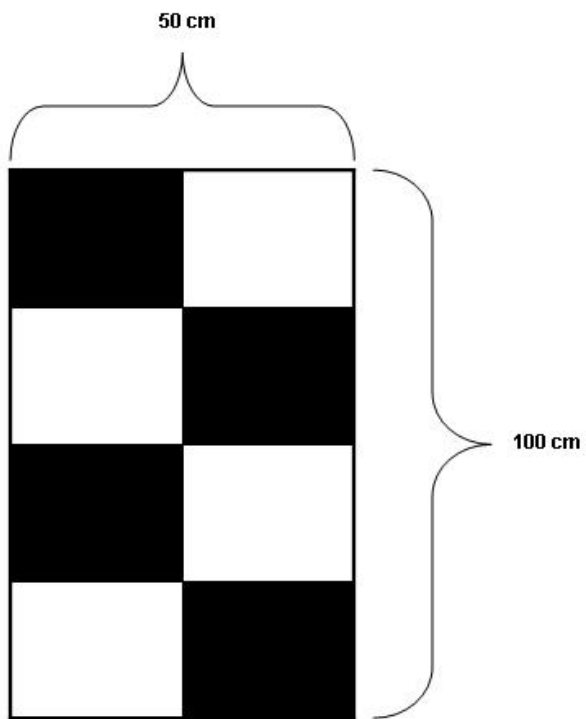


FIGURE 1-1. Illustration of visibility board used to estimate visibility from a Marbled Murrelet nest site to the ground.

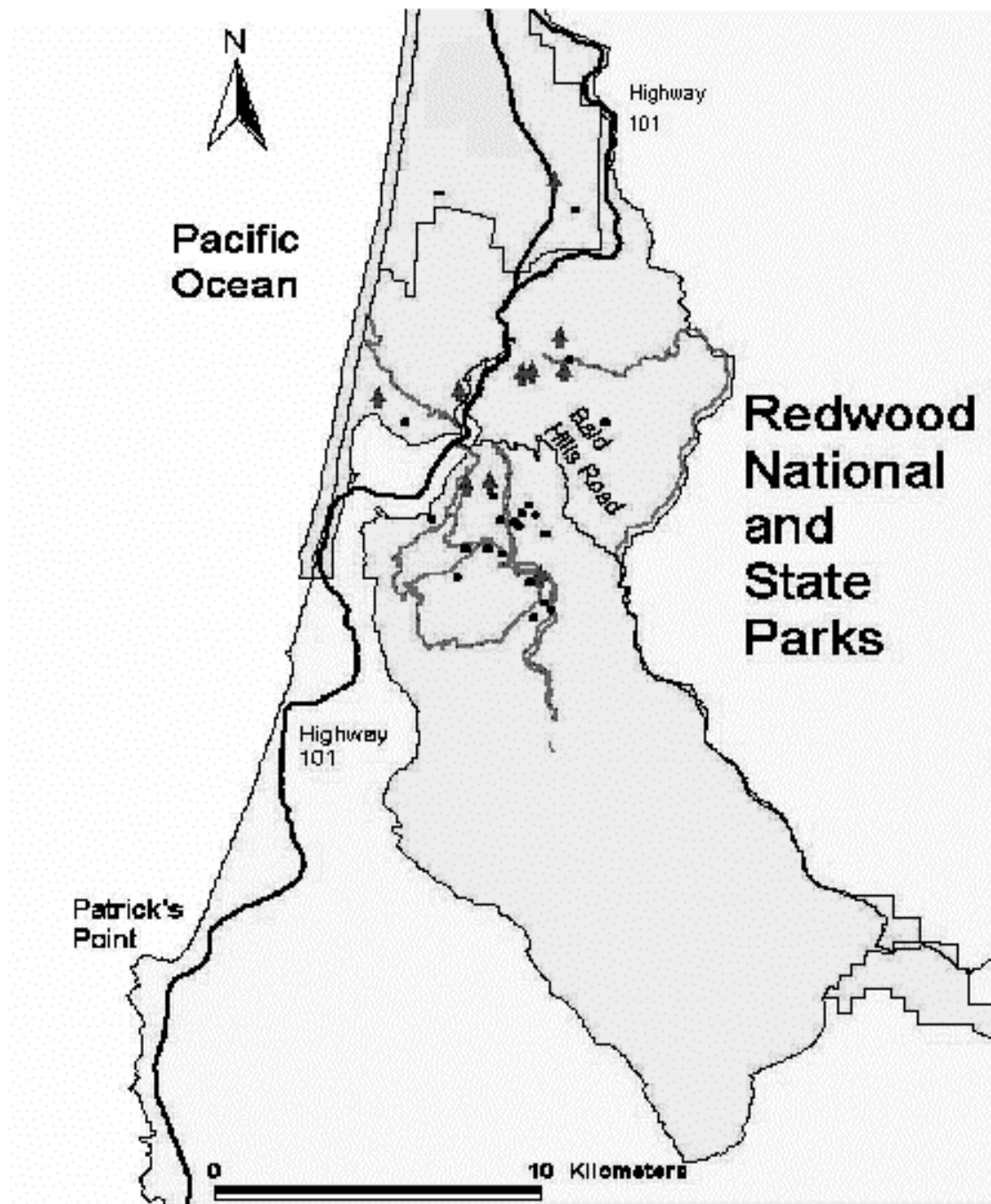


FIGURE 1-2. Locations of Marbled Murrelet nests relative to trails (solid grey lines) and paved roads (solid black lines) in Redwood National and State Parks. Trees that were located exactly are indicated by small trees. Locations for trees from aircraft telemetry are indicated by solid circles.

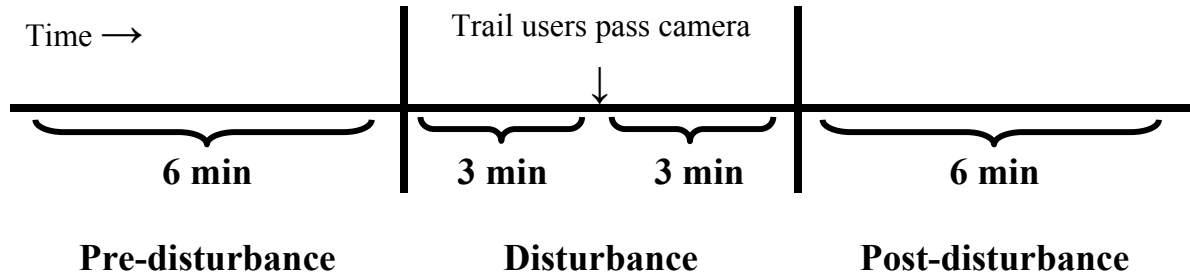


FIGURE 1-3. Diagrammatic representation of disturbance periods used to assess effect of trail activity on Marbled Murrelet adult and chick behavior in Redwood National and State Parks, California in 2003.

TABLE 1-1. Number of Marbled Murrelets captured during each night of capture operation, in two locations off the coast of Redwood National and State Parks, California from 2001 - 2003.

	2001				2002				2003				
	April			May	April	May			April		May		
	13	24	25	13	13	1	17	21	16	30	1	11	12
Gold Bluffs Beach/Big Lagoon	5	7	4	7		9	23	9	6	13	8	6	5
Trinidad Beach					3								
Yearly Total				23				44					38

TABLE 1-2. Morphometric measurements of captured Marbled Murrelets in Redwood National and State Parks, California from 2001 – 2003.

	2001		2002		2003	
	$\bar{x} \pm \text{SE}$	n	$\bar{x} \pm \text{SE}$	n	$\bar{x} \pm \text{SE}$	n
Measurements						
Mass (g)	216.0 ± 4.0	22	219.0 ± 4.0	44	215.0 ± 3.0	38
Bill Depth (mm)	6.1 ± 0.1	23	6.4 ± 0.1	44	6.2 ± 0.1	38
Culmen Length (mm)	18.8 ± 0.2	23	17.7 ± 0.2	44	17.9 ± 0.2	38
Flat-wing Chord Length (mm)	125.0 ± 0.8	23	122.4 ± 0.6	44	123.5 ± 0.7	37
Brood Patch Score	1.6 ± 0.3	23	1.8 ± 0.2	44	1.2 ± 0.2	38
Time released after capture (min)	73.2 ± 3.2	23	69.0 ± 3.1	44	69.7 ± 4.0	34

TABLE 1-3. Comparison of nest-site/tree characteristics between nests that successfully hatched and those that did not successfully hatch. Data for aircraft locations are for control nests only. Ground locations include experimental nests. Data are combined across years (2001 – 2003).

	Hatching Success		Hatching Failure		<i>P</i> ¹
	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n	
From Aircraft					
Distance to Trail (km)	0.58 \pm 0.1	11	0.36 \pm 0.1	16	0.25
Distance to Road (km)	1.7 \pm 0.3	11	1.7 \pm 0.2	16	0.65
User Disturbance Index	1.5 \pm 0.4	9	6.4 \pm 4.3	15	0.48
From Ground					
Distance to Trail (km)	0.46 \pm 0.2	7	0.32 \pm 0.2	3	0.56
Distance to Road (km)	1.12 \pm 0.3	7	1.70 \pm 0.3	3	0.18
Visibility (from nest platform)	1.0 \pm 0.5	7	1.9 \pm 1.1	3	0.4
Ambient Sound (dB) (at nest platform)	48.0 \pm 2.6	7	43.4 \pm 5.8	3	0.37

¹ Logistic Regression

TABLE 1-4. Distances (km) from Marbled Murrelet nest-trees to nearest trails and roads from aircraft telemetry and exactly located sites using ground telemetry in Redwood National and State Parks, California from 2001 – 2003.

	2001				2002				2003			
	Hatching Success		Hatching Failure		Hatching Success		Hatching Failure		Hatching Success		Hatching Failure	
	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n
Located from Aircraft												
Distance to Trail	0.36 ± 0.2	3	0.27 ± 0.2	2	0.71 ± 0.2	7	0.41 ± 0.2	9	0.29	1	0.29 ± 0.1	5
Distance to Road	1.31 ± 0.4	3	1.59 ± 0.2	2	1.70 ± 0.3	7	1.70 ± 0.2	9	2.9 ± 1.2	1	1.70 ± 0.3	5
Located from Ground												
Distance to Trail	0.02	1			0.50 ± 0.01	5	0.14	1	0.04	1	0.35 ± 0.2	2
Distance to Road	0.52	1			1.50 ± 0.30	5	1.9	1	0.2	1	1.60 ± 0.1	2

TABLE 1-5. Average daily trail activity (number of people present) for 4 trails in Redwood National and State Parks, California. ‘Days’ refers to total number of days observed.

Month	Trail							
	Davison Grove		Redwood Creek		Lost Man Creek		Orick Horse	
	People	Days	People	Days	People	Days	People	Days
April	0	4	803	30	1026	30	0	30
May	52	14	2362	31	1232	31	7	31
June	60	27	245	30	1933	30	68	30
July	13	3	3987	31	1366	31	75	31
Daily Average	2.6		60.6		45.5		1.2	

TABLE 1-6. List of behaviors exhibited (+) by Marbled Murrelet adults and chick during activity on nearby trail in Redwood National and State Parks, California in 2003.

Activity	Adult	Chick
Rest	+	+
Turn head	+	
Raise head	+	
Shuffle	+	+
Head shake	+	+
Wing flutter	+	+
Body shake		+
Preen		+
Peck		+
Neck stretch		+
Defecate		+

TABLE 1-7. Mean (\pm SE) proportion of time two Marbled Murrelet adults displayed behaviors during pre-disturbance (6 min), disturbance (6 min) and post-disturbance (6 min) periods associated with trail activity on a nearby trail (< 25 m) in Redwood National and State Parks, California in 2003. Behaviors listed had average proportions of at least 1% during the disturbance period. Proportions were averaged during a five day period.

Activity	Experimental Period		
	Pre-Disturbance	Disturbance	Post-Disturbance
	$\bar{x} \pm \text{SE}$	$\bar{x} \pm \text{SE}$	$\bar{x} \pm \text{SE}$
Rest	0.91 ± 0.05	0.99 ± 0.01	0.98 ± 0.02
Turn Head	0.02 ± 0.02	0.01 ± 0.01	0

TABLE 1-8. Mean (\pm SE) proportion of time a Marbled Murrelet chick displayed behaviors during pre-disturbance (6 min), disturbance (6 min) and post-disturbance (6 min) periods associated with trail user activity on a nearby trail (< 25 m) in Redwood National and State Parks, California in 2003. Behaviors listed had average proportions of at least 1% during the disturbance period.

Activity	Pre-Disturbance	Disturbance	Post-Disturbance
	$\bar{x} \pm \text{SE}$	$\bar{x} \pm \text{SE}$	$\bar{x} \pm \text{SE}$
Rest	0.82 ± 0.05	0.82 ± 0.05	0.83 ± 0.06
Preen	0.08 ± 0.03	0.10 ± 0.05	0.06 ± 0.03
Shuffle	0.07 ± 0.03	0.07 ± 0.02	0.09 ± 0.05

TABLE 1-9. List of behaviors exhibited (+) by
Marbled Murrelet adults and chicks
during experimental disturbance
sessions.

Activity	Adult	Chick
Rest	+	+
Turn head	+	+
Raise head	+	+
Shuffle	+	+
Head shake	+	+
Wing flutter	+	+
Head nod	+	
Wing flick	+	
Body shake	+	+
Bill open	+	+
Bill snap	+	+
Bill up	+	+
Tail pump	+	+
Yawn	+	
Preen		+
Peck		+
Neck stretch		+
Tail shake		+
Wing stretch		+
Bob head		+
Stand		+
Wing flap		+
Scratch		+
Defecate		+

TABLE 1-10. Sound levels (dB) recorded at base of nest trees before, during, and after disturbance experiments conducted in 2002 ($n = 6$) and 2003 ($n = 6$) in Redwood National and State Parks, California. Pre-disturbance and post-disturbance measurements are for ambient sound levels. Session lows occurred when a chainsaw was at idle 25 m from the base of the nest tree. Session highs occurred when a chainsaw was at full throttle 25 m from the base of the nest tree. Values followed by the same superscripted letter are statistically similar within the same year ($P > 0.05$).

Age	Year	Experimental Period			
		Random Locations	Pre-Disturbance	Disturbance	Post-Disturbance
		$\bar{x} \pm \text{SE}$	$\bar{x} \pm \text{SE}$	$\bar{x} \pm \text{SE}$	$\bar{x} \pm \text{SE}$
Adult	2002	40.9 ± 1.0^a ($n = 10$)	44.3 ± 3.1^a	72.2 ± 1.5	44.0 ± 3.1^a
	2003	43.3 ± 1.6^b ($n = 12$)	40.0 ± 2.1^b	66.6 ± 1.2	41.1 ± 0.8^b
Chick	2002		46.2 ± 5.0^c	72.1 ± 6.8^c	45.0 ± 1.8^c

TABLE 1-11. Mean (\pm SE) proportion of time Marbled Murrelet adults displayed behaviors during pre-disturbance (30 min), disturbance (15 min) and post-disturbance (30 min) periods of experimental sessions conducted in 2002 ($n = 6$) and 2003 ($n = 6$) in Redwood National and State Parks, California. Behaviors listed had average proportions of at least 1% during the disturbance period.

Activity	Pre-Disturbance		Disturbance		Post-Disturbance	
	2002	2003	2002	2003	2002	2003
	$\bar{x} \pm \text{SE}$	$\bar{x} \pm \text{SE}$	$\bar{x} \pm \text{SE}$	$\bar{x} \pm \text{SE}$	$\bar{x} \pm \text{SE}$	$\bar{x} \pm \text{SE}$
Rest	0.95 ± 0.3	0.99 ± 0.0	0.45 ± 0.2	0.56 ± 0.2	0.95 ± 0.0	0.96 ± 0.0
Raise head	0.01 ± 0.0	0	0.28 ± 0.1	0.26 ± 0.2	0.01 ± 0.0	0.01 ± 0.0
Turn head	0.03 ± 0.0	0	0.05 ± 0.0	0.02 ± 0.0	0.01 ± 0.0	0.02 ± 0.0
Bill up	0	0	0.14 ± 0.1	0.16 ± 0.2	0.02 ± 0.0	0.01 ± 0.0
Total observation time (min)	166.7	141.9	85.4	83	166.7	154

TABLE 1-12. Average proportion of time Marbled Murrelet adults displayed behaviors during pre-disturbance (30 min), disturbance (15 min) and post-disturbance (30 min) periods of experimental sessions. Data are combined for 2002 ($n = 6$) and 2003 ($n = 6$) in Redwood National and State Parks, California. Behaviors listed had average proportions of at least 1% during the disturbance period.

	Pre-Disturbance	Disturbance	Post-Disturbance
Rest	0.97	0.5	0.96
Raise head	< 0.01	0.27	0.01
Tail pump	0	0.04	< 0.01
Turn head	0.02	0.04	0.01
Bill up	0	0.15	0.01

TABLE 1-13. Proportion of time male ($n = 6$) and female ($n = 5$) Marbled Murrelet adults displayed behaviors during pre-disturbance (30 min), disturbance (15 min) and post-disturbance (30 min) periods of experimental sessions conducted in 2002 ($n = 6$) and 2003 ($n = 6$) in Redwood National and State Parks, California. Behaviors listed had average proportions of at least 1% during the disturbance period.

Activity	Pre-Disturbance		Disturbance		Post-Disturbance	
	Male	Female	Male	Female	Male	Female
	$\bar{x} \pm \text{SE}$	$\bar{x} \pm \text{SE}$	$\bar{x} \pm \text{SE}$	$\bar{x} \pm \text{SE}$	$\bar{x} \pm \text{SE}$	$\bar{x} \pm \text{SE}$
Rest	0.95 ± 0.03	0.99 ± 0.0	0.43 ± 0.17	0.49 ± 0.22	0.94 ± 0.03	0.98 ± 0.01
Raise head	0.01 ± 0.01	0	0.28 ± 0.15	0.31 ± 0.18	0.02 ± 0.01	0.01 ± 0.01
Turn head	0.03 ± 0.03	< 0.01	0.04 ± 0.03	0.04 ± 0.03	0.03 ± 0.02	0
Bill up	0	0	0.17 ± 0.16	0.16 ± 0.16	0.01 ± 0.01	0.01 ± 0.01

TABLE 1-14. Mean (\pm SE) proportion of time Marbled Murrelet chicks ($n = 4$) displayed behaviors during pre-disturbance (30 min), disturbance (15 min) and post disturbance (30 min) periods of experimental sessions conducted in 2001 ($n = 1$) and 2002 ($n = 3$) in Redwood National and State Parks, California. Behaviors listed had average proportions of at least 1% during the disturbance period.

Activity	Pre-Trial	Trial	Post-Trial
Rest	0.84 ± 0.18	0.66 ± 0.38	0.92 ± 0.08
Preen	0.11 ± 0.18	0.07 ± 0.13	0.02 ± 0.03
Raise Head	0	0.07 ± 0.15	< 0.01
Bill up	0	0.02 ± 0.03	0
Body shake	< 0.01	0.01 ± 0.02	< 0.01

TABLE 1-15. Number of corvids seen and heard during visual and auditory point counts during experimental disturbance sessions of Marbled Murrelet adults and chicks in 2002 in Redwood National and State Parks, California. Visual point counts were conducted at 25 m from the nest tree, and auditory point counts were taken at 100 m from the nest tree.

	n	Experimental Stage		
		Pre-Disturbance	Disturbance ¹	Post-Disturbance
Visual Detections of Corvids				
Adult murrelet sessions	12	2	3	9
Chick murrelet sessions	4	0	0	1
Total		2	3	10
Auditory Detections of Corvids				
Adult murrelet sessions	12	5	4	8
Chick murrelet sessions	4	6	7	5
Total		11	11	13

¹ Values in this column are based on 15 min. observation period. The expected values for χ^2 analyses were weighted accordingly.

CHAPTER 2

BREEDING BIOLOGY OF MARBLED MURRELETS (*BRACHYRAMPHUS MARMORATUS*) NESTING IN REDWOOD NATIONAL AND STATE PARKS, CALIFORNIA

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Wildlife species are increasingly impacted as a result of human activities that erode and modify the ecological systems (Arrow et al. 1995). Species that exhibit delayed sexual maturity and low reproductive potential (k-selected species) are particularly sensitive to habitat modifications and loss (Bell and Merton 2002). Among birds, the auks (family Alcidae) exhibit delayed sexual maturity and low annual reproductive output (all species produce either a single one-egg or two-egg clutch each breeding season; Gaston and Jones 1998). Consequently, if reproduction is severely or repeatedly compromised (e.g. Piatt et al. 1990), it can cause population size to decrease to the point at which the population is more susceptible to extinction as a result of chance environmental or demographic events (Gilpin and Soule 1990, Gabriel and Burger 1992, Lande 1993).

Alcids and other seabirds utilize both the terrestrial and marine environment. The terrestrial environment is used for nesting (Grenier and Nelson 1995, Gaston and Jones 1998, Burger 2002) and the marine environment is used for feeding (e.g. Sealy 1968, Carter and Sealy 1990, Agler et al. 1999, Meyer et al. 2002). Populations can be affected by disturbances in either or both environments. In the terrestrial environment, nesting seabirds can be affected by human disturbance (see Chapter 1, Anderson and Keith 1980, Piatt et al. 1990, Rodway et al. 1996), habitat loss (Kuletz et al. 2003) and predation (Hartman et al. 1997, Gilchrist 1999, Williams et al. 2003). In the marine environment, human-related impacts include incidental mortality in gill-nets (Carter and Sealy 1982, Degagne and Day 1991, Piatt and Gould 1994, Day et al. 1999), longline fishing (Huin and Croxall 1996, Nel et al. 2000) oil spills (e.g. Piatt et al. 1990, Carter et al. 2000) and other forms of marine pollution (Dickerman and Goelet 1987). Further, changes in prey abundance and distribution arising from changes in climactic regimes can alter reproduction (Agler et al. 1999).

The Marbled Murrelet (*Brachyramphus marmoratus*) is a small (200g) seabird of the family Alcidae that has been negatively affected by anthropogenic activities, including oil spills (Carter and Kuletz 1995), gill net fishing (Carter and Sealy 1982), and particularly the loss and fragmentation of their nesting habitat (Carter and Erickson 1992, Perry 1995). Throughout much of their range along the Pacific coast from Alaska to central California, Marbled Murrelets typically nest on branches of old-growth coniferous trees with suitable nesting platforms (branches with a diameter greater than 10 cm; Grenier and Nelson 1995, Jordan and Hughes 1995, Manley and Kelson 1995, Naslund et al. 1995, Nelson 1997, US Fish and Wildlife Service 1997). Over the last 30-50 years Marbled Murrelet populations have declined because of habitat loss (see Perry 1995) resulting from the harvest of old growth coniferous forests (Carter and Erickson 1992, Rodway et al. 1992, Carter and Kuletz 1995, Kelson et al. 1995), as well as other anthropogenic disturbances (Carter and Sealy 1982, Sealy and Carter 1984, Carter and Morrison 1992, Carter et al. 1995). More recent studies have shown that murrelet populations continue to decline (Burger 2002, Strong 2003; but see Miller et al. in press). The Marbled Murrelet was state-listed as endangered in California in 1992 (Larsen 1991, Calif. Fish and Game Comm. 1992). Later, populations in Washington, Oregon, and California were federally-listed as threatened (US Fish and Wildlife Service 1992; see also COSEWIC 2003).

In 1997, the U. S. Fish and Wildlife Service (USFWS) established the Marbled Murrelet Recovery Plan (hereafter recovery plan; USFWS 1997). The recovery of Marbled Murrelet populations would benefit from refined estimates of breeding success or population productivity (USFWS 1997). Recent demographic analyses have suggested that Marbled Murrelet populations, especially in California, Oregon and Washington, may become extinct

within the next 100 years (McShane et al. 2004). However, detailed site specific measures of demographics and productivity have been lacking (Beissinger 1995).

Knowledge of the demographic characteristics of a population and the factors that constrain population growth are important for assessing the extinction risk of rare populations (Beissinger 1995), as well as implementing appropriate conservation and recovery measures (Caughley 1994). For Marbled Murrelets, the systematic collection of data required to elucidate population demographics and data on breeding biology is hampered by several aspects of their nesting biology. Marbled Murrelet nests are difficult to locate and study because 1) Marbled Murrelets typically fly inland to attend nest sites during twilight hours (Nelson and Hamer 1995b), 2) adults are usually silent around the nest (Nelson and Hamer 1995b), and 3) murrelets have cryptic plumage, are small in size (Carter and Stein 1995), and tend to nest in the upper canopy of old-growth coniferous forests (Hamer and Nelson 1995a). Consequently, few nests have been intensively observed and followed, particularly during the 28-30-day incubation period (e.g. Singer et al. 1991, Naslund 1993, Singer et al. 1995), and empirical data required to obtain a statistically valid sample of productivity is lacking. However, recent advances in capture techniques (Kaiser et al. 1995, Whitworth et al. 1997) and refinements of radio-telemetry techniques (Mauser and Jarvis 1991, Newman et al. 1999) have facilitated further study of Marbled Murrelet biology (Hull et al. 2001; Bradley et al. 2002, 2004; Hébert et al. 2003; Peery et al. 2004).

Recent genetic analyses based on blood samples collected from Alaska to central California, indicate that Marbled Murrelet populations in California are distinct from populations in other areas of its range, especially from Alaska and British Columbia (Friesen et al. 2005). Therefore, information on the breeding biology of other Marbled Murrelet

populations, although important, may not be applicable to populations in California. Additionally, Marbled Murrelet populations in California nest in a unique habitat type (redwoods) not found elsewhere in their range. In California, the largest population of Marbled Murrelets is associated with Redwood National and State Parks (hereafter RNSP) in Humboldt and Del Norte counties, northern California (Miller and Ralph 1995, Ralph and Miller 1995, Miller et al. in press).

At present, there are no published accounts of the breeding biology of murrelets nesting in RNSP. We investigated productivity, nesting chronology, egg-laying, incubation, the morphological characteristics of breeding birds and factors that might constrain nesting success and thus reproductive success, as well as adult survivorship of Marbled Murrelets using radio-telemetry techniques.

METHODS

CAPTURE

We captured Marbled Murrelets in the coastal waters of northern California between Big Lagoon and Gold Bluffs Beach (N 41.186: W 124.135 and N 41.388: W 124.062, respectively; in 2001 – 2003), and in Trinidad Bay (N 41.069: W 124.171; in 2002). Capture occurred between 2100h and 0400h, using the night-lighting and dip net technique (Whitworth et al. 1997). Capture crews, equipped with high intensity spotlights and a long-handled dip net, searched near-shore waters (within 5 km of shore) in two 4.5-m inflatable boats. A third 4.5-m inflatable boat served as a transport boat, and a safety/backup boat. Captured Marbled Murrelets were transported, inside plastic tubs with lids, from the capture boat to a larger boat (or pier in Trinidad Bay) to measure morphology, attach radio-transmitters, and collect blood samples (hereafter handling process). Birds captured between

Big Lagoon and Gold Bluffs Beach were processed on either the Humboldt State University research vessel *Coral Sea* (in 2001 - 2003), or a 15-m fishing-trawler (in 2002 and 2003).

HANDLING PROCESS

We first examined murrelets for the presence of a brood patch. When present, brood patches were scored using the scale developed by Sealy (1974). Murrelets with a brood patch were examined using ultrasound to assess their reproductive status (presence of follicles, size of follicles). In addition, we measured mass (g) using a 300-g Pesola spring scale, as well as bill length and depth (mm), and flattened wing chord length using dial calipers. Each murrelet was then banded with a U. S. Geological Survey stainless steel leg band. To each Marbled Murrelet captured, we attached a 2-g radio-transmitter with a unique frequency (Model BD-2G, Holohil Systems Ltd., Ontario Canada) using a subcutaneous anchor (Mauser and Jarvis 1991), following the procedure described by Newman et al. (1999). A sub-sample of murrelets was sedated with Isoflurane prior to radio-attachment to assess the use of anesthesia as a technique for handling murrelets (Appendix A). Following attachment of the radio-transmitter we attempted to collect 1.5 - 2.0 ml of blood for analysis of reproductive hormones and for sex determination from genomic DNA using the methods outlined by Griffiths et al. (1996, 1998). After radio-attachment and blood collection, murrelets were returned to the plastic holding tubs for approximately 20 min, after which they were transported to their capture-site and hand-released onto the water. We observed the murrelets for normal behavior for approximately 30 seconds, or as deemed appropriate based on the behavior of the bird. All birds exhibited normal behavior (flying, diving, preening) when released (for additional details see Appendix A).

LOCATION OF NESTS

Aircraft Telemetry.--Locations of radio-marked birds in forests (and at sea; Chapter 3) were determined from fixed-wing aircraft (Cessna 182 or 185). Aircraft were equipped with a receiver (model R4000, Advanced Telemetry Systems, Inc., Isanti, Minnesota) and either a 2-element H-antenna or a single-element omni-directional antenna. Locations of radio-marked Marbled Murrelets were established using a global positioning system (GPS) and procedures described by Gilmer et al. (1981) and Whitworth et al. (2000a, b).

Flights were conducted between 0800h and 2030h. The departure time and length of the aircraft flight depended on the weather, location of birds, and number of birds to be located. A bird detected inland after 0800h was considered to have initiated nesting. Non-breeding Marbled Murrelets do not remain inland beyond 90 min after sunrise during the period of nest initiation (April to July; Chapter 4; see Nelson 1997).

Ground Telemetry.--Once a potential nest initiation had been indicated by aircraft telemetry, we began a ground search for the nest tree using an ATS receiver (Model R4000) and a 2-element H-antenna (Model RA-2A, Telonics, Mesa, Arizona). When a tree or trees had been identified as a potential nest site we subsequently conducted early morning observational surveys (see Paton et al. 1990) to identify the specific nest tree used by the radio-marked Marbled Murrelet. A nest tree was identified when a murrelet was observed landing in a suspected nest tree, and the strength of the radio signal coincided with the arrival of a bird at that tree. An investigator then ascended an adjacent tree to confirm the location of the nest site. Once located, a subset of the nests had video cameras installed in the tree, or in an adjacent tree to observe (and record) behaviors, and nest fates.

To monitor the daily movements of radio-marked murrelets to and from the nesting habitat, we established automated telemetry stations (see Chapter 4). The automated telemetry stations, together with ground-based and aircraft telemetry allowed us to assess attendance patterns of individual murrelets during the incubation and chick periods.

MORPHOLOGY

Previous studies on seabirds have shown that the likelihood of breeding and reproductive success has been positively correlated with adult body size (e.g. Chastel et al. 1995, Saether et al. 1997) and parental age (Pugesek 1983, Saether 1990). To determine whether or not adult size influenced the initiation of nesting by Marbled Murrelets during our study, we compared morphometric data between murrelets that did nest after capture and murrelets that did not nest after capture (hereafter nesters and non-nesters, respectively). We also used morphometric data to determine if mass and size influenced the success in those birds that attempted nesting. Because mean (\pm SE) values for morphometric data varied significantly between years (see Results), we standardized morphometric data between years. We used the method described by Perrins and McCleery (1985), where the yearly mean was subtracted from each observation and divided by the yearly standard deviation.

NESTING

Chronology.-- During the incubation period, individual Marbled Murrelets alternate 24 h incubation periods with 24 h periods at sea (Nelson 1997) presumably exchanging incubation duties every 24 h with their mate. Thus, once incubation began, one member of the pair was at the nest and the other would be at sea. We defined a known nesting attempt to have occurred when a bird was detected inland by the aircraft (after 0800h).

To establish the nesting chronology of Marbled Murrelets nesting in RNSP, we integrated information from aircraft and ground-based telemetry, as well as information gathered when an investigator climbed known nest trees. Egg-laying and the onset of incubation was designated as the first day that a radio-marked murrelet was detected at an inland location after 0800h. Hatching and fledging dates were estimated to occur 28 days after laying and 28 days after hatching, respectively (Simons 1980, Nelson 1997). The chick-rearing period can exceed 28 days (Nelson 1997, personal observation). Therefore our estimates were conservative and represent minimum values.

Egg-laying and Incubation.--We examined several aspects of incubation. At a subset of nests we used video observations to determine which sex incubated first and the time of egg-laying. Video observations were obtained from a small, persistent video camera (8cm long by 2cm diameter) placed adjacent to a known and previously used nesting site. One site was monitored from 2002 to 2005 (see Chapter 1 and Appendix B, and C for additional details).

We stratified the radio-marked murrelets that began a regular schedule of attending a nest and those that were not regular. We set the day of egg-laying as day one of incubation and numbered subsequent days consecutively up to day 28 of incubation. Therefore, expected incubation for a radio-marked murrelet would be every other day (i.e., day 1, day 3, day 5, etc.). The incubation pattern was deemed irregular if a radio-marked murrelet was detected at the nest site on consecutive days (i.e., day 2 and day 3) or skipped a regularly scheduled incubation bout (i.e. day 1,4 or day 2,5). We also measured incubation attentiveness by determining how many nests were active each day of the incubation period (1 – 28) and how many of these nests were being tended by a radio-marked murrelet, and

expressed this as a percentage. We excluded birds that were exposed to the sound of an operating chainsaw from this analysis (see Chapter 1).

Hatching Success.--We determined hatching success by integrating aircraft telemetry (locating birds inland versus at-sea), ground-based telemetry, automated telemetry stations (see Chapter 4), information gathered when a nest tree was climbed after the breeding season, and video recordings. Together these data allowed us to observe the typical Marbled Murrelet incubation pattern and to identify successful incubation processes at a nest (28 days). If the radio-marked bird stopped the ritualized incubation pattern before adequate time to complete incubation (27 days), we considered the nest to have failed during incubation, unless ground observations or tree climbing indicated the presence of a chick (e.g. for a radio-marked murrelet that had initiated nesting prior to capture).

We calculated hatching success as the number of eggs that hatched successfully as a proportion of the number of nesting attempts. After an incubation process ended prematurely and sufficient time elapsed for an egg to be formed (≥ 12 days) and laid, and then a bird was again detected inland, this was considered as a re-nest or second nesting attempt. Our measure of hatching success included re-nesting attempts.

For radio-marked murrelets which exhibited irregular incubation patterns we determined if the variation in incubation attentiveness affected hatching success. We calculated the daily survival probability (Mayfield 1975) of nests during the incubation period. Using χ^2 analysis (see Mayfield 1975), we then compared the daily survival probability of nests tended by adults that exhibited a regular incubation pattern and nests tended by adults with an irregular incubation pattern. We also compared hatching success between nests tended by adults with regular and irregular incubation periods.

Given that some murrelets skipped incubation bouts early (the first 12 days of incubation) and/or late (the last 12 days of incubation) in the incubation period, we also determined whether or not the risk of nest-failure varied during the incubation period. We compared the daily survival probability of nests during the first and second half of the incubation period. Studies have reported seasonal variation in reproductive success, such that nests initiated earlier in the breeding season (before the mean date of nest initiation) tend to be more successful than nests initiated later in the breeding season (after the mean date of nest initiation) (Ainley et al. 1990, Boekelheide et al. 1990, Burger et al. 1996; but see Hatch 1990). To examine this relationship we compared the daily survival probability, regardless of incubation attentiveness, of nests initiated before and after the mean date of nest initiation.

Many murrelets had brood patches at capture but never nested. We later observed predation of a nest between laying and the first potential for detection by aircraft telemetry (see Appendix D). Consequently we also calculated a second measure of hatching success with the assumption that birds with brood patch scores of 2 or 3 probably went on to lay an egg and we had failed to detect that nesting attempt. We then added known nesting detections to brood patch birds that had not been detected nesting, and recalculated hatch success. We report both success corrected for brood patches and not corrected for brood patches.

Fledging Success.--We estimated fledging success as the number of fledglings produced as a proportion of the number of eggs that hatched successfully. After hatching, regular daily feedings of a chick by the parents were detected through ground observations, telemetry at the nest-site, automated telemetry receiving stations, and video observations. We determined regular feedings over a period of at least 28 days as an indication of

successful fledging. However, interpretation of radio-telemetry data can be confounded by the fact that some adults continue to make early morning visits to the nest site after a nest had failed (Hébert et al. 2003, see Appendix C, see Chapter 4). Therefore, we assigned successful fledging based on radio-telemetry if the radio-marked adult was detected inland in the evening at least once 25 – 28 days after the suspected hatch date. Determining the outcome of a nesting attempt could also be confounded by radio-failure during the nesting period. To confirm outcomes in these cases, we located nests in the tree when possible and used the presence of a complete fecal ring with embedded down feathers as an indication of successful fledging. However, not all nest trees were found and fledging success could not be determined with all nests. Consequently, we report the minimum fledging success (all unknowns assumed to have failed) and the maximum fledging success (all unknowns assumed to be successful).

Reproductive Success.--We estimated overall reproductive success for nesting murrelets. Reproductive success was calculated as the number of fledglings produced divided by the number of nesting attempts. In addition, we noted that some of the captured murrelets had a developed brood patch (i.e. brood patch score of 2 or 3; Sealy 1974) but did not nest after capture (see also McFarlane-Tranquilla et al. 2003). We assumed that these birds had initiated nesting prior to capture and the nesting effort failed prior to capture, or that nesting was attempted after capture and we failed to detect that nest (see also Appendix D). Therefore, we performed an additional calculation of reproductive success, which included non-nesting murrelets captured with a fully developed brood patch. Similar to fledging success, we also calculated maximum and minimum reproduction success to reflect possible outcomes from nests that had unknown outcomes.

STATISTICAL ANALYSES

Morphometric data were compared between years using analysis of variance (ANOVA). Standardized morphometric data were compared between male and female murrelets using multiple analysis of variance (MANOVA) with sex as the independent variable. We used logistic regression to determine if mass or size affected the likelihood of nesting, where nesting (binomial) was the dependent variable, and mass and size were the covariates. We compared hatching success between murrelets with a regular and irregular incubation pattern using Fisher's Exact Test (FET), whereas we compared hatching success between years using a heterogeneity Chi-square test (Zar 1998). All measures of central tendency are expressed as the mean (\pm SE).

RESULTS

MORPHOLOGY

A total of 102 murrelets were captured and had radios attached during the three years (Table 2-1). The mean mass of radio-marked murrelets in 2001 was 216 ± 4 g ($n = 22$). Morphometric measurements varied slightly from year to year (Table 2-2). Analysis of genomic DNA was used to classify gender and sex-ratios for captured murrelets for each year (Table 2-3). When the data were combined across years, the sex-ratio of Marbled Murrelets captured off the coast of northern California was 0.98:1.0.

Overall, the mass of captured Marbled Murrelets was similar between years ($P > 0.5$), whereas wing chord length and brood patch score tended to be different between years (MANOVA, $F_{2,98} = 2.4$, $P = 0.097$; $F_{2,98} = 2.9$, $P = 0.06$, respectively; Table 2-2). Culmen length and bill depth were significantly different between years (MANOVA, $F_{2,98} = 5.1$, $P = 0.008$; $F_{2,98} = 7.6$, $P = 0.001$; respectively). When the data were standardized and combined

across years, male murrelets were significantly lighter than females (MANOVA, $F_{1,93} = 6.89$, $P = 0.01$; Table 2-4), but males had longer wing chord measurements (MANOVA, $F_{1,93} = 4.21$, $P = 0.043$; Table 2-4). Culmen length and bill depth were similar for male and female Marbled Murrelets ($P > 0.30$ for both comparisons).

The use of anesthesia may have confounded differences in reproductive success (see Appendix A). Consequently, we compared morphology of nesters and non-nesters for birds that did not receive anesthesia during processing. Standardized mass, wing chord length and bill depth were similar for male murrelets regardless of reproductive status ($P > 0.1$ for all comparisons; Table 2-5). However, standardized culmen length tended to be shorter among non-nesting males compared to nesting males (Wald's $F = 3.03$, $df = 1$, $P = 0.082$; Table 2-5). Standardized mass, wing chord length, and culmen length were similar for non-nesting females and nesting females ($P > 0.1$ for all comparisons; Table 2-5). However, bill depth tended to be smaller for non-nesting females (Wald's $F = 3.65$, $df = 1$, $P = 0.06$) compared to nesting females (Table 2-5).

NESTING

Chronology.--Calculations of dates assumed a 28-day incubation period, followed by a 28-day chick-rearing period, and were based on detection of inland radio-marked marbled murrelets by aircraft. In 2002, the first radio-marked murrelet was estimated to have initiated nesting 3 days before the bird was captured, and the last nest was a re-nesting attempt. Mean nest initiation dates tended to differ between years (ANOVA, $F_{2,32} = 3.3$, $P = 0.052$; Table 2-6). Mean nest initiation was marginally later in 2002 compared to 2001 (LSD, $P = 0.063$) and significantly later than 2003 (LSD, $P = 0.04$). Mean initiation dates were similar in 2001 and 2003 ($P > 0.8$).

Egg-laying and Incubation.--Egg laying was observed in 2003, 2004 and 2005 at a nest-site that was used for five consecutive years (see Appendix B). In 2003 at this site, the egg was laid at 0530h, in 2004 at approximately 0544h, and in 2005 at 0615h. In general, the female moved very little during laying and the only indication that an egg was being laid was a slight elevation of the rump, presumably at the time of oviposition. Within minutes of laying the egg, the female left the nest and the male began the first period of incubation.

In 2002, both members were radio marked in two nesting pairs of Marbled Murrelets. At one of these nests, both members of the pair were on the water the day before laying. The following day the male was detected inland. We are confident that the male conducted the first incubation shift, as neither of the radio-marked birds were detected inland after 0800h prior to our estimated date of nest initiation. For the other pair, the female was the first bird detected inland. However, the aircraft could not fly the previous day and we suspect that we missed the first day of incubation. Thus we infer that the male also took the first incubation shift.

Across all years, nine (33%, $n = 27$) radio-marked murrelets exhibited irregular incubation patterns, seven of which did so within the first 5 days after the onset of incubation. The other two missed an incubation bout on day 15 and 19 of their respective incubation periods. The latest that an incubation bout was missed was on day 25. In total, the nine birds that had an irregular incubation pattern missed a total of 16 days during incubation (individuals ranged 1 – 4). At a nest where both members of the pair were radio-marked (not included above) the female skipped an incubation bout on day 12 and her radio-marked mate did not assume incubation duties, thereby leaving the egg unattended. The number of nests with successful hatching was similar (FET, $P > 0.4$) for nests tended by

adults with regular (6 hatches of 18 attempts) and irregular (5 hatches of 9 attempts) incubation patterns.

For 26 of the nesting attempts included in the analyses of regular and irregular patterns of incubation, 15 of the individuals were male and 11 were female. There was no difference in the proportion of males (5/15) and females (4/11) that exhibited an irregular incubation pattern (FET, $P = 1.0$). When the data were combined across years and sexes, murrelets that exhibited a regular incubation pattern were significantly heavier at capture ($t = 2.27$, $df = 25$, $P = 0.03$) compared to murrelets with an irregular incubation pattern (Table 2-7). When the data were separated by sex, mass was similar for male murrelets with a regular incubation pattern and males with an irregular incubation pattern ($P > 0.60$). By contrast, female murrelets that exhibited a regular incubation pattern were significantly heavier at capture compared to females that exhibited an irregular incubation pattern ($t = 2.3$, $df = 9$, $P < 0.05$; Table 2-7).

Overall, the daily survival probability of all Marbled Murrelet nesting attempts (includes re-nests) during the incubation period was 0.965 ($n = 27$). There was a tendency for the daily survival probability of nests to be lower during the first 12 days of incubation compared to the last 12 days of incubation ($\chi^2 = 3.61$, $df = 1$, $P < 0.06$; Table 2-8). Similarly, the number of nests that failed in the first 12 days of incubation tended to be greater than the number of nests that failed in the last 12 days of the incubation period ($\chi^2 = 3.73$, $df = 1$, $P < 0.06$; Table 2-8). The daily survival probability for nests initiated early in the breeding season was similar ($P > 0.3$; Table 2-8) to that of nests initiated later in the breeding season. Likewise, the number of nests with successful hatching was similar ($P > 0.5$) for nests initiated early in the breeding season and nests initiated later in the breeding season.

NESTING SUCCESS

A total of 38 nesting attempts (including re-nests) were detected between 2001 and 2003. Of these, we excluded from analyses one nesting attempt when the adult lost its radio-transmitter, and hatching success could not be ascertained.

All nesting attempts determined from aircraft-locations were determined to have failed or succeeded. Across all years, slightly less than half these nests failed (Table 2-9). When birds with brood patch scores of 2 or 3 at capture were assumed to have nested, but failed before detection, the hatching success was only 22.2% for all years combined. Overall, hatching success was similar between years ($\chi^2 = 0.69$, $df = 2$, $P > 0.7$). Hatching success over the three years was 43.2%. Hatching success was lower when birds that had been exposed to experimental disturbance test (Chapter 1) were excluded from the analysis (Table 2-10).

For fledgling success, uncertainty was caused by radio or camera failure before completion of our observations. If all unknowns in fact were successful fledgings, then fledgling success averaged 56.2% for all years combined (Table 2-11). If all unknowns were unsuccessful, fledgling success would have averaged 31.2% for all years combined.

The reproductive success varied in its calculation based on the uncertainty in fledgling success and whether we included known brood patch birds as failed nesting attempts. Assuming all unknown birds fledged, and ignoring the consequences of brood patches at capture, reproductive success could be as great as 24.3% (Table 2-12). However, if brood patches did represent failed nesting, and all unknown fledgings were in fact chick mortalities, the reproductive success would be as low as 6.9% for all years combined.

Nest failure during the incubation period occurred on average 7.6 ± 1.4 days ($n = 29$) after nest initiation. If we use the total number of radio-marked birds as the population available to breed (assumes no bias at capture) we can use the number of known nesters to estimate that 33.3% of the population was breeding. If we included all brood patch birds plus our known nesting, 65.7% of the population attempted to breed (Table 2-13).

It could be argued that the experiments on disturbance (Chapter 1) may have influenced our calculations of reproductive success. Consequently, we recalculated the productivity measures with exclusion of any tested birds (Table 2-14). Hatching and fledging success were similar for all years combined. Overall reproductive success was lower (3.1%) when the calculations excluded nests where experimental treatment occurred (Table 2-14).

ADULT MORTALITY

Excluding data for one murrelet known to have lost its transmitter, and two adults that died during handling, eight murrelets (7.9%; 3m) were presumed to have died during the periods of observation (see Appendix E for details). Three of the birds were males and the remaining 5 were females. Using the Mayfield method applied to radio-life as a measure of exposure, we calculated a daily survival probability for radio-marked murrelets of 0.999. This yields an average weekly survival probability of 0.99 and an annual survival probability of 0.605, resulting in approximately 61% of the radio-marked adults surviving for a year (although we caution that annual extrapolation from survivorship only during breeding may not be valid because of season-specific differences in mortality risk).

DISCUSSION

MORPHOLOGY

Morphometric measurements of Marbled Murrelets captured in northern California were similar to other murrelet populations (Sealy 1975, Loughheed et al. 1998; see also Nelson 1997), except the average flattened wing chord length for murrelets from northern California was shorter than murrelets in British Columbia (see Sealy 1975). Given that all other measurements were similar to those of other studies (Loughheed et al. 1998; see also Nelson 1997), we believe that differences in wing chord length reported here may have reflected subtle differences in methodology between the studies.

As with other studies (Sealy 1972, McFarlane-Tranquilla 2001), male Marbled Murrelets captured in northern California were significantly lighter than female murrelets. Male Marbled Murrelets were expected to be lighter than females during the breeding season because females store lipids for egg production (Sealy 1972, McFarlane-Tranquilla 2001). However, we did not detect a difference in mass between nesting and non-nesting males, nor between nesting and non-nesting females. Several factors may have contributed to this observed lack of difference. First, the differences or lack of differences in mass and size of murrelets may not have been related to nesting status. For example, in Ancient Murrelets (*Synthliboramphus antiquus*) and Xantus' Murrelet (*S. hypoleucus*) mass and size did not differ between nesting birds and non-nesting birds (Gaston 1994, Drost and Lewis 1995). Second, the mass of nesting and non-nesting Marbled Murrelets was confounded by the wide variation in the initiation of nests, while measurement occurred over a relatively shorter period for capturing; thus murrelets were measured at different stages in reproduction. Murrelets caught before they initiate nesting, especially females, may be lighter (see

McFarlane Tranquilla et al. 2003), and would thus depress the mean value for mass of nesting birds.

SEX RATIO

Across all years, the male:female sex ratio (0.98:1.0) of Marbled Murrelets captured in northern California was not significantly different from expected (1:1). Other studies (e.g. Sealy 1972; Vanderkist et al. 1999; Burkett et al., unpublished data) have also reported adult sex-ratios of 1:1. The skewed sex-ratio (1.0: 2.3) we observed in 2001 may be due to a bias in capture or from a small sample size (Vanderkist et al. 1999). Gravid females tend to be heavier than males (Sealy 1972, McFarlane-Tranquilla 2001) and therefore experience heavier wing-loading, potentially rendering females more susceptible to capture using the night-lighting technique. However, in 2001 the captured Marbled Murrelet females were of comparable mass to the males, so it is unlikely that females would be more susceptible to capture as a result of being heavier. The 2001 sample was our smallest annual capture.

NESTING

Egg laying and Incubation.--We present the first specific information on timing of egg-laying for Marbled Murrelets, and alcids in general. Laying occurred during the early morning hours, which was not surprising given that Marbled Murrelets visit nest-sites most frequently around dawn during both the breeding and non-breeding periods (Eisenhower and Reimchen 1990, Naslund 1993, Chapter 4). The timing of egg-laying may have important consequences for land-managers providing for conservation of Marbled Murrelets.

Anecdotal observations (see Nelson 1997) indicate that disturbance around the nest-site when a murrelet was approaching to exchange incubation duties can delay the timing of the exchange (Hamer and Nelson 1998). Thus it is important that land managers minimize

disturbance around nest sites before 0700h, when egg-laying occurs. Disturbance before 0700h could cause incoming females to dump their eggs at a site other than the nest-site, which may lead to a failed nesting attempt.

In all cases, male Marbled Murrelets apparently began the first incubation duties. Similar behavior has been reported for other alcid species (e.g. Sealy 1968, 1972; Manuwal 1974). Having male alcids begin incubation likely allows the female immediate opportunity to forage and replenish her nutrient reserves following the production of the egg.

For Marbled Murrelets, it was assumed that incubation duties were shared equally by mates (Nelson 1997). Our observations suggested that for most murrelet pairs, incubation was indeed shared equally between the sexes. However, a significant proportion (33%) of incubating murrelets missed at least one day of incubation, or incubated for two days in a row. Irregular incubation patterns have also been observed in Ancient Murrelets, as well as Crested (*Aethia cristatella*) and Least Auklets (*A. pusilla*; Sealy 1984), and Cassin's Auklets (*Ptychoramphus aleuticus*; Astheimer 1991). However, in these studies, the interruptions were usually associated with disturbances caused by handling (see Sealy 1984). Although interruptions of incubation may extend the incubation period (Sealy 1984), such interruptions in the absence of disturbance at the nest-site may also be necessary for adults to maintain condition. For instance, Simons (1980) noted that Marbled Murrelets tending a ground nest in Alaska left the nest unattended for 1-2 days during a storm. Incubation during the storm could have depleted nutrient reserves of the incubators while foraging was difficult, which could have required extended time away from the nest. Alternatively, we may have missed the disturbance at the nest site that caused the adults to leave the nest unattended for periods of time.

If interruptions of the incubation schedule were associated with the energy fitness of the tending adults, it would be predicted that an irregular incubation pattern would be most common in younger, less experienced birds that had greater difficulty in finding food. As such, missing an incubation bout allowed them to forage and supplement their nutrient reserves (Sealy 1984). Likewise, it would also be predicted that irregular incubation patterns may be more frequent during years of poor food availability. We unfortunately did not have the ability to test either of these predictions.

An irregular incubation schedule has the potential of leaving an egg unattended if the mate does not compensate (which did occur). If unattended, these eggs may be more susceptible to predation by corvids (see Appendix D). However, the survival probability we calculated for nests tended by adult murrelets with a regular incubation pattern was similar to that for nests tended by murrelets with an irregular incubation pattern. Hatching success was also similar between nests tended by adults with regular or irregular incubation patterns.

Like other alcids, (e.g. Astheimer 1991, Gaston and Jones 1998) Marbled Murrelets were more likely to miss an incubation bout earlier (within 5 days of egg-laying) compared to later in the incubation period. Coincidentally, we also observed that the survival probability of nests was lower during the first 12 days of the incubation period compared to the last 12 days of the incubation period. Several factors may contribute to the increased risk of nest failure early in the incubation period. First, during this study 7 murrelets missed an incubation bout within 5 days of the onset of incubation. Three of these nests failed in the first nine days of incubation. Such behavior may represent inexperienced breeders that abandon the nest early in the incubation period. We observed overall hatching success to be similar at nests tended by adults with regular and irregular incubation patterns, but the low

hatching success (22 – 43%) may have masked any potential trends. Indeed, we found that females with a regular incubation period were significantly heavier at capture relative to females with an irregular incubation pattern. Similarly, Yorio and Boersma (1994) reported Magellanic Penguins (*Spheniscus magellanicus*) had greater likelihood of nest desertion during incubation when body condition was reduced at the start of an incubation bout.

Finally, we did not detect differences in survival probability or hatching success for nests initiated prior to the yearly mean initiation date and those initiated after that date. Other studies of alcids have reported that early nesters tended to have higher reproductive success compared to individuals that nested later in the breeding season (e.g. Ainley et al. 1990, Boekelheide et al. 1990). The lack of a relationship between timing of breeding and reproductive success may also be related to our ability to detect differences when overall reproductive success was as low as observed in the northern California Marbled Murrelet population.

Chronology.-- In California, records from grounded chicks, fledglings and nest observations indicate that incubation (i.e. egg-laying) begins in mid-March and continues until mid-August (see Hamer and Neslon 1995). In general, egg laying and incubation by Marbled Murrelets in RNSP fall within this range. The earliest date of nest initiation for Marbled Murrelets nesting in RNSP was 22 April, and the last date of egg-laying was 21 July. Based on this last date of clutch initiation, incubation may occur for Marbled Murrelets nesting in RNSP until 18 August, which coincides well with the breeding chronology derived by Carter and Erickson (1992) for California. Similarly, the earliest date of fledging in our study (17 June) coincides well with that derived by Carter and Erickson (1992), but is later than that derived by Hamer and Nelson (1995). The latest date of fledging in our study (15

September) coincides well with the range provided by Carter and Erickson (1992) and by Hamer and Nelson (1995). Several factors may contribute to the differences in the range of initiation dates and fledging dates between our study and other studies (Hamer and Nelson 1995). First, there may be geographic differences in the timing for the onset of the breeding season. For instance, egg laying by Marbled Murrelets nesting in Alaska begins in mid-May, but nesting for Marbled Murrelets in California begins in mid-March (see Nelson 1997). Also, the data used by Hamer and Nelson (1995) to establish the breeding chronology for Marbled Murrelets nesting in California was based mainly on reports from California's central coast, especially Big Basin State Park (560 km south of RNSP). It is possible that Marbled Murrelets in northern California experience different climate and oceanographic conditions compared to murrelets nesting on the central coast. Second, notwithstanding differences between populations, there may also be yearly differences in the onset of breeding associated with environmental variations. Conditions present during past studies (1980's and early 1990's) may not be similar to those conditions experienced by Marbled Murrelets during 2001 – 2003.

Finally, there was potential seasonal variation in our ability and efforts to capture Marbled Murrelets that was associated with ocean conditions (i.e. general ocean conditions improve from April to May, and capture on the open ocean required calmer sea conditions), such that we may not have always captured the earliest nesters. This could skew our dates of nest initiation to later in the season, relative to the range of dates reported by Hamer and Nelson (1995). We did capture murrelets in April that had fully developed brood patches, suggesting that they may have already attempted nesting. If so, then nesting occurred earlier

than indicated by our data, and was consistent with the chronology derived by Hamer and Nelson (1995).

Reproductive Success.--We divided reproductive effort into the hatching, nesting, and overall reproductive success so as to illustrate where in the reproductive process most failure occurred and the assumptions that were made at each stage of the reproductive cycle for the calculations of success and failure. Hatching success during our study was markedly lower than that observed in other alcids (Ricklefs 1969), as well as other populations of Marbled Murrelets. Nelson (1997) calculated an average hatching success of 67% for Marbled Murrelets across their range, from Alaska to central California. Recently, Bradley et al. (2004) reported an average hatching success of 86% for a population of Marbled Murrelets in Desolation Sound, British Columbia. Our value of hatching success included nests that were exactly located as well as nests that were located only to the general area. At these later sites, we inferred hatching success from radio-telemetry data gathered with aerial telemetry, the use of automated telemetry, as well as early morning ground-based radio-telemetry surveys. In other investigations that exclusively used aircraft techniques to monitor hatching success, they may have failed to find some nests that initiated and failed before their aircraft detected nesting, and their estimates of hatching success could be somewhat inflated.

In fact, we believe that in spite of using early-morning telemetry ground-surveys, automated telemetry, and aircraft, our estimate of hatching success based on detection of nests was greater than actual success. We observed with video a nest site that had been used during each nesting season for five years. Because of the repeated use, the video camera was installed before nesting began. In one of the four nesting attempts observed, an egg was laid

and lost to a predator (within 70 minutes of being laid) well before aircraft could have detected the nesting attempt.

If the birds with brood-patches that were not observed nesting did in fact attempt nesting and lost that egg to a predator, they should be included in our calculations as a failed attempt. When we included these in our calculations, the estimate of hatching-success was 22.2%. Murrelets that had not yet developed brood patches at capture, and whose attempts failed as described above, would further depress the estimate of hatching success (thus less than the calculated 22.2%). Regardless of methodology or assumption, Marbled Murrelets in RNSP appear to have very low hatching success compared with elsewhere in their range.

McShane et al. (2004) found 50% of the Marbled Murrelet population participated in the reproductive effort. Based only on birds that were known to initiate nesting, our estimate of the proportion of the population that participated in breeding was low. If we included the birds with brood patch scores of 2+, the proportion of the Marbled Murrelet population breeding in RNSP was more similar to other populations. We consider this corroborating evidence that the inferred failed-nesting of birds with brood patches (at capture) was appropriate.

Alternatively, radio-telemetry effects might be considered as a potential explanation for non-nesting birds with brood patches. In Cassin's Auklets (*Ptychoramphus aleuticus*), Ackerman et al. (2004) found the effects of telemetry on the individual birds was subtle, and only detectable statistically. Further, telemetry effects of this magnitude were not detected by others using similar techniques (Bradley et al. 2004, Peery et al. 2004). Thus, we believe that the hatching success values we present here are a true measure of hatching success in our population.

When fledging success was calculated, nests where hatching was successful but fledging status remained unknown provided additional uncertainty to the estimate. Unlike incubation, where adults spend 24 h at the nest, the radio-marked murrelets come only to feed the chick. After fledging or even after failure, adults return to the nest site early in the morning (Chapter 4). For nests with known outcomes, our calculation of fledging success was 31.2%. When we assumed nests with unknown outcomes were all successful, maximum fledging success was 56.2%. However, we have no reason to assume that all the unknown nests were in fact successful. The range of possible fledging success bracketed the average (45%) reported by Nelson (1997). Our value for maximum fledging success was similar to the average (69%) reported by Bradley et al. (2004), who also used radio-telemetry to infer nesting outcomes at nests that had not been exactly located. However, our measures of fledging success are higher than that (15.8%) reported by Peery et al. (2004) for a population of Marbled Murrelets in coastal central California where failure due to predation was great (67%).

For many years at-sea surveys have been conducted in an effort to monitor murrelet populations off the northern California coast (Ralph and Long 1995, Miller et al. 2003) and elsewhere (Kuletz and Piatt 1999, see McShane et al. 2004). At-sea juvenile/adult ratios should reflect the reproductive output (assuming no juvenile movements outside the area used by adults). In order to compare our estimates of reproductive success to the at-sea juvenile/adult ratios in Miller et al. (2003) for northern California, we made two adjustments to at-sea numbers. First, our estimates of reproductive success were based on nests, and thus on pairs of birds, so we divided the adult counts by two. Secondly, not all birds participate in breeding; we corrected the at-sea adult count to reflect the percent of the population in RNSP

that participated in the breeding effort (Table 2-13) in each year. We used only ratios from the 2001 and 2003 years because few 2002 productivity surveys had been conducted (Miller et al. 2003). Survival of fledglings is not well known (Beissinger and Nur 1997). However, the at sea surveys were conducted in early August and before chicks had been exposed to longer periods of risk. The resulting calculation yielded a range of 5 - 15% reproductive success from the at-sea juvenile/adult ratios, which was consistent with our range of estimates of reproductive success from the nests. Just as our estimates of hatching and reproductive success were much lower than British Columbia (Bradley et al. 2004), so were the at-sea estimates of productivity off northern California (Miller et al. 1999) compared to Alaska (Kuletz and Piatt 1999).

We believe it is unlikely that at-sea surveys were missing juveniles. Although Loughheed et al. (2003) did find habitat use differed between adults and juveniles, the coast of northern California is very different than where they conducted their studies. The coast of northern California lacks protected waters and is not broken with inland waterways or large near-shore islands that provide sheltered areas. Adults in our study were all near shore (Chapter 3) and there was no evidence that suggested Marbled Murrelets used waters outside the survey area. Although our estimate of 6.9 – 12.5% reproductive success was lower than most northern investigations, these numbers were consistent with at-sea surveys and population trends elsewhere in California (eg: Peery et al. 2004).

Clearly, the reproductive success we calculated for 2001-2003 in the northern California population is insufficient to maintain current population levels. The low reproductive rates of Marbled Murrelets nesting in RNSP could not supply immigrants to other populations (eg: Peery et al. 2005). Demographic analyses indicate that Marbled

Murrelet populations may be declining by 4 – 7 % annually (Beissinger 1995). Recent theoretical analyses based on observed productivity rates concluded that Marbled Murrelet populations in California were at risk of becoming extinct within 100 years (McShane et al. 2004). In spite of the low reproductive success, Huff et al. (2003) did not report declining population estimates from at-sea surveys off northern California in the three years coincident with our study. However, McShane et al. (2004) note that detection of population trends require longer intervals. Even if long-term data were available, the very large confidence intervals associated with those estimates would make detection of year-to-year declines very difficult. Further, because alcids tend to be relatively long-lived, population counts in at-sea surveys will lag behind the declines in reproductive output.

Several factors may constrain reproductive success in Marbled Murrelets. Other studies have identified predation (Nelson and Hamer 1995, Peery et al. 2004) and poor food availability (Peery et al. 2004, Becker et al. 2006) as important factors limiting reproductive success in Marbled Murrelets. During our study, we observed predation by both jays and ravens. If the non-nesting birds with brood patches that we failed to detect nesting were in fact breeders that lost their egg very quickly to predators, we can use this as one measure of predation rate. This alone would have constituted 64%, 39%, and 50% failure rates in 2001, 2002, and 2003, respectively, or an annual average of 51%. Predation was also a part of the verified failures, and thus the contribution of predation to these numbers would be even greater (see Appendix D). Additionally, at the nest where video observations had recorded nest success for 5 years, we detected two instances of egg predation by corvids in 4 of the 5 years, and suspected predation in a fifth year. This would yield a nest-failure rate due to predation of 60% (100% of failures), which was similar to our previous calculation and to the

67% reported by Peery et al. (2004). It is difficult to dismiss predation as an important factor constraining Marbled Murrelet reproductive success, especially given the fragmented nature of the habitat that favors predation by corvids (Andren 1992, Marzluff et al. 1994, Liebezeit and George 2002). Consequently, efforts to recover the Marbled Murrelet should include measures that minimize predation by corvids, particularly during the incubation period.

Another important factor that may impact Marbled Murrelet reproductive success is adult mortality, especially as a result of predation. Marbled Murrelets are particularly susceptible to avian predators such as Peregrine Falcons (*Falco peregrinus*) and Northern Goshawks (*Accipiter gentiles*; Nelson 1997). Over the course of our study, we confirmed the mortality of at least eight adults (7.8%; see Appendix E). In one instance we found the radio-transmitter under a tree, suggesting that the adult murrelet had been depredated by a bird of prey. Although sample sizes were inadequate, we calculated survival using the Mayfield method to illustrate the impact of adult mortality. Daily survival probability was 0.999 for our radio-marked adults, which was a weekly survival probability of 0.990, and an annual survival probability of 0.605. This estimate of weekly adult survivorship in RNSP was similar to that observed by Loughheed et al. (2002). However, this estimate of annual survival probability was significantly lower than that reported for other alcids (Hudson 1985), and lower than the annual survival of 0.845 estimated by Beissinger and Nur (1995) based on body size and demographic data. Our estimate of annual survival probability was also lower than the 0.829 and 0.929 estimated by Cam et al. (2003) based on capture-recapture data. Theoretical treatments were only as strong as their assumptions, and given that there was little survivorship data available for most Marbled Murrelet populations, and given the high potential predation rates and low reproductive success estimates, there is substantial need for

additional data to refine estimates of survivorship (see Beissinger and Nur 1997, Loughheed et al. 2002, Cam et al. 2003).

CONCLUSIONS

The focus of recovery of Marbled Murrelets has been the protection, and in some cases acquisition, of forests dominated by old growth trees. It has been assumed that RNSP should be capable of providing a reserve of good habitat for Marbled Murrelets (US Fish and Wildlife Service 1997). Although RNSP contains substantial quantities of habitat appropriate for murrelets (US Fish and Wildlife Service 1997), their reproductive success within these areas was very poor in 2001 – 2003, including within some of the largest contiguous blocks of old growth forest. Predation leading to nest failure appears to be a predominant factor in the poor reproduction, therefore anthropogenic presence and activity can be deleterious if it causes predation risk. We encourage land managers to consider the quality as well as the quantity of available nesting habitat for Marbled Murrelets. The factors contributing to the observed habitat degradation probably included attraction, feeding, and density of corvids. Increasing corvid densities have been associated with human use (Marzluff et al. 1994, Liebezeit and George 2002), and corvids can be attracted to the presence of humans and their food (Marzluff et al. 1994, Liebezeit and George 2002). Parks specifically manage people within their bounds. Anthropogenic activity also occurs adjacent to the park boundaries and these can influence predation. Although noise disturbance (Chapter 1) by itself may not degrade murrelet habitat, Parks should not be considered intrinsically good habitat without the evaluation of habitat quality and specifically predation risk.

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TABLE 2-1. Number of Marbled Murrelets captured during each night of capture operation, in two locations off the coast of Redwood National and State Parks, California from 2001 - 2003.

Location	Year												
	2001				2002				2003				
	April			May	April	May			April		May		
	13	24	25	13	13	1	17	21	16	30	1	11	12
Gold Bluffs Beach/Big Lagoon	5	7	4	7		9	23	9	6	13	8	6	5
Trinidad Beach					3								
Total				23				44					38

TABLE 2-2. Morphometric measurements of captured Marbled Murrelets in Redwood National and State Parks, California from 2001 – 2003.

Measurements	2001		2002		2003	
	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n
Mass (g)	216.0 ± 4.0	22	219.0 ± 4.0	44	215.0 ± 3.0	38
Bill Depth (mm)	6.1 ± 0.1	23	6.4 ± 0.1	44	6.2 ± 0.1	38
Culmen Length (mm)	18.8 ± 0.2	23	17.7 ± 0.2	44	17.9 ± 0.2	38
Flat-wing Chord Length (mm)	125.0 ± 0.8	23	122.4 ± 0.6	44	123.5 ± 0.7	37
Brood Patch Score	1.6 ± 0.3	23	1.8 ± 0.2	44	1.2 ± 0.2	38

TABLE 2-3. Sex and sex ratio of captured Marbled Murrelets in Redwood
National and State Parks, California from 2001 – 2003.

	Year		
	2001	2002	2003
Number of murrelets with gender analysis	20	42	33
Male	6	23	18
Female	14	19	15
Sex ratio (m:f)	1.0:2.3	1.21:1.0	1.2:1.0

TABLE 2-4. Morphometric measurements of male and female
Marbled Murrelets captured in northern California in
2001 – 2003.

Parameter	Male		Female	
	$\bar{x} \pm \text{SE}$	n	$\bar{x} \pm \text{SE}$	n
Mass (g)	212.0 ± 3.0	45	224.0 ± 3.0	41
Wing chord (mm)	123.8 ± 0.7	45	122.9 ± 0.6	42
Culmen (mm)	18.1 ± 0.2	45	18.0 ± 0.2	42
Bill depth (mm)	6.2 ± 0.1	45	6.3 ± 0.1	42

TABLE 2-5. Morphometric measurements for Marbled Murrelets

captured in northern California in 2001 - 2003 that were detected nesting or where nesting was not directly detected. Murrelets that received anesthesia were excluded from this analysis.

	Reproductive Status			
	Did Not Nest		Nested	
	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n
Male				
Mass (g)	214.0 ± 4.0	21	208.0 ± 4.0	14
Wing chord (mm)	122.8 ± 1.0	21	124.6 ± 1.1	14
Culmen (mm)	17.7 ± 0.2	21	18.6 ± 0.4	14
Bill depth (mm)	6.3 ± 0.1	21	6.1 ± 0.2	14
Female				
Mass (g)	218.0 ± 4.0	19	231.0 ± 7.0	11
Wing chord (mm)	123.0 ± 1.0	20	122.3 ± 1.0	11
Culmen (mm)	18.1 ± 0.2	20	18.3 ± 0.3	11
Bill depth (mm)	6.2 ± 0.1	20	6.4 ± 0.1	11

TABLE 2-6. Nesting chronology for Marbled Murrelets from 2001 - 2003 in
Redwood National and State Parks, California.

	Year		
	2001	2002	2003
Number of nests	5	19	8
First nest initiated	22 Apr	6 May	10 May
Last nest initiated	5 Jul	21 Jul	12 Jun
Earliest fledge	17 Jun	1 Jul	21 Jun
Latest fledge	30 Aug	15 Sep	7 Aug
Mean nest initiation (\pm SE)	23 May (\pm 14)	10 Jun (\pm 4)	24 May (\pm 5)

TABLE 2-7. Weights of Marbled Murrelets stratified by incubation periods that were regular (switching incubation bout with the mate on a regular schedule) and irregular (leaving an incubation bout early, skipping ≥ 1 scheduled incubation bout, or an individual incubating for two days in a row) in Redwood National and State Parks, California.

Incubation	All Years / Sexes Combined		Males		Females	
	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n
Regular (g)	218 ± 4	18	210 ± 3	9	228 ± 7	8
Irregular (g)	203 ± 5	9	206 ± 9	5	202 ± 2	4

TABLE 2-8. Number of failed nests and daily survival probability for Marbled Murrelets in early (first 12 days of incubation) and late (last 12 days of incubation) incubation periods, and early (\bar{x} date of nest initiation – 1 SD) and late (\bar{x} date of nest initiation + 1 SD) in the breeding season. Data used are only from nests whose initiation and fate were known.

	Incubation Period		Breeding Season	
	Early	Late	Early	Late
Number of nesting attempts	27	14	11	8
Number of failed nests	12	2	6	3
Daily Survival Probability	0.953	0.987	0.971	0.955

TABLE 2-9. Hatching success for Marbled Murrelets using known nesting and nesting (including re-nest attempts) inferred by presence of a brood patch (score = 2+, Sealy 1974). Minimum and maximum are reported to express uncertainty in the fate of nests that could not be adequately observed to make definitive categorizations (maximum assume all unknown eggs survived, minimum assume all unknown eggs failed). Numbers do not exclude birds that were experimentally tested.

	2001	2002	2003	All Years Combined
Known nesting attempts	6	20	11	37
Known nesting attempts plus attempts inferred by brood patch	17	33	22	72
Nests failed during incubation (no brood patch inferred nesting)	3	10	7	20
Nests failed during incubation (with brood patch inferred nesting)	14	23	18	55
Unknown outcome			1	1
Successful hatches	3	10	3	16
Hatching Success				
Known nesting only (%) (hatched/ known attempts)	50	50	27	43.2
Brood-patch included (%) (hatched/ known plus inferred attempts)	18	30	14	22.2

TABLE 2-10. Number of nesting attempts, number of failed nests during incubation, and average day of nest failure ($\bar{x} \pm \text{SE}$) for radio-marked Marbled Murrelets from 2001 - 2003 in Redwood National and State Parks, California when all nests subjected to experimental disturbance during the incubation period were excluded.

	Year		
	2001	2002	2003
Nesting attempts	6	16	8
Failed nests	3	9	6
Hatching success ¹ (%)	50	40	25
Average day failed into incubation	5.7 ± 3.3	8.7 ± 1.8	10.2 ± 4.2

¹No brood-patch inferences to nesting

TABLE 2-11. Fledging success for Marbled Murrelets using all known nesting and nesting inferred by presence of a brood patch (score = 2+, Sealy 1974). Minimum and maximum are reported to express uncertainty in the fate of nests that could not be adequately observed to make definitive categorizations (maximum assume all unknown eggs survived, minimum assume all unknown eggs failed). Numbers do not exclude birds that were experimentally tested.

	Year			All Years
	2001	2002	2003	Combined
Fledging attempts	3	10	3	16
Failed during chick rearing	0	6	1	7
Successful in chick rearing	1	3	1	5
Unknown outcomes during chick rearing	2	1	1	4
Fledging Success				
Minimum (%)	33.3	30	33.3	31.2
Maximum (%)	100	40	66.7	56.2

TABLE 2-12. Reproductive success for Marbled Murrelets using known nesting and nesting inferred by presence of a brood patch. Minimum and maximum are reported to express uncertainty in the fate of nests that could not be adequately observed to make definitive categorizations (maximum assume all unknown eggs survived, minimum assume all unknown eggs failed). Numbers do not exclude birds that were experimentally tested.

	Year			All Years
	2001	2002	2003	Combined
Known nesting attempts (fledged/ eggs known to be laid)				
Minimum (%)	17	15	9	13.5
Maximum (%)	50	20	18	24.3
Brood patch added to nesting attempts (fledged/ nests attempted)				
Minimum (%)	6	9	4	6.9
Maximum (%)	18	12	9	12.5

TABLE 2-13. Percent of Marbled Murrelet population (# of birds) in Redwood

National and State Parks, California breeding in years 2001 - 2003.

Note that numbers differ from calculations based on nesting attempts
(which include re-nesting efforts).

	Year			Total Study
	2001	2002	2003	
Birds radio-marked	23	44	35	102
Brood patch present at capture	14	32	14	60
Nesting detected	3	19	4	26
No-nesting detected	11	13	10	34
Brood patch absent at capture ¹	9	12	21	42
Nesting detected	2	1	4	7
No-nesting detected	7	11	17	35
Percent of Population Breeding				
Known nesting (%)	21.7	47.7	22.8	33.3
Brood-patch plus known nesting (%)	69.6	75	51	65.7

¹Brood-patch score of 2+ (Sealy 1974) at capture.

TABLE 2-14. Reproductive success for Marbled Murrelets, which excluded nests exposed to disturbance in years 2001 - 2003 in Redwood National and State Parks, California. Brood-patch inferred nesting attempts come from murrelets that had a brood-patch score of 2 or greater (Sealy 1974) at capture but were not otherwise detected nesting.

	Source Table	Known Nesting Attempts	Known Nesting Plus Brood-Patch Inferred Nesting Attempts
Total nesting attempts	2-9	37	72
Nests exposed to saw; excluded		7	7
Nesting attempts analyzed	2-10	30	65
Successful hatches	2-10	12	12
Failed hatches	2-10	18	53
Hatching Success (%)		40	18.5
Total fledging attempts		12	12
Attempts exposed to saw; excluded		3	3
Fledging attempts analyzed		9	9
Successful fledges		2	2
Failed fledges		3	3
Unknown		4	4
Fledging Success ¹ (%)		40	40
Minimum ² (%)		22.2	22.2
Maximum ² (%)		66.7	66.7
Reproductive Success ¹ (%)		7.7	3.3
Minimum ² (%)		6.6	3.1
Minimum ² (%)		20	9.2

¹ Unknown outcomes excluded from this calculation.

² Minimum assumes all unknown outcomes were failures, while maximum assumes all unknown outcomes were successful.

CHAPTER 3

AT-SEA DISTRIBUTION AND MOVEMENTS OF MARBLED MURRELETS (*BRACHYRAMPHUS MARMORATUS*) IN NORTHERN CALIFORNIA

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Like other alcids, Marbled Murrelets (*Brachyramphus marmoratus*) utilize the terrestrial ecosystem for nesting and the marine ecosystem to obtain nutrients (Sealy 1975a, Carter and Sealy 1987, Carter and Sealy 1990, Burkett 1995). During the breeding season, incubating Marbled Murrelets alternate 24 h incubation bouts with 24 h periods at sea (Singer et al. 1991, Naslund 1993, Nelson and Peck 1995), whereas non-nesting murrelets typically spend most of their time at sea, with the exception of a few hours around sunrise when they may fly inland (Nelson 1997, Whitworth et al. 2000a). Adults feeding chicks fly inland with food during the morning and evening twilight hours (Sealy 1974, Carter and Sealy 1990, Nelson 1997), and only rarely during daylight hours (Carter and Sealy 1990, Nelson 1997). During the non-breeding season Marbled Murrelets spend most of their time at sea, but may fly inland to visit nesting areas during the early morning hours (Naslund 1993, O'Donnell et al. 1995; pers. obs.).

At-sea surveys of Marbled Murrelets consistently report that murrelets forage in coastal waters within 2 km of shore (e.g. Burger 1995, Ralph and Miller 1995, Strachan et al. 1995, Strong et al. 1995, see also Carter and Sealy 1990, Golightly et al. 2004). Censuses have also shown a strong relationship between at-sea distribution of Marbled Murrelets and nearby nesting habitat (Meyer et al. 2002). Despite this, little is known of the exact distribution of Marbled Murrelets in their marine environment. It is not known if male and female Marbled Murrelets occupy the same at-sea areas, or likewise if nesting and non-nesting Marbled Murrelets occupy similar areas at sea. Recent studies (Beauchamp et al. 1999, Vanderkist et al. 1999) have observed that Marbled Murrelets exhibit a seasonal shift in their distribution and that male Marbled Murrelets may be more active than females during the breeding season (chick feeding). If the latter is true, then nesting male Marbled Murrelets

may utilize a greater home range than nesting females and non-nesting Marbled Murrelets, to help subsidize increased nutrient demands.

The Marbled Murrelet Recovery Plan (US Fish and Wildlife Service 1997) recognized the need for studies to determine the exact distribution of Marbled Murrelets at sea, and how this distribution varies seasonally and yearly. Information on the at-sea distribution of Marbled Murrelets would facilitate a pro-active response in the event of an oil spill and help refine mortality estimates after an oil spill. Knowledge of the at-sea distribution of Marbled Murrelets would also help agencies identify critical foraging and loafing areas, that could then be protected as necessary (e.g. Carter and Kuletz 1995).

The purpose of this study was to examine the at-sea locations of Marbled Murrelets during the breeding season and compare those locations by sex and nesting status (those that did not nest after capture, or those that nested after capture). We determined 1) their at-sea distribution relative to the shoreline and distance to old-growth forest, 2) the extent of travel during the breeding season, and 3) home range size on the ocean.

METHODS

CAPTURE

We captured Marbled Murrelets in the coastal waters of northern California between Big Lagoon and Gold Bluffs Beach (N 41.186: W 124.135 and N 41.388: W 124.062, respectively; 2001 – 2003), and in Trinidad Bay (N 41.069: W 124.171; 2002). Capture occurred between 2100h and 0400h, using the night-lighting and dip net technique (Whitworth et al. 1997). Capture crews, equipped with high intensity spotlights and a long-handled dip net, searched near-shore waters (within 5 km of shore) in two 4.5-m inflatable boats. A third 4.5-m inflatable boat served as a transport boat, and a safety\backup boat.

Captured Marbled Murrelets were transported, inside plastic tubs with lids, from the capture boat to a larger boat to collect data on morphology, attach radio-transmitters, and collect blood samples (hereafter handling process). At Trinidad Bay the processing site was a travel trailer next to the pier. Birds captured between Big Lagoon and Gold Bluffs Beach were processed on either the Humboldt State University research vessel *Coral Sea* (in 2001 - 2003), or a chartered 15-m fishing-trawler (in 2002 and 2003).

HANDLING PROCESS

We first examined murrelets for the presence of a brood patch. When present, brood patches were scored using the scale developed by Sealy (1974). Murrelets with a brood patch were examined using ultrasound to assess their reproductive status. In addition, we measured mass (g) using a 300-g Pesola spring scale, as well as bill length and depth (mm), and flattened wing chord length using dial calipers. Each murrelet was then banded with a U. S. Geological Survey stainless steel leg band. To each Marbled Murrelet captured, we attached a 2-g radio-transmitter, with a unique frequency (Model BD-2G, Holohil Systems Ltd., Ontario Canada), attached with a subcutaneous anchor (Mauser and Jarvis 1991), following the procedure described by Newman et al. (1999). A sub-sample of murrelets was sedated with Isoflurane prior to radio-attachment to assess the technique (Appendix A). Following attachment of the radio-transmitter we attempted to collect 1.5 - 2.0 ml of blood for analysis of reproductive hormones and for sex determination from genomic DNA using the methods outlined by Griffiths et al. (1996, 1998). After radio-attachment and blood collection, murrelets were returned to the plastic holding tubs for approximately 20 min, after which they were transported to their capture-site and hand-released onto the water. We observed the murrelets for normal behavior for approximately 30 seconds, or as deemed

appropriate based on the behavior of the bird. All birds exhibited normal behavior (flying, diving, preening) when released.

TELEMETRY FROM AIRCRAFT

Beginning the morning after the first capture session, we determined the locations of radio-marked murrelets from fixed-wing aircraft (Cessna 182 or 185). Aircraft were equipped with a receiver (model R4000, Advanced Telemetry Systems, Inc., Isanti, Minnesota) and either a 2-element H-antenna or a single-element omni-directional antenna. Locations of radio-marked Marbled Murrelets were established using a global positioning system (GPS) and aerial telemetry procedures (Gilmer et al., 1981, Whitworth et al. 2000a, b). Flights were conducted between 0800h and 2030h. The departure time and length of the aircraft flight depended on the weather, location of birds, and number of birds to be located. A bird detected inland after 0800h was considered to have initiated nesting.

At the beginning of each telemetry flight we recorded date, time, and weather conditions. Telemetry flights began over the ocean. If a bird was not detected at sea, the plane flew inland over areas with old-growth forest to determine the location of the bird. Flights typically occurred over coastal waters and adjacent old-growth forests between Eureka, California (N 40.47: W 124.09) to the south, and Crescent City, California (N 41.58: W 124.10) to the north. If a bird was not detected in this area, the search was expanded to the coastal waters and adjacent old growth forests south to Humboldt Redwoods State Park (N 40.19: W 123.55) and north to Brookings, Oregon (N 42.04: W 124.16).

Telemetry Accuracy.--To assist in scaling our field decisions about birds near the waters edge, it was necessary to understand the actual accuracy of the locations reported by the aircraft. We tested the accuracy of telemetry locations from ocean areas by constructing

error circles (Zimmerman and Powell 1995), and calculated a 95% probability of the true origin of the signal occurring within an area circumscribed by a circle around the assumed location. This circle had a radius that was the mean of the measured errors between the true points and the assumed locations (as located from aircraft telemetry) plus two standard deviations of that mean. To calculate the difference between the true location of the signal and the assumed location, we placed five to six transmitters on small plastic water bottles (590 ml) filled with 0.9% normal saline. These water bottles were placed on small styrofoam platforms, and each platform was set afloat and distributed to different locations on the ocean near Trinidad (N 41.03: W 124.08), California in 2001, and near Crescent City, California in 2002. Aircraft crews determined the location of each of the water bottles using telemetry, while boat crews noted the true location of the bottles with a GPS. Using a boat, the location of the transmitters was then changed and 30 min later the aircraft pilots again determined the location of the test radio-transmitters.

A second consideration in the telemetry determination of which birds nested and which birds did not, was the need for consistent detectability of birds (avoiding false negatives in at-sea detections). Assessment of the aircrafts effectiveness at detecting birds was confounded by occasional premature failure of the radio-battery. Early radio-battery exhaustion would cause premature radio failure, and subsequently the possibility of not observing a bird's nest initiation. If a radio-marked bird was not located during an aerial survey, but located during a subsequent survey, the radio was identified as active during all previous surveys. To determine the average percent detectability we calculated the ratio of the number of radio-transmitters located to the number of active radio-transmitters for each telemetry flight.

AT-SEA DISTRIBUTION AND MOVEMENTS

Locations of each bird were analyzed in a geographic information system (GIS) using the Animal Movement extension (Hooge and Eichenlaub 2000) for Arc-View (ArcView 3.3, Environmental Systems Research Institute, Redlands, California). For these analyses we only used data for Marbled Murrelets with radios that were active for at least 10 days, and for which we obtained a minimum of five detections. For each bird, we calculated the average distance to nearest shoreline (mean low tide). We used 2-sample t-tests to compare the distances from the beach for Marbled Murrelets that did and did not nest after capture (hereafter nesters and non-nesters, respectively). We also compared distance from shore between male and female Marbled Murrelets. We examined the maximum extent of along-shore movements by calculating the distance between the most extreme north and south locations (distance between the two locations that were furthest apart in the north-south direction) for each bird. In addition, we calculated the mean distance each bird traveled north and south of Redwood Creek (located in Redwood National Park; N 41.76: W 124.05).

We calculated minimum convex polygon home range size (km²) on the water using the Animal Movement extension (Hooge and Eichenlaub 2000). This allowed comparison of home range size between male and female Marbled Murrelets, and between nesters and non-nesters. For each polygon we removed 5% of the outliers. If a polygon included land mass, that portion of the polygon was removed using the “Erase” function in the X-Tools extension of ArcView (ArcView 3.3).

Statistical analyses were performed using SPSS software (ver. 11.5, SPSS corp, Chicago, IL). For each year (2001 – 2003), we used analysis of variance to compare average distance to shore, extent of maximum north-south movement, and home range size between

male and female Marbled Murrelets, and between nesters and non-nesters. For analysis of capture distances from shore, we made a post-hoc analysis using a Least Significant Difference (LSD) multi-comparison test. To minimize inter-year differences in the dependent variables we standardized the data using the method described by Perrins and McCleery (1985). The yearly mean of the dependent variable was subtracted from each observation and the result was divided by the yearly standard deviation. The resulting standardized data for each dependent variable were then analyzed using 2-factor analysis of variance (sex, nesting status). Although statistical analyses for the total sample were performed on standardized data, we present actual values.

RESULTS

CAPTURE AND HANDLING PROCESS

We captured and attached radios to 102 Marbled Murrelets between April and May during the three years, in coastal waters adjacent to Redwood National and State Parks, between Big Lagoon and Gold Bluffs Beach, California or near Trinidad, California (Table 3-1). Capture distance from shore differed significantly between years (ANOVA, Table 3-1); murrelets were captured significantly closer to shore in 2002 compared to 2003 (Least Significant Difference, $P < 0.05$).

TELEMETRY FROM AIRCRAFT

The number of flights, period of flights, detectability (number of birds detected per flight/ number of birds with functioning transmitters), and number of days of transmission varied between years (Table 3-2). The average number of days of transmission was calculated by excluding birds where radios failed within four days after release (4 cases) or if a bird died before the 10th day following capture (2 cases, see Appendix E for details). When

comparing the average number of days of transmission between nesters and non-nesters for each year, there was no significant difference in 2001 and 2003 ($P = 0.20$ and $P = 0.90$, respectively). However, there was a significant difference in 2002 ($F_{1,41} = 4.66$, $P = 0.037$).

Telemetry Accuracy.--With 45 test locations and four pilots, we calculated 95% probability error-circles of 15.5 km^2 and 4 km^2 for 2001 and 2002, respectively (Table 3-3).

AT-SEA DISTRIBUTION AND MOVEMENTS

Distance From Shore.--Mean distances from shore were similar between both males and females as well as between nesters and non-nesters, for each year ($P > 0.25$, $P > 0.90$, $P > 0.30$ for males/females; $P > 0.60$, $P > 0.90$, $P > 0.30$ for nesters/non-nesters; in 2001, 2002, 2003 respectively; Table 3-4). When the data were combined across years, mean distance to shore was similar between years ($P = 0.33$). Marbled Murrelets were located $1.4 \pm 0.1 \text{ km}$ ($n = 93$) from shore, on average. Overall, males and females were located at similar standardized distances from shore ($P > 0.95$; Table 3-5). Nesters were detected at a similar ($P > 0.80$) distance from shore as non-nesters (Table 3-5).

North-South Movements.--In 2001, radio-marked Marbled Murrelets ranged from the mouth of Humboldt Bay (N 40.82: W 124.18) to Brookings, Oregon (Fig. 3-1) and there was no difference in maximum extent traveled between the sexes or between nesters and non-nesters ($P > 0.50$ and $P > 0.45$, respectively; Table 3-6). In 2002, radio-marked Marbled Murrelets ranged from Punta Gorda (N 40.25: W 124.37; Mendocino County), north to Newport, Oregon (N 44.63: W 124.05; Fig. 3-2) and maximum extent traveled between sexes and between nesters and non-nesters was similar ($P > 0.10$ and $P = 0.20$, respectively; Table 3-6). In 2003, radio-marked Marbled Murrelets ranged from Cape Mendocino (N 40.43: W 124.42; Mendocino County), north to Alexander Island, WA (N 47.80: W 124.51; Fig. 3-3)

and maximum extent traveled was similar between sexes and between nesters and non-nesters ($P > 0.35$ and $P = 0.15$, respectively; Table 3-6).

Overall, there was a tendency for the mean maximum extent of north-south distance traveled by radio-marked Marbled Murrelets to differ between years, but this difference was not statistically significant ($F_{2,91} = 2.68$, $P = 0.074$). When the data were combined across years the mean standardized maximum extent of north-south distance traveled tended to be greater for male murrelets compared to female murrelets and this difference approached significance ($F_{1,85} = 3.8$, $P = 0.055$; Table 3-5). The mean standardized maximum extent of north-south distance traveled by non-nesters was significantly greater than nesters ($F_{1,85} = 4.99$, $P = 0.03$; Table 3-5). The standardized maximum extent of north-south distance traveled for male non-nesters tended to be greater than that of male nesters ($F_{1,42} = 3.7$, $P = 0.062$; Table 3-5). In contrast, the standardized maximum extent of north-south distance traveled by female nesters was similar to that of female non-nesters ($P > 0.20$; Table 3-5).

When the data were combined across years, murrelets were detected 16.7 ± 0.4 km ($n = 1840$ detections) south and 22.3 ± 0.8 km ($n = 1780$ detections) north of Redwood Creek. The maximum distance any bird went south of Redwood Creek was 119.9 km (Cape Mendocino, CA) and the maximum distance any bird went north of Redwood Creek was 724.5 km (Alexander Island, WA). Overall, there were six detections that were greater than 100 km south of Redwood Creek representing three murrelets, two of which were male. There were 26 detections that were more than 100 km north of Redwood Creek representing 12 birds, nine of which were male.

Home Range.--Mean home range size was estimated for all birds whose radio transmitters transmitted at least ten days. In 2001, home range size was similar for males and

females, and for nesters and non-nesters ($P > 0.10$ and $P > 0.30$, respectively; Table 3-7). In 2002 and 2003, the difference between males and females was not significant ($P > 0.15$ and $P > 0.25$, respectively; Table 3-7). However, non-nesters had significantly larger home ranges than nesters in 2002 and a tendency towards larger home ranges in 2003 ($F_{1,40} = 4.20$, $P = 0.047$ and $P > 0.10$, respectively; Table 3-7).

Between years, overall home range size was similar ($P = 0.42$). When the data were combined across years, the mean home range size for males was significantly larger than that of females ($F_{1,85} = 3.98$, $P = 0.049$; Table 3-5). Also, home range size for non-nesters was significantly larger ($F_{1,85} = 8.59$, $P = 0.004$) compared to nesters (Table 3-5). The interaction between sex and nesting status was also significant ($F_{1,85} = 4.84$, $P = 0.031$). Home range size for non-nesting males was significantly larger than nesting males ($F_{1,42} = 7.92$, $P = 0.007$; Table 3-5). In contrast, home range size of nesting females was similar to that of non-nesting females ($P > 0.30$; Table 3-5). Finally, when comparing within each reproductive group, non-nesting males had a significantly larger standardized home range size compared to non-nesting females ($F_{1,55} = 8.67$, $P = 0.005$; Table 3-5), while standardized home range size was similar for nesting males and females ($P > 0.70$; Table 3-5).

DISCUSSION

Previous studies have reported Marbled Murrelets using shallow marine habitats with upwelling, underwater sills, and tidal rips (Sealy 1975b, Carter and Sealy 1990, Ainley et al. 1995, Strong et al. 1995, Ostrand et al. 1998). Such sites likely concentrate prey, and can thus be spatially predictable (Carter and Sealy 1990). In northern California, the coastline is relatively free of embayments and promontories, and the continental shelf is narrow (< 35

km) for much of the coastline, with the exception of the waters of Eureka (about 40 km to the south of our study area) where the continental shelf broadens (< 50 km; Briggs et al. 1987).

Together, these characteristics should standardize the location of upwellings, and breadth of surface and subsurface currents along the coast of northern California, such that prey likely occurs at a relatively predictable distance from shore throughout much of our study area. Using an underwater camera and sonar during at-sea surveys, Golightly et al. (2004) observed that potential Marbled Murrelet prey targets occurred more frequently at 1.6 km from shore in waters averaging 30 m deep or less, regardless of sampling location, and the dispersion of Marbled Murrelets on the water showed a significant association with the presence of potential prey (see also Ostrand et al. 1998).

The average distance to shore recorded for radio-marked Marbled Murrelets in 2001-2003 (1.2 – 1.6 km) was similar to that observed by previous at-sea surveys off the coast of northern California (Ralph and Miller 1995) and Oregon (Strong et al. 1995). By comparison, Marbled Murrelets along the north coast of California, foraged at a greater distance from shore relative to Marbled Murrelets that foraged along the coast of central California (0.9 km; Burkett et al., unpublished data), or along the coast of British Columbia (< 1 km; Burger 1995). These differences may relate to overall differences in the topography of the coast, as well as associated bathymetric differences (e.g. Speich and Wahl 1995), and consequently prey distribution (Carter and Sealy 1990).

Distance from shore at which Marbled Murrelets were detected did not vary with sex or nesting status. By contrast, Loughheed (2000) observed that Marbled Murrelets nesting in British Columbia foraged closer to shore than non-nesting murrelets and argued that this minimized travel distance to the nest to feed a chick. The non-nesting murrelets may have

been less constrained by foraging efficiency, and thus could occupy safer and less productive waters more distant from shore (Lougheed 2000). The differences between our observations and those made by Lougheed (2000) may be due to differences in topography and bathymetric characteristics of the near shore waters. Considering that murrelets in Desolation Sound, B. C., nest an average of 39 km from their foraging grounds, foraging closer to shore may allow energy savings by reducing travel time. Conversely, radio-marked murrelets in northern California usually nested within 10 km of the coast, and thus it was unlikely that significant economies could be gained by foraging 500 m closer to shore, especially considering that prey species were also located further off shore (Golightly et al. 2004).

We observed a tendency ($P = 0.055$) for male Marbled Murrelets to travel greater north-south distances than female Marbled Murrelets, which was greater than our telemetry error. Also, the maximum north-south distance traveled by non-nesters was significantly greater than that of nesters. Similarly, males had significantly larger home range size than females and non-nesters had a significantly larger home range size compared to nesters. In fact, home range size was highly correlated with maximum extent of north-south distance traveled ($r = 0.859$, $n = 94$, $P < 0.001$). Therefore, since the distance from shore at which nesting and non-nesting murrelets were detected was similar, and male and female murrelets were also detected at similar distance from shore, differences in home range size by sex and nesting status likely reflect differences in the maximum extent of travel along the coast.

Larger home range size for non-nesting males may be affected by foraging inefficiency, not being constrained by the necessity of travel to a nest-site, and exploration of reproductive opportunities. First, as in other seabirds (e.g. Burger 1987, Williams et al.

1992) non-nesting males may have been younger and less experienced at foraging and thus needed to travel greater distances to find appropriate foraging areas. However, a similar argument could be made of non-nesting females. Non-nesting females had significantly smaller home range size compared to non-nesting males. Therefore, lack of foraging experience likely does not explain larger home range size for non-nesting males. An alternative explanation may be that all birds that did not nest after capture had been classified as non-nesters. The majority of the murrelets we captured had at least a partially developed brood patch. Thus it may have been possible that these individuals initiated nesting prior to capture and failed prior to or just after capture. This also makes it possible that birds which were classified as non-nesters may have included experienced birds.

A second explanation was that non-nesting males may be less constrained to a restricted area in which to forage. The non-nesting males did not need to travel to nest sites every other day during incubation and every day during the chick period. This would allow non-nesting males to track profitable prey without being constrained by traveling costs. In agreement with this, maximum extent of north-south distance traveled tended to be greater ($P = 0.067$) for non-nesting males compared to nesting males. However, it would be expected that non-nesting females would experience a similar lack of constraint on foraging efficiency associated with traveling to a nest. Non-nesting females had significantly smaller home range size compared to non-nesting males and these non-nesting females had a home range size similar to that of nesting females. Therefore, differences in constraints on foraging economy due to nesting do not explain the differences in home range size or travel extent between nesting males and non-nesting males, or non-nesting males and non-nesting females.

Finally, larger home range size for non-nesting males may be the result of behaviors associated with habitat selection, and/or mate-selection and courtship behavior. For instance, non-nesting males may visit several ‘staging’ (e.g. Sealy 1976) or foraging areas (e.g. Carter and Sealy 1990) searching for potential mates or perhaps even to obtain extra-pair copulations on the water (Quinlan 1984, see also Strachen et al. 1995) or inland (Nelson 1997). Also, given that 28 non-nesting males in our study had a brood patch at capture, it was inferred that these birds were failed breeders. Studies of other seabirds have noted in some cases that failed breeders can divorce (Bried et al. 1999, Ainley et al. 2002), and thus some ‘non-nesting’ males may have been failed breeders seeking new mates. In some instances, loss of a mate or divorce can be followed by a change in nest site (Butler and Buckley 2002). Therefore, visiting different staging areas may provide non-nesting individuals with cues relevant to habitat selection, in addition to seeking a mate.

Movement patterns of radio-marked murrelets during this study were consistent with current population genetics analyses (Friesen et al. 2005). The genetic analysis suggests that the northern California Marbled Murrelet population is distinct from the central California population (Friesen et al. 2005). Although murrelets off the coast of northern California did not move great distances from Redwood Creek, the main drainage into adjacent nesting habitat, three birds ventured more than 100 km south, whereas 12 birds ventured more than 100 km north. This suggests that if there is genetic drift, northern California birds are more likely to move north than they are south.

For Marbled Murrelets in northern California, at-sea distribution was influenced by several factors. The topography and associated bathymetric characteristics likely does not differ along the coastal region within our study area. This appears to concentrate Marbled

Murrelets, irrespective of sex or nesting status at a fairly predictable distance from shore.

However, non-nesting males tended to forage over a wider area compared to nesters. Non-nesting males may be exploiting reproductive opportunities at more distant locations while nesting murrelets optimized energy by minimizing the extent of their movements.

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FIGURE 3-1. At-sea locations of radio-marked Marbled Murrelets (indicated by solid-black triangle) obtained during aircraft telemetry in 2001.



FIGURE 3-2. At-sea locations of radio-marked Marbled Murrelets (indicated by solid-black triangle) obtained during aircraft telemetry in 2002.

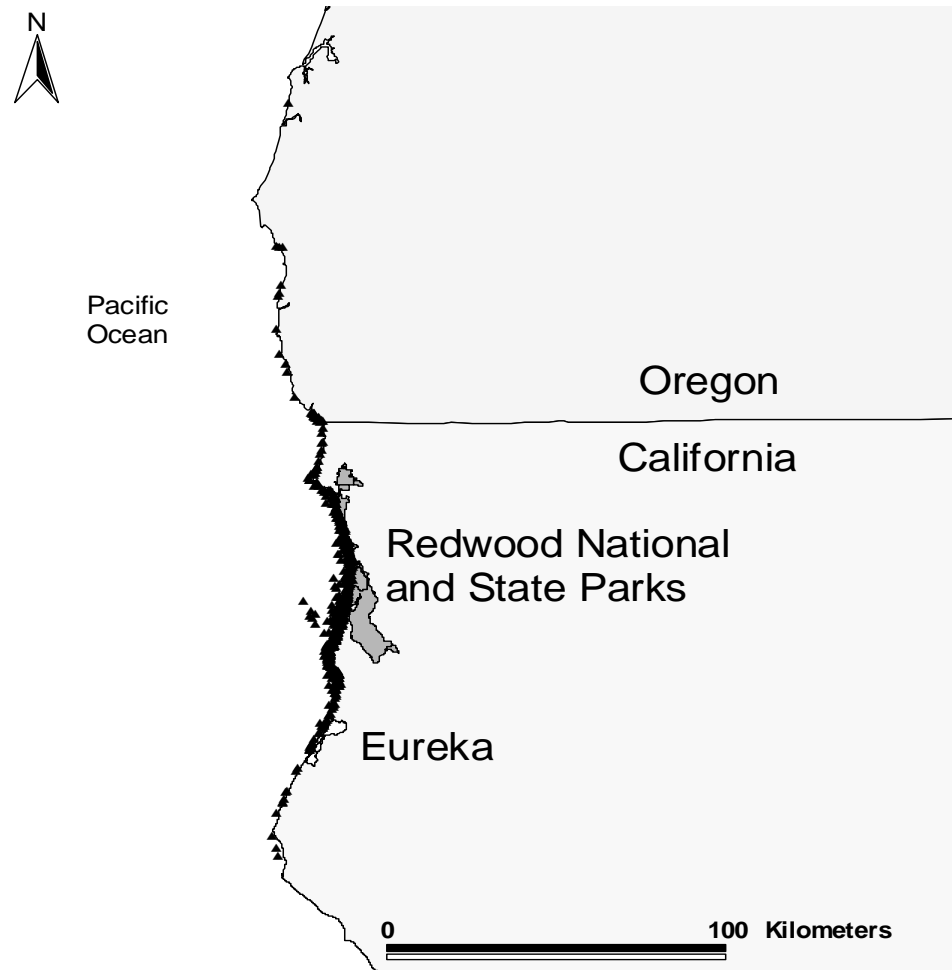


FIGURE 3-3. At-sea locations of radio-marked Marbled Murrelets (indicated by solid-black triangle) obtained during aircraft telemetry in 2003. Data is not shown for a Marbled Murrelet that went as far north as Alexander Island, Washington.

TABLE 3-1. Number of Marbled Murrelets captured in coastal waters adjacent to Redwood National Park, California from 2001-2003 and the distance of the capture from shore.

	2001	2002	2003	F	<i>P</i>
Distance from shore (m)	1871 \pm 362	1535 \pm 109	2444 \pm 186	8.1	0.001
Number captured	23	44	38		
n (used in calculations) ¹	12	38	38		

¹ n differs from number captured because accurate location of capture did not always occur.

TABLE 3-2. Flight extent, number of flights, radio detectability and mean number of days that all Marbled Murrelet transmitters were functional in northern California from 2001-2003. Detectability is the number of birds detected per flight divided by the number of birds with functioning transmitters.

	2001	2002	2003
Flight Dates			
First flight	13 Apr	13 Apr	17 Apr
Last flight	19 Aug	26 Aug	6 Aug
Detections From Aircraft			
Number of flight days	94	103	72
Radio detectability (%)	92.7	90.9	83
Radio Transmission			
Maximum Radio Life (of at least one radio)			
Period	13 Apr – 12 Aug	13 Apr – 26 Aug	17 Apr – 6 Aug
Days	121	135	111
Mean (\pm SE) Radio Transmission (days)			
All birds (<i>n</i>)	55.7 \pm 6.7 (23)	65.3 \pm 3.7 (44)	48.3 \pm 4.4 (35)
All birds with early failures excluded ^{1(a-c)} (<i>n</i>)	64.6 \pm 6.3 ^{1a} (20)	66.8 \pm 3.5 ^{1b} (43)	50.4.6 \pm 4.2 ^{1c} (33)
Nesters (<i>n</i>)	78.8 \pm 14.4 (5)	74.2 \pm 3.8 (21)	50.2 \pm 4.9 (25)
Non-nesters (<i>n</i>)	59.9 \pm 6.7 (15)	59.8 \pm 5.4 (22)	51.7 \pm 8.1 (8)

^{1a} Two birds excluded for which radio-transmitters failed soon after release and another bird with few locations (found dead).

^{1b} One bird excluded due to failure of radio-transmitter soon after release.

^{1c} One bird excluded due to failure of radio-transmitter soon after release and another with few locations (presumed dead).

TABLE 3-3. Telemetry accuracy tests for aircraft and pilots used to determine locations of Marbled Murrelets in northern California from 2001-2002.

Year	Number of Test Locations	Number of Pilots	Straight Line Error (m)		
			Mean	SD	Range (mean by pilot)
2001	20	3	747	737	147 - 1369
2002	25	4	468	332	183 - 924

TABLE 3-4. Mean distances (km) of Marbled Murrelet detections from shore in northern California from 2001-2003.

	2001		2002		2003	
	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n
All Murrelets	1.5 ± 0.1	20	1.4 ± 0.1	42	1.2 ± 0.1	32
Males	1.6 ± 0.2	5	1.4 ± 0.1	22	1.2 ± 0.1	17
Females	1.4 ± 0.1	14	1.4 ± 0.2	18	1.4 ± 0.2	13
Nesters	1.4 ± 0.1	5	1.4 ± 0.1	21	1.1 ± 0.2	8
Non-nesters	1.5 ± 0.1	15	1.3 ± 0.2	21	1.3 ± 0.1	24

TABLE 3-5. Distance to shore ($\bar{x} \pm SE$), maximum extent of north-south distance traveled, and home range size for Marbled Murrelets located in nearshore waters of northern California. Data were combined for 2001-2003.

	Distance to shore (km)		North-South Distance (km)		Home Range Size (km)	
	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n
Gender						
Male	1.3 ± 0.1	45	120 ± 19	45	682 ± 148	45
Female	1.4 ± 0.1	45	79 ± 6	45	344 ± 48	45
Nesting						
All nesters	1.3 ± 0.1	34	72 ± 7	34	240 ± 38	34
All non-nesters	1.4 ± 0.1	60	114 ± 14	60	655 ± 111	60
Male only non-nesters			152 ± 31	25	1018 ± 238	25
Female only non-nesters			83 ± 7	32	375 ± 60	32
Male only nesters			78 ± 9	19	239 ± 46	19
Female only nesters			69 ± 11	13	269 ± 74	13

TABLE 3-6. Mean maximum extent of north-south distances (km) traveled by Marbled Murrelets, along the coast in northern California from 2001-2003.

	2001		2002		2003	
	$\bar{x} \pm \text{SE}$	n	$\bar{x} \pm \text{SE}$	n	$\bar{x} \pm \text{SE}$	n
All Murrelets	69.7 ± 8.1	20	92.1 ± 10.4	42	126.7 ± 23.2	32
Males	79.0 ± 19.4	5	109.4 ± 17.9	22	146 ± 42	17
Females	65.8 ± 9.6	14	74.1 ± 8.6	18	100.0 ± 12.0	13
Nesters	53.1 ± 10.5	5	78.5 ± 9.8	21	68.1 ± 7.6	8
Non-nesters	75.3 ± 10.0	15	106.0 ± 18.1	21	146.3 ± 29.9	24

TABLE 3-7. Mean home range size (km²) of Marbled Murrelets along the coast in northern California from 2001-2003.

	2001		2002		2003	
	$\bar{x} \pm \text{SE}$	n	$\bar{x} \pm \text{SE}$	n	$\bar{x} \pm \text{SE}$	n
All Murrelets	330 ± 85	20	442 ± 85	42	697 ± 179	32
Males	556 ± 279	5	554 ± 148	22	884 ± 324	17
Females	254 ± 69	14	318 ± 72	18	477 ± 103	13
Nesters	381 ± 110	15	274 ± 58	21	866 ± 230	24
Non-nesters	175 ± 67	5	609 ± 153	21	192 ± 95	8

CHAPTER 4

TEMPORAL PATTERNS OF MARBLED MURRELETS (*BRACYRAMPHUS MARMORATUS*) FLYING TO INLAND FOREST SITES IN REDWOOD NATIONAL AND STATE PARKS, CALIFORNIA

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The Marbled Murrelet (*Brachyramphus marmoratus*) is a small (24-25 cm long, 188-269 g) seabird in the family Alcidae that forages in near-shore ocean waters (within 5 km of land) and nests in mature coastal forests from central California to southern Alaska (Ainley et al. 1995, Ralph et al. 1995, Nelson 1997). Marbled Murrelets do not construct nests, but lay a single egg in a depression of moss or duff on large diameter limbs in the upper canopy of old growth conifer forests (Sealy 1974, Singer et al. 1991, Burger 1995, Hamer and Nelson 1995b, Nelson 1997). It was not until 1974 that the first tree nest of a Marbled Murrelet was discovered (Binford et al. 1975).

Demographic analysis of murrelet populations prior to 1995 predicted a 4-6% decline per year in the Pacific Northwest (Beissinger 1995, USFWS 1997). More recent analysis concluded that Marbled Murrelet populations in California were at risk of extinction within 100 years (McShane et al. 2004) and reproductive rates of murrelets in northern California are too low to sustain current population levels (Chapter 2). The decline of Marbled Murrelets throughout the Pacific Northwest was precipitated by fragmentation and substantial loss of nesting habitat (USFWS 1992, USFWS 1997). As of 1986, Fox (1988) concluded that old-growth coast redwood (*Sequoia sempervirens*) forests comprised only 9.5% of their former range with the most dense old growth redwoods occurring in only 3.9% of their former range. In recent times new factors have continued the decline of murrelets including poor reproductive rates due to predation (Chapter 2), and mortality from gill net fisheries and oil spills (USFWS 1992, USFWS 1997). The state of California recognized the need to protect Marbled Murrelets and identified them as Endangered in 1992 (California Code of Regulations Title 14 650.5(a)(5)(r), CDFG 2000). Later in the same year, Marbled

Murrelets were declared threatened in Washington, Oregon, and California and afforded protection through the federal Endangered Species Act (USFWS 1992).

It was estimated that Marbled Murrelets likely delayed breeding until age 3 (range 2-5 years) and lived an average of 10 years (Beissinger 1995, De Santo and Nelson 1995, McShane et al. 2004). Murrelets are asynchronous breeders and can initiate nesting as early as late March (Hamer and Nelson 1995a, McShane et al. 2004). In northern California, Marbled Murrelets have initiated nesting in late April to early May, and as late as mid July (Hamer and Nelson 1995b, Golightly et al. 2002, Chapter 2). One egg is laid and both sexes alternate incubation in 24 hour shifts for approximately 27-30 days (De Santo and Nelson 1995). Thus, every 24 hours during incubation one member of the nesting pair flies inland to the nest while its mate returns back to the sea to feed. Newly hatched chicks are semi-precocial and downy (De Santo and Nelson 1995).

Sustainable populations require suitable habitat conditions for their survival and reproduction (Block and Brennan 1993). Marbled Murrelets nest in terrestrial habitats, which are characterized by low elevation mature old-growth coniferous forests from southern Alaska to central California (Paton and Ralph 1990, Singer et al. 1991, Burger 1995, Grenier and Nelson 1995, Hamer 1995, Kuletz et al. 1995, Miller and Ralph 1995, Raphael et al. 1995, USFWS 1997). Paton et al. (1990) developed a standardized inland survey protocol to assess inland habitat use by Marbled Murrelets, which has since been improved (Ralph et al. 1994, Evans Mack et al. 2003). This protocol used audio and visual detections of Marbled Murrelets to determine relative activity over broad landscapes. The protocol cannot be used to estimate numbers of individuals or pairs at a site, or extrapolate estimates of density or abundance (Mandsen et al. 1999). The behaviors of murrelets detected by the protocol have

been used to classify a site as “occupied” and, hence potentially important for breeding (Evans Mack et al. 2003). However, this protocol cannot determine if nesting actually occurred at a site, and the true relationship between behavioral observation of murrelets and the potential for breeding has not been determined. This inland survey protocol has been commonly used in terrestrial investigations of Marbled Murrelet biology (Paton and Ralph 1990, Singer et al. 1991, Naslund 1993, Burger 1995, Grenier and Nelson 1995, Hamer 1995, Kuletz et al. 1995, Miller and Ralph 1995, Naslund and O’Donnell 1995, O’Donnell et al. 1995, Meyer et al. 2002, Rodway and Regehr 2002). Similarly, researchers have used radar to document birds that have flown inland and to determine relative use of different forest stands by Marbled Murrelets (Burger 1997, Loughheed 1998, Chatwin et al. 1999, Cooper and Blaha 1999, Raphael et al. 1999, Singer and Hamer 1999, Cooper et al. 2001, Burger 2001, Raphael et al. 2002). However, neither method can be used to locate specific nest sites, determine reproductive success, or separate inland detections of murrelets into those that nest and those that do not nest.

Cooke (1999) suggested that only breeding Marbled Murrelets have entered and left inland forests during the breeding season, yet others have presumed that non-nesting murrelets also visited forest stands in the breeding season (Nelson 1997). It has been suggested that non-nesting Marbled Murrelets regularly flew inland during the breeding season (Peery et al. 2004). If the behavior of non-nesters or failed nesters differed from nesting birds, better interpretation could be made of terrestrial visits. This could improve audio and visual survey methods, radar methods, and add biological insight. Behavioral differences between the different inland flying murrelets may include timing of flying inland,

length of time spent inland, or patterns of flight. Additionally, males could differ from females in any of these parameters.

Our objectives were to 1) describe temporal patterns of Marbled Murrelets flying to inland forest sites; 2) identify potential changes in timing of inland flights with stage of reproductive cycle; 3) identify the characteristics of the birds that flew inland (nester or non-nester); and 4) assess the appropriateness of audio/visual and radar surveys to identify nesters. Specifically, we examined whether timing of inland flights differed between nesting and non-nesting Marbled Murrelets, and between male and female Marbled Murrelets. Further, we examined if the duration of inland flights differed between nesting and non-nesting, or between male and female Marbled Murrelets.

To investigate these patterns, it was necessary to identify sex and breeding status, as well as reliably detect these birds when they flew inland. We used radio transmitters to detect when birds flew inland. When captured for radio transmitter attachment, blood was obtained and we used DNA and ultrasound techniques to identify gender and assess breeding status. Further, nesting was determined (see Chapter 2) to establish chronology for comparison to inland flights of specific individual murrelets.

STUDY AREA

Redwood National and State Park (hereafter RNSP) is located on the northern California coast in Humboldt and Del Norte Counties (Figure 4-1) and is cooperatively managed between the National Park Service and California Department of Parks and Recreation. RNSP preserves the largest remaining contiguous forest composed of ancient coast redwood (*Sequoia sempervirens*; National Park Service 1999). The park was established in 1968, expanded in 1978, and preserved nearly 16,000 ha of old-growth

redwood forests (National Park Service 1999). Recent expansion in the Mill Creek watershed of Del Norte County added approximately 81 ha of old-growth redwood in 2002 (J. B. Wheeler, National Park Service, personal communication). Old-growth coniferous forests dominated by redwood trees are critical habitat for Marbled Murrelets nesting in northern California (Ralph et al. 1995, USFWS 1992, 1997, CDFG 2000) and previous studies have documented the value of this region for murrelets both inland (Paton and Ralph 1990, Carter and Erickson 1992, O'Donnell 1993, Miller and Ralph 1995) and at-sea (Carter and Erickson 1992, Miller et al. 2002).

The park is bisected by U.S. Highway 101 and has about 264 km of trails used by pedestrians, bicyclists, and equestrians (National Park Service 1999). Nearly 400,000 visitors a year (National Park Service Public Use Statistics Office 2002, 2003) come to the park primarily to beach-comb, picnic, hike, view wildlife, and camp in the old-growth redwoods (National Park Service 1999). The redwood coast region is characterized by a maritime climate with cool, dry summers (13-18°C) and wet, mild winters (7-13°C; Harris 1991).

METHODS

MURRELET CAPTURE AND RADIO-TRANSMITTER ATTACHMENT

Marbled Murrelets were captured on near-shore coastal waters of Humboldt County, California between Clam Beach (40°60'N, 124°7'W) and Gold Bluffs Beach (41°24'N, 124°4'W) with the intent of sampling birds that would use adjacent inland habitats of RNSP. By capturing murrelets at-sea and not inland, sampling of the inland nesting area was not biased by investigator assumptions about terrestrial habitat use. Capture effort occurred at

sea between 2100 and 0400 hours using the dip-net, night-lighting technique (Whitworth et al. 1997, see Chapter 2).

Captured Marbled Murrelets were inspected for evidence of a brood patch and if present, the brood patch was indexed on a scale of 0-6 according to Sealy (1974). Ultrasound was also performed on birds with brood patches to help determine gender (Chapter 2). All murrelets had a uniquely numbered stainless steel U.S. Geological Survey leg band attached. Radio transmitters (weight was 2g, Model BD-2G, Holohil Systems, Ltd., Ontario, Canada) with unique frequencies were attached to each bird using a subcutaneous anchor and suture (Mauser and Jarvis 1991, Newman et al. 1999). Approximately 1.5 – 2.0 ml of blood was collected from the medial metatarsal vein for analysis of sex. Murrelets were placed in plastic bins for approximately 20 min after transmitter attachment and then transported to their site of capture and released.

LOCATING MARBLED MURRELETS

Marbled Murrelet locations were determined using radio telemetry receivers (model R4000, Advanced Telemetry Systems Inc., Isanti, Minnesota, USA). Three methods were used to locate individual birds: 1) telemetry from aircraft, 2) automated telemetry stations, and 3) manual telemetry. Telemetry from aircraft (aerial telemetry) was performed from fixed-wing aircraft (Cessna 182, 185) with a 4 element Yagi or dipole antenna. Flights were conducted between 0800h and 2030h over the study site and adjacent near-shore waters to locate individual murrelets. Locations of radio-marked birds were established using a global positioning system (GPS) and procedures followed Gilmer et al. (1981). Telemetry flights were attempted every day between first radio transmitter attachment and last radio signal, but weather and equipment failure caused days to be missed.

Automated telemetry stations with fixed antennae and data recording capability (radio frequency and time) were deployed throughout the area where nests were located by aircraft. The automated telemetry stations collected continuous presence/absence data of radio-marked Marbled Murrelets 24 hrs per day, 7 days per week from 18 April to 26 August in 2002 and from 2 May to 15 July 2003. Automated telemetry stations were placed in known flyways, in stands with known occupied behavior, and near nests that were located by aerial telemetry. However, logistics of installation and maintenance of the equipment also determined locations of automated stations. The telemetry stations were relocated if they did not detect radio-marked murrelets.

The automated telemetry stations were composed of a R4000 receiver and a data collection computer (model # DCCII D5041, Advanced Telemetry Systems Inc., Isanti, Minnesota, USA) powered by a 12-volt deep-cycle marine battery. The equipment was secured in a locked, camouflaged, steel box with a 3 or 4 element Yagi antenna elevated approximately 3.5 m and directed upstream in drainages or toward active nests. Batteries were replaced every 5-7 days. Data from the automated telemetry data collection computers were downloaded into a laptop computer every 5-7 days using software program Procomm Plus (version 4.8, Symantec Corporation, Cupertino, California, USA) with Advanced Telemetry Systems Inc. script GETDATA. The data collection computers were programmed to use pulse-rate pattern matching to decipher valid transmitter signals from noise-corrupted frequencies. Data collection computer frequency tables were updated weekly so as to scan and record only active transmitter frequencies (missing/inactive radios were determined from at-sea aerial flight telemetry).

In addition to aerial telemetry and automated telemetry stations, ground based manual telemetry surveys were performed throughout the study area to locate radio-marked murrelets in areas not available for deployment of automated telemetry stations. Manual telemetry surveys focused on areas with known radio-marked murrelets and on areas of appropriate habitat where radio-marked murrelets had not been detected. In this way we minimized the chance of missing any inland-flying radio-marked murrelets. Manual telemetry surveys were conducted approximately 50 min before sunrise and ended approximately 45 min after sunrise (mimicking the standard inland audio-visual survey protocol; Evans Mack et al. 2003) from 9 May to 20 August 2002 and from 22 April to 30 July 2003. In addition to dawn telemetry surveys, in 2003 similar manual telemetry surveys were conducted in the evening beginning approximately 20 min before sunset and ending approximately 1.5 hrs after sunset. At the beginning of each survey, date, time, location, observer, cloud cover, and precipitation were recorded. The receivers were equipped with either a 3 element folding Yagi antennae (Advanced Telemetry Systems Inc., Isanti, Minnesota, USA) or a 2 element “H” style antenna (model RA-2AK, Telonics, Inc., Mesa, Arizona, USA) and used to locate Marbled Murrelets from a stationary location. All active radio frequencies of marbled murrelets were scanned at either 2 or 4 second intervals. When a signal was detected, the receiver was paused on that frequency and the direction (bearing) and activity (flying or stationary) of the bird were recorded. Throughout the survey, bird frequency, detection time, signal strength, bearing, and calls/sightings were recorded for each manual telemetry detection.

To ensure coverage of the study area with automated telemetry stations and manual telemetry surveys, minimum convex polygons were constructed using all nest site locations

and a geographic information system (ArcView GIS 3.3, Environmental Systems Research Institute, Inc., Redlands, California, and Animal Movement Program 2.0 extension, Hooze et al. 1999). These polygons delineated the primary area to focus effort, but additional surveys were conducted elsewhere to ensure that radio-marked Marbled Murrelets did not go undetected inland.

DATA ANALYSIS

Individual Marbled Murrelets were categorized into three groups for analyses: 1) nesters, 2) birds that flew inland but did not nest, and 3) birds that never flew inland. Nesters were defined as radio-marked Marbled Murrelets that were detected on a nest on at least one day according to aerial telemetry. Birds that flew inland but did not nest (non-nesters inland) were defined as birds that were never detected on a nest, but were detected inland at least once on a ground based manual telemetry survey or by an automated telemetry station. Birds that were never detected on a nest and never detected inland by any means were classed as birds that never flew inland. Only nesters and non-nesters that flew inland were included in temporal analyses.

Nesting Marbled Murrelets were also categorized into the following 4 breeding phases: pre-laying, incubating, chick rearing, and post nesting (after fledging or failure). Since Marbled Murrelets incubated in 24 hr shifts where the birds flew to and from the nest at dawn, the incubating phase was excluded from duration and evening temporal analysis. It was not possible to categorize non-nesting birds flying inland into similar time periods for comparative analysis because Marbled Murrelets were very asynchronous nesters and the breeding phases were consequently not discrete.

To analyze possible temporal differences between nesting and non-nesting murrelets through the breeding season, we divided the season into thirds (early, middle, late) based on the first and last inland detection for each year. In 2002, the early, middle, and late periods were 7 May to 7 June, 8 June to 8 July, and 9 July to 9 August, respectively. In 2003, the early, middle, and late periods were 24 April to 21 May, 22 May to 17 June, 18 June to 15 July, respectively.

Radio telemetry locations were not exact unless murrelets were present coincidentally with the radio signal. All automated and manual telemetry stations were either far enough away from the ocean, or blocked by terrain, such that birds on the ocean were not confused with inland flights. The initial time detected inland was recorded in minutes after sunrise for dawn surveys and minutes before sunset for evening surveys. The duration (in minutes) of inland flights of individual Marbled Murrelets were calculated as the difference between the first and last detection of a specific bird. Initial timing samples and duration samples were not the same because in some cases a bird was detected only once, which did not always allow a duration calculation. Official sunrise and sunset times were obtained from the U.S. Naval Observatory Astronomical Applications Department (Washington, DC; <http://aa.usno.navy.mil/data>).

Differences in the proportion of radio-marked Marbled Murrelets detected inland between years were compared using the chi-square test statistic. Two Sample T-tests (Zar 1999) were used to compare brood patch scores between years, and Analysis of Variance (Zar 1999) was used to test for differences in brood patch score between groups (nester, non-nester inland, non-nester never inland) within years. Because some analyses required repeated measures on individual radio-marked murrelets (an individual bird flying inland

several times through the season), we used Repeated Measures Analysis of Variance (Kuehl 2000, Hintze 2001). Inland flight duration and initial time of inland flights were compared using Repeated Measures Analysis of Variance with year, sex, and class as fixed independent variables, and individual bird as a repeated independent variable. Birds of unknown sex were excluded from analyses. The Tukey-Kramer Multiple Comparison Test was used to determine differences within independent variables. Sample sizes associated with the duration and initial timing of murrelet inland flights were the number of murrelet flights used in the analysis and not the number of birds. Data are presented as mean \pm 1 S.E. All data analyses were conducted using NCSS statistical software (Hintze 2001).

RESULTS

In 2002, 44 Marbled Murrelets were captured and marked with radio transmitters. The effort to locate these birds consisted of 103 aerial telemetry flights, 76 ground based manual telemetry dawn surveys, and 517 automated telemetry days (6 stations at 7 locations, Figure 2). In 2003, 35 Marbled Murrelets were captured and marked with radio transmitters. The effort to locate these birds consisted of 69 aerial telemetry flights, 67 dawn and 26 evening ground based manual telemetry surveys, and 340 automated telemetry days (6 stations at 8 locations, Figure 3).

In 2002, 34 radio-marked murrelets (77%) were detected inland at least once and 10 murrelets (23%) were never detected inland. Of the birds detected inland, 21 initiated nesting, whereas 13 never exhibited observable nesting behavior. However, 8 (62 %) of the inland non-nesting murrelets had a brood patch score of 2 or greater (see chapter 2) at capture. Of the birds marked in 2003, 24 murrelets (69%) were detected inland at least once and 11 murrelets (31%) were never detected inland. Of the birds detected inland, 8 were

known to have initiated nesting, whereas 16 never exhibited observable nesting behavior. Of the 16 birds that did not nest but flew inland, 7 (44%) had a brood patch scores of 2 or greater (see chapter 2) at capture. Although the proportion of birds detected flying inland did not differ between years ($\chi^2 = 0.76$, $df = 1$, $P > 0.3$), significantly more radio-marked Marbled Murrelets initiated nesting in 2002 (61.8%) than in 2003 (33.3%; $\chi^2 = 4.55$, $df = 1$, $P = 0.03$).

Brood patch score also differed between years ($P = 0.006$, $F = 7.72$, $df = 1$; 2-way ANOVA), but not between sexes ($P = 0.54$, $F = 0.38$, $df = 1$; Table 4-1). Marbled Murrelets in 2002 had significantly greater brood patch scores on average than in 2003. Within years, brood patch scores were similar between males and females in 2002 ($t = 2.02$, $df = 41$, $P = 0.76$) and in 2003 ($t = 2.04$, $df = 31$, $P = 0.27$). In 2002 brood patch score for nesting murrelets was significantly greater than scores for non-nesting murrelets detected inland and non-nesting murrelets never detected inland; there was no difference in brood patch score between the two non-nesting groups ($F = 6.59$, $df = 2$, $P = 0.003$). In 2003 brood patch score did not differ between the three groups of radio-marked murrelets ($F = 1.34$, $df = 2$, $P = 0.28$).

INLAND FLIGHT DURATIONS

Using detections from automated and manual telemetry methods, a total of 436 inland flight durations were measured for Marbled Murrelets with 386 (88.5%) in 2002 and 50 (11.5%) in 2003. Of the 391 dawn inland flight durations recorded, 341 (87.2%) were in 2002 and 50 (12.8%) were 2003. Forty-five evening inland flight durations were recorded in 2002 and none were recorded in 2003.

The duration of morning Marbled Murrelet inland flights differed significantly between years ($P = 0.004$, $F = 9.19$, $df = 1$; 3-way ANOVA), but not between sex or whether they nested or did not nest ($P = 0.49$, $F = 0.48$, $df = 1$; $P = 0.79$, $F = 0.07$, $df = 1$; respectively). Inland flights were nearly 3 times longer in 2002 than in 2003 (Table 4-2).

Durations of evening flights were only recorded in 2002 despite the added effort of evening manual telemetry surveys in 2003. Nesting birds were 95.6% ($n = 43$) of evening inland flights in 2002 and had a duration of 14.0 ± 1.3 minutes. Non-nesting murrelets in the evening of 2002 had a duration of 15.0 ± 3.0 ($n = 2$) minutes. The duration of evening flights were similar between males (14.7 ± 1.8 , $n = 27$) and females (12.9 ± 1.8 , $n = 18$) in 2002 ($F = 1.16$, $df = 1$, $P = 0.32$).

For 2002 we compared the difference between dawn flight durations and evening flight durations (Table 4-3). In general, morning flight durations were significantly longer than evening flight durations. The duration of inland flights for nesting radio-marked Marbled Murrelets in 2002 were significantly longer at dawn than at dusk. Only 2 durations were recorded for evening inland flights for non-nesting murrelets so statistical analysis was not possible for non-nesting murrelets. The duration of male murrelets flying inland in 2002 were significantly longer at dawn than at dusk. The duration of female murrelet inland flights in 2002 did not differ between morning and evening.

INITIAL TIME DETECTED INLAND

The initial time in the morning that radio-marked Marbled Murrelets were detected inland did not differ between years ($F = 0.18$, $df = 1$, $P = 0.67$), sexes ($F = 0.39$, $df = 1$, $P = 0.53$), or whether a bird was grouped as a nester or as a non-nester inland ($F = 2.05$, $df = 1$, $P = 0.16$; Table 4-4). The initial time that murrelets were detected inland in the evening

appeared to be different between years, but the few evening samples in 2003 prevented statistical analysis (Table 4-4). Of all initial evening flight times, 92.2% were in 2002 and only 7.8% were in 2003. In 2002, nesting birds appear to have flown in earlier in the evenings than non-nesting birds, but small non-nester sample size prevented statistical analysis. Male murrelets in 2002 statistically flew in at similar times in the evening as females ($F = 0.35$, $df = 1$, $P = 0.57$), however male inland flights were highly variable and averaged 23 minutes earlier than females. In 2003, all evening inland flights were of nesting birds. Although there were inadequate samples to test statistically, male inland flights appeared to occur later than females (Table 4-4).

DIFFERENCES IN DURATION AND INITIAL TIME OF INLAND FLIGHTS BY NEST PHASE

The inland flight durations of nesting murrelets were stratified into the periods pre-lay, chick rearing, and post nesting. In 2002, 245 dawn inland flight durations were recorded for these periods, whereas in 2003 only 20 dawn inland flight durations were recorded (Figure 4-4). Because of the small sample size for dawn inland flight durations in 2003, statistical analysis was limited to 2002. The duration of dawn inland flights significantly differed by nest phase for nesting birds in 2002 ($F = 7.41$, $df = 2$, $P = 0.005$). The duration of dawn inland flights for post nesting birds were significantly longer than flights of birds in the pre-lay and chick rearing phases (multiple comparison test, $P < 0.05$).

In the evenings of 2002, no birds in the pre-lay phase were detected flying inland, and 83.3% of the inland flights were of nesting murrelets in the chick rearing phase (Figure 4-5). There was no difference in duration of inland evening flights between birds in the chick rearing and post nest phases in 2002 ($F = 0.04$, $df = 1$, $P = 0.85$; Figure 4-5). Although 3

birds flew inland in the evening in 2003, no evening durations could be calculated because of a lack of starting and finishing points.

The initial times that nesting murrelets were detected inland at dawn were also stratified by breeding stage, including incubating. In 2002, the timing of murrelets flying inland in the morning significantly differed by breeding phase ($F = 9.20$, $df = 3$, $P < 0.001$; Figure 4-6). The timing of inland flights of chick-rearing murrelets were significantly later in the morning than inland flights of murrelets in other breeding phases (multiple comparison test, $P > 0.05$). In 2003 there were no differences between the timing of inland flights for murrelets when compared between the four breeding periods ($F = 0.84$, $df = 3$, $P = 0.47$), but only 5 observations occurred during the chick rearing phase (Figure 4-6).

The timing of evening inland flights of nesting murrelets was also stratified into breeding phases, but the incubating phase was excluded because the 24 hr incubation changes occurred at dawn. In 2002, initial evening times were recorded for 62 inland flights of nesting murrelets, whereas in 2003 initial evening times were recorded for 4 inland flights of nesting murrelets (Figure 4-7). No nesting murrelets were recorded flying inland in the evening of 2002 or 2003 during the pre-lay phase. In 2002, nesting murrelets in the chick rearing and post nesting phase flew inland at similar times before sunset ($F = 0.04$, $df = 1$, $P = 0.85$). In 2003, the initial time for 3 evening inland flights recorded for nesting murrelets in the chick rearing phase were well before sunset (Figure 4-7). One evening flight occurred during the post nesting stage in 2003 at 167 minutes after sunset.

SEASONAL DIFFERENCES BETWEEN NESTING AND NON-NESTING MURRELETS

When the study season was divided into thirds (early, middle, and late), the duration of morning inland murrelet flights were similar across the season within years for nesting and

non-nesting Marbled Murrelets (Figure 4-5). When compared between years, the duration of morning inland murrelet flights were significantly longer in 2002 than in 2003 for the early ($F = 8.99$, $df = 1$, $P = 0.006$) and late periods ($F = 4.42$, $df = 1$, $P = 0.048$), but not different for mid season ($F = 3.05$, $df = 1$, $P = 0.09$; Table 4-5). The duration of morning inland flights were similar between nesting and non-nesting murrelets during each period in 2002 (early $F = 0.07$, $df = 1$, $P = 0.79$; mid $F = 0.24$, $df = 1$, $P = 0.63$; late $F = 1.06$, $df = 1$, $P = 0.32$; Table 4-5). Small sample sizes prevented statistical comparison of nesting and non-nesting dawn inland flight durations in 2003 (Table 4-5).

Evening inland flight durations were only recorded for radio-marked murrelets in the mid and late season of 2002. Evening inland flights of nesting murrelets were 16.8 ± 2.4 minutes ($n = 16$) in mid season and 12.3 ± 1.5 ($n = 27$) in late season. One non-nesting murrelet evening duration was recorded in mid season (18.0 minutes) and one in late season (12.0 minutes).

Initial morning flight times of radio-marked murrelets were similar across the 3 seasonal periods within years for nesting and non-nesting Marbled Murrelets (Table 4-6). When compared between years, the initial time that murrelets flew inland were similar during early ($F = 0.05$, $df = 1$, $P = 0.83$), mid ($F = 0.59$, $df = 1$, $P = 0.44$), and late season ($F = 0.45$, $df = 1$, $P = 0.51$, Table 4-6). Likewise, when stratified by seasonal period, initial inland dawn times were similar between years for nesting (early $F = 0.55$, $df = 1$, $P = 0.47$; mid $F = 0.82$, $df = 1$, $P = 0.37$; late $F = 0.24$, $df = 1$, $P = 0.63$) and non-nesting birds (early $F = 1.22$, $df = 1$, $P = 0.28$; mid $F = 0.25$, $df = 1$, $P = 0.62$; late $F = 0.01$, $df = 1$, $P = 0.93$; Table 4-5). In the mornings of 2002, there was no difference in initial time inland between nesting and non-nesting birds for each period (early $F = 1.05$, $df = 1$, $P = 0.32$; mid $F = 0.27$, $df = 1$, $P = 0.61$;

late $F = 0.38$, $df = 1$, $P = 0.55$; Table 4-6). In the mornings of 2003, there also was no difference in initial time inland between nesting and non-nesting birds for each period (early $F = 2.54$, $df = 1$, $P = 0.13$; mid $F = 1.20$, $df = 1$, $P = 0.29$; late $F = 0.07$, $df = 1$, $P = 0.80$; Table 4-6).

Evening inland flight times were only recorded in mid and late portions of the season in 2002. Nesting murrelets flew inland 26.7 ± 16.0 ($n = 23$) minutes before sunrise during mid season and 23.5 ± 16.6 ($n = 44$) minutes before sunrise during late season in 2002 ($F < 0.01$, $df = 1$, $P = 0.95$). Two non-nesting murrelet flights were recorded in mid season (0.5 ± 11.5 min. before sunset) and 2 were recorded in late season (0.0 ± 14.0) at about the time of sunset. In 2003, 1 flight of a nesting murrelet was recorded 167 minutes after sunset in the early season. Mid season inland evening flights in 2003 were of nesting birds that flew inland 41.6 ± 19.3 ($n = 5$) minutes before sunset. No evening inland flights were recorded in late 2003.

DISCUSSION

Inland-flying Marbled Murrelets were composed of both nesters and non-nesters. Individual nesters flew inland before nesting, and continued to regularly fly inland after fledging a chick or after nest failure. The asynchrony in initiation of nesting, or the possibility of re-nesting, and the fact that different individual murrelets were using the terrestrial landscapes for different purposes, made interpretation of counts of inland flyers of little value beyond identifying their potential to use the forest stands in which they were found. Thus, we stratified between years, sexes, behaviors and timing in our attempt to detect biological patterns. Even so, the use of averages to characterize these attributes was affected by considerable variation. Thus, some of the comparisons we made where we failed

to detect differences should be viewed with caution. These same cautions apply, but more severely, to the sampling protocols used to assess Marbled Murrelet use of terrestrial habitat.

INTER YEAR VARIATION IN FLIGHT PATTERNS

Marbled Murrelets in RNSP had greater reproductive success in 2002 than in 2003 (Chapter 2). Although a similar proportion of the population flew inland both years, we detected more activity in 2002 than 2003. This greater amount of activity was apparent in the sample size of inland flying murrelets between years with more inland detections in 2002 (e.g. Table 4-4). Ocean conditions, such as sea surface temperature and upwelling, have been shown to influence provisioning of chicks, chick growth, and reproductive success in seabirds (Weimerskirch et al. 2001, Abraham and Sydeman 2004, Peck et al. 2004). Typically, sea surface temperature is negatively correlated, and upwelling is positively correlated with high ocean productivity and, hence, good foraging conditions for alcids (Gaston and Jones 1998). A weak El Niño system developed in the later part of 2002 and continued through the winter into 2003 (IRI 2002, 2003). Monthly mean sea surface temperatures measured 17 nautical miles southwest of Humboldt Bay (Station 46022 Eel River buoy) were greater in 2003 than 2002 for April-August (National Data Buoy Center 2006). Similarly, Pacific Decadal Oscillation indices were negative in 2002 (cooler than average) and positive in 2003 (warmer than average) for April-July. Other seabirds experienced noticeably poor reproductive success in 2003 in California. On Southeast Farallon Island (450 km south), central California, all 11 monitored species experienced reduced reproductive success in 2003, and this was attributed to warmer than normal sea surface temperatures (Warzybok et al. 2003).

Although Marbled Murrelets flew inland at the same time of day in 2002 and 2003, flights were of longer duration in 2002 for both nesters and non-nesters. In good years with high food abundance, many seabirds (e.g. Common Murres, *Uria aalge*; Parker 2005), Thick-billed Murres (*Uria lomvia*, Gaston and Nettleship 1982), and Pigeon Guillemots (*Cepphus columba*, Nelson 1987) will spend more time at the nest colony. In Oregon, Jodice and Collopy (2000) suggested a positive relationship between Marbled Murrelet activity at inland forest stands and improved ocean and foraging conditions. For non-nesters this may have allowed for higher attendance at breeding sites (Gaston and Nettleship 1982), thus allowing interaction with potential mates and learning aspects of successful sites (Reed et al. 1999). Similarly, Hamilton (2005) found that non-breeding Xantus's Murrelets (*Synthliboramphus hypoleucus*) spent more time near the colony in good years with high food abundance than in bad years with poor food availability. For nesters, additional time could be spent at the nest site in a good year, potentially protecting a good nest-site (see Appendix D) or socializing with other murrelets (Appendix C).

Regardless of why these murrelets spent more time inland, the chance of observing or detecting Marbled Murrelets would be better in good years than in bad, as illustrated in our study. Thus, comparisons of inland counts between years may have been much more reflective of ocean and foraging conditions (e.g. Peery et al. 2004) rather than the absolute number of murrelets using a stand of trees. One might infer that where inland counts of murrelets were greater one year than in another that more of the birds could have nested. However, there are two cautions when making this inference about reproductive success based on simple counts of inland flying birds. First, such inferences should not be made across space; conversely, comparison across time but at the same location might be possible.

The differences in counts would be relative to the site where they occurred, and many other factors could vary across space and affect the detectability or proportion of a population breeding at different sites. Second, any change in proportion of the population nesting may not be reflected in the reproductive success. For example, predation risk at forest stands occurs regardless of ocean condition. In RNSP we found high rates of predation and reproductive success was consistently poor (Chapter 2), but we also found significant inter year variation in inland flights.

MURRELET BIOLOGY

We determined that nesting Marbled Murrelets, like other seabirds (see Gaston and Jones 1998, Reed et al. 1999), visited the site of their nest before and well after nesting. Video observations (Appendix B) suggest that sites for nesting may be limiting. Visiting nest-sites prior to nesting may assist in maintaining a claim to a particular site (Naslund 1993, Reed and Oring 1992, Manuwal et al. 2001). There also was fidelity to sites used in previous years (Appendix B). Visitations before nesting may allow assessment of the continued suitability of a site. Lastly, more than 2 birds were observed visiting nest platforms (Appendix C). Thus, pre-nesting visits may involve social interactions and strengthen pair bonds (Wagner 1991, Naslund 1993). Visits after nesting may also be related to these factors. Late season visits to inland forest stands would allow evaluation for settlement in the following year and may be important for failed nesters or prospecting sub-adults (Reed et al. 1999). Whereas early season visits may allow prompt selection of a nest site and mate, late season visits may allow birds to evaluate the current year's reproductive success of conspecifics and predict the future potential of nesting areas (Boulinier and Danchin 1997, Danchin et al. 1998, Doligez et al. 2002).

There were birds in both years that we classified as non-nesting which flew inland. More than half of these birds (53%) had brood patch scores of 2+ at capture (although nesters had greater brood patch scores in 2002 than non-nesters, Table 4-1). Thus, we infer that within the group that we classified as non-nesting but flew inland, at least some were in fact breeders whose nest failed so early that it was not detected (see Chapter 2). However, there were also birds within this group that probably never nested and yet still flew inland. In several species of alcids, juveniles have been known to visit colonies prior to their breeding year (reviewed in Reed et al. 1999). Stands of old growth trees may be analogous to colonies, as nests were spatially constrained on the landscape (Hébert and Golightly 2003). This observation was apparent in the small minimum convex polygons of nests reported here (Figures 4-2, 4-3). Pre-breeding visits by juveniles or other non-nesters can serve as a way to gain advanced information about possible breeding sites within a general area before settling to breed within the area, typically referred to as prospecting behavior (Reed et al. 1999). During prospecting, birds may gain information about potential or suitable nesting sites, foraging areas, or future breeding partners (Dittman and Becker 2003). For example, prospecting by Black-legged Kittiwakes (*Rissa tridactyla*) appeared to be an active process of sampling potential breeding sites and probably involved assessing local reproductive success (Cadiou et al. 1994). Further, greater prospecting behavior occurred in the more successful colony and the number of breeding pairs increased in that colony (Cadiou 1999). Similarly, Great Cormorants (*Phalacrocorax carbo*) that prospected at higher activity levels were more successful in their first breeding attempt compared to individuals with low prospecting activity (Schjorring et al. 1990). Likewise, immature Common Murres that had greater colony attendance in one year were more likely to breed in the following year (Halley

et al. 1995). Prospecting by non-nesting murrelets may serve as an important source for gathering information about future breeding sites such as proper nest construction and placement, and to locate areas of high reproductive success. Marbled Murrelet prospecting may also facilitate mate acquisition (see Block and Brennan 1993).

A small portion (9%) of the birds that never flew inland also had brood patch scores of 2+ at capture. These too may have been breeders that failed early in the incubation and the nest attempt was undetectable. Further, non-nesters flew inland less frequently than nesters. Failed-nesters would be less likely to be detected flying inland, especially if their nesting attempt was prior to radio-marking (but see Hébert et al. 2003). If we add the number of 2+ brood patch birds that were never detected inland to the group of birds that flew inland, approximately 82% of radio-marked birds flew inland. Thus, we conclude that most of the population participated in inland flights, either in pre-breeding, nesting, post-nesting, or prospecting.

Flying inland may have resulted in similar activities among different individuals, or different behaviors whose total duration was similar. The morning flight durations were similar for both sexes and for nesters (outside of incubating and chick rearing) and non-nesters. Chick-rearing nesters spent more time in their morning flights than in their evening flights. This suggests that they were involved in more behaviors than simply feeding their chick at this stage of nesting. For nesting birds during pre laying and post-nesting periods, inland flights may be important for pair bond, nest, and territory maintenance (Naslund 1993, Nelson 1997, Gaston and Jones 1998). For non-nesting birds, inland flights may serve as forays to meet potential mates or gain useful information about good nesting sites.

We found that most evening flights were nesters in the chick-rearing stage of the reproductive cycle, and were probably delivering food to the chick (Carter and Sealy 1990). Flights were of short duration and similar between sexes. Thus, both adults were probably conducting similar activities on their evening flights inland. Although flights in the evening occurred regularly, they were not as consistent as morning flights. Also, they did not occur in the pre-laying period and very few occurred in the post-nesting period. We infer that costs or risks of evening inland flights may have been greater. Many believe that crepuscular activity in Marbled Murrelets (Nelson 1997) and nocturnal activity in other seabirds (Gaston and Jones 1998, Jones et al. 1990, Mougéot and Bretagnolle 2000, Keitt et al. 2004) occurs in order to avoid predation. Birds may have been more detectable by predators in late afternoon light, but the benefit from feeding the chick may outweigh this risk. There may also be safety in numbers (Page and Whitacre 1975, Birkhead 1985) and larger associations of birds would occur in the morning when combined with nest exchanges by incubators (occurring in the early morning). Also, any delay at the nest in evening would cause the bird to necessarily return to sea after dark. Notably, we had just one detection of a murrelet flying inland and back to sea well after sunset. A last consideration to these late afternoon flights would be for potential predators to detect the nest. A bird that comes inland at first light might only be detected by a predator when leaving the nest, whereas a bird landing at the nest in the evening and leaving in time to return to sea before dark may be detected twice, and give a predator greater opportunity to find the chick, or to steal the food delivery.

Murrelets feeding chicks in the morning entered the forest slightly later than all other birds, but we are uncertain why they were later than other murrelets. If inland flights have predation risk, and low light levels help conceal inland flying birds, these murrelets should

have flown inland with all other murrelets. However, a diurnal shift in food availability, adequate time to find and acquire the food, or the distance that food had to be carried could explain the delay. Appropriate food must also be of the proper size. Marbled Murrelets fed chicks larger food items than adults consumed themselves (Carter 1984). Golightly et al. (2004) reported foraging areas for this population were several km south of the mouth of Redwood Creek. Often inland-flying birds staged near the mouth of Redwood Creek as they were about to enter terrestrial habitat. However, chick-feeding birds may have had to catch the food at a more distant location and fly an extra distance, thus explaining the short delay.

Post nesting murrelets spent longer time periods inland than when tending a chick at the nest. Certainly the cessation of chick-feeding would remove the immediate energetic demands to return to foraging areas. However, we do not know which behaviors or activities these post nesting birds engaged while spending additional time inland. It is probable that these inland flights were to maintain pair bonds or search for future potential mates, maintain nest site or territories, or scout for future nesting sites based conspecific reproductive success.

IMPLICATION FOR SAMPLING PROCEDURES

Monitoring of populations of seabirds, either because they are threatened and of small population size (eg: Marbled Murrelets) or as indicators of ocean condition and fishery health (Montevecchi 1993), will require a procedure that matches the goal of monitoring (Hellawell 1991, Spellerberg 1991). Specifically, attributes of behavior, productivity, or the population can be different at different scales (Monaghan 1996, Diamond and Devlin 2003, Parker 2005). The existing protocol for estimating use of terrestrial habitat (Evans Mack et al. 2003) depends on the presence/absence of specific behaviors. This primarily includes above-

canopy and sub-canopy flights and vocalizations by individuals or groups of birds (Evans Mack et al. 2003). Unfortunately this design does not measure reproduction or population size, and thus cannot be used to assess population trends or whether murrelet presence at specific sites infers importance to breeding. Conversely, at-sea surveys (eg: Miller et al. 2003) do monitor population trends but do so only over long periods of time and are not responsive to either short-term changes or changes in land use at specific parcels.

Alternatively, radio telemetry can be utilized to determine nesting status of individual birds (Lougheed et al. 2002a, Peery et al. 2004, this volume), identify specific areas used for nesting (Chapter 2, Bradley 2002), and identify short-term changes in population trends (Lougheed et al. 2002b, Peery et al. 2004). Unfortunately radio-telemetry is extremely expensive and may itself have risks to reproduction (see Ackerman et al. 2004)

Terrestrial counts of murrelets in the early morning during the nesting period may detect nesting birds, non-nesting birds, and both sexes. Further, because birds fly inland before nesting and post nesting, and because there is great asynchrony in the initiation of nesting (Chapter 2), discrimination of possible nesting birds among those flying inland has not been possible. The duration of flights also varied through the season which yielded variation in detectability. There is the potential for higher variation in audio-visual surveys than radar surveys due to observer error, whereas, radar can track individuals for short periods of time and view wider areas (Hamer et al. 1995). However, both audio-visual and radar surveys are unable to distinguish between nesting and non-nesting birds and between male and female birds, and therefore, do not accurately reflect breeding status or population size.

However, evening inland flights occurred mostly in birds feeding chicks, and so this was an important parameter that could serve as an indicator of reproductive output within a single year. A large proportion of nests failed during the incubation phase (Chapter 2). Consequently, evening counts do not reflect the portion of the population that attempted nesting and failed. From a perspective of monitoring overall reproductive output, only potential fledgling-producing birds would be necessary, which evening counts could include.

It could be argued that greater counts significantly add to the power of a monitoring variable. Evening flight counts were smaller because they represented only the portion of the population engaged in feeding chicks. We argue that this is often the exact parameter that managers need for purposes of monitoring population condition. Full counts of surface-nesting birds, and thus breeding population counts have been typically used to monitor populations (eg: Double-crested Cormorant (*Phalacrocorax auritus*) Carter et al. 1995, Capitolo et al. 2005; Common Murre, Takekawa et al. 1990, Carter et al. 2001, Capitolo et al. 2006). Below-surface nesters, such as Cassin's Auklets (*Ptychoramphus aleuticus*) and Xantus's Murrelets are more problematic. Here, counts for monitoring have been made of burrows or nest boxes (Carter et al. 1992). However, more than population counts or indexes may be needed by land or wildlife managers. In order to assess population level problems, estimates of reproductive output provide more insight (Parker 2005). For Marbled Murrelets, this is exactly what evening counts can produce without the variance introduced by non-breeders or flights of post breeding (and potentially failed) nesters.

Further, because chick feeding only occurs for 28 days in the reproductive cycle (Hamer and Nelson 1995b), it would be possible to design a sampling scheme that would be robust to the asynchrony in nest initiation and avoid double counting of the same individual.

The relatively short duration of inland flights in the evening would minimize double counts, especially for techniques such as radar. Sampling at different periods separated by more than a month would sample different individuals. Thus, 2 or 3 sample periods would likely index all chick feeders across a season. Replicates in short succession (days) could provide for repeated measures of each period. We caution that forage availability may affect the number of evening flights in ways presently unknown, and further study would be warranted.

However, evening flight counts would target the reproductive component of the population, contain fewer confounding variables, and have fewer double counts of the same individuals. It would be possible to separate variance in counting from variance through time.

We also subdivided the nesting season by early, mid, and late counts and measured duration of inland flights to potentially identify times of the season that might be most fruitful for assessing use of terrestrial habitat by Marbled Murrelets. For morning flights, we were able to detect significant differences between years by using counts from the early or late part of the breeding season. We could not detect differences between years during the middle of the breeding season. This was likely due to the great variance associated with asynchrony of breeding as well as a mix of different behaviors associated with inland flights mid-season. Thus, if the goal was to use inland count data to detect differences in abundance across years, standardized surveys could be conducted early or late in the breeding season. Surveys in mid-season will have high variance and will unlikely detect annual changes. Thus, it should be an important consideration of when surveys are conducted within the breeding season.

Many of the statistically significant differences in inland flights occurred between years. Consequently, the greatest detectable variation in counts of inland flying murrelets may be differences between years.

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PERSONAL COMMUNICATION

WHEELER, J. B. April 2006. Redwood National and State Parks, Orick, California, USA.

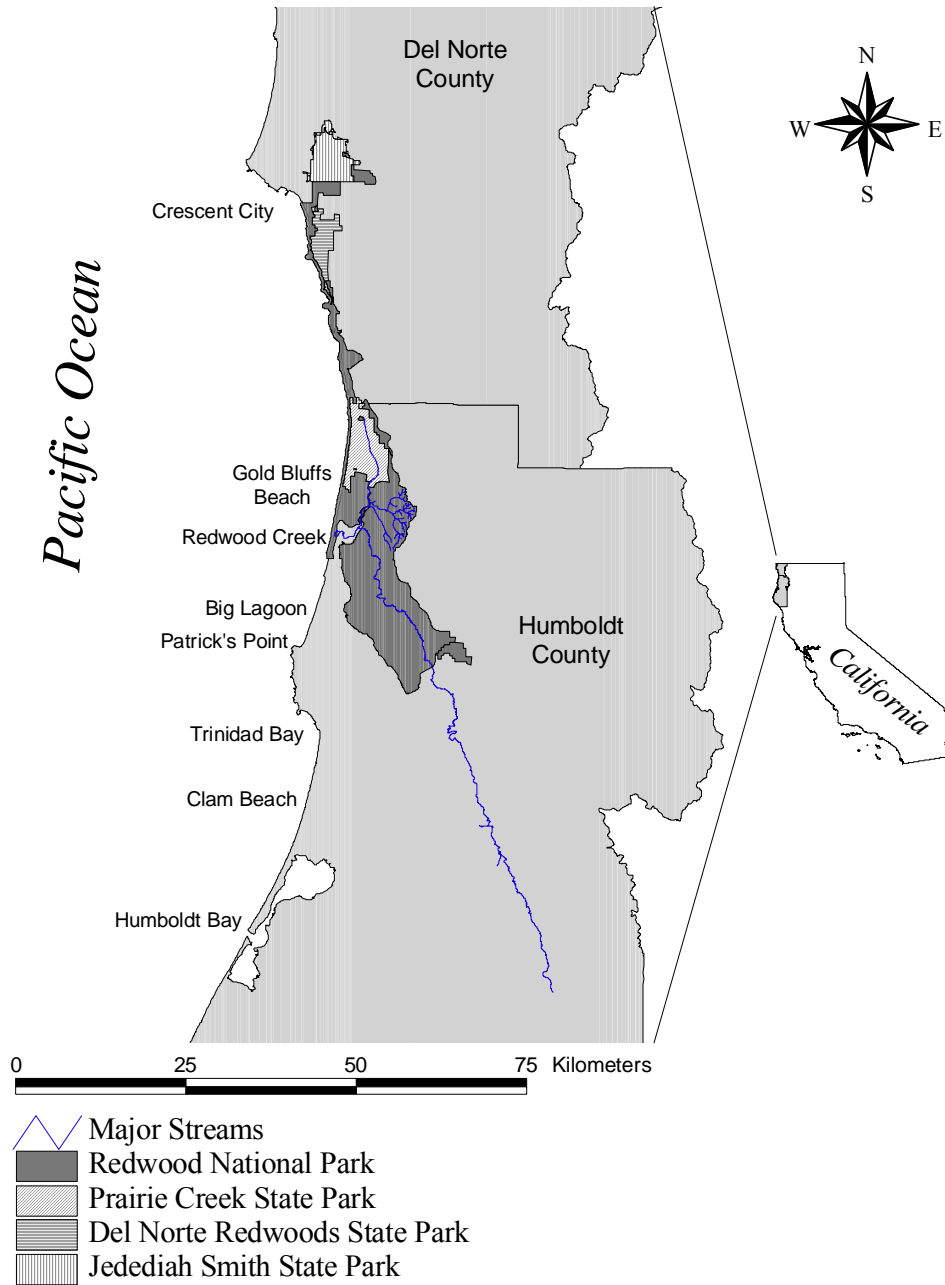


FIGURE 4-1. Map depicting general Marbled Murrelet study area in Humboldt County, California (2002-2003). Birds were captured at-sea between Clam Beach and Gold Bluff Beach. All known nesting of radio-marked Marbled Murrelets occurred in Redwood National Park and Prairie Creek State Park.

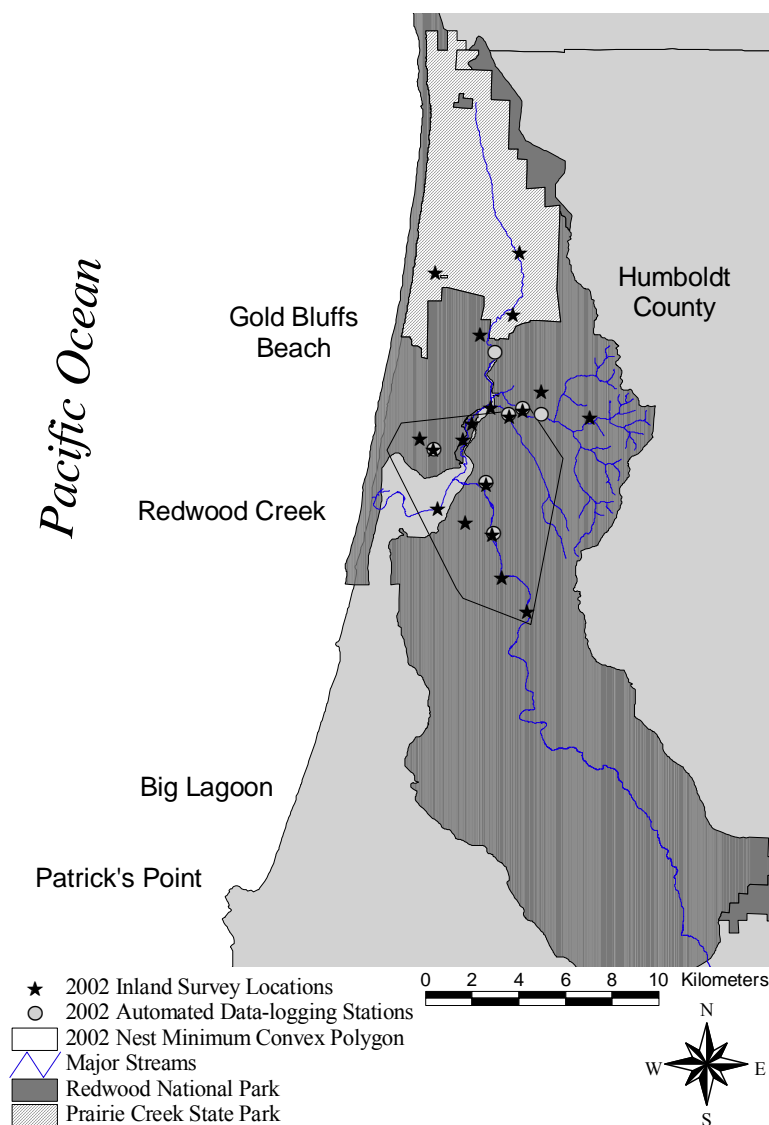


FIGURE 4-2. Location of ground based manual telemetry surveys and automated telemetry stations in 2002 in relation to nesting area (minimum convex polygon) in the Marbled Murrelet study area in northern California. Additional manual telemetry surveys were conducted further north near appropriate habitat along the Klamath and Smith Rivers, but no radio-marked murrelets were ever detected.

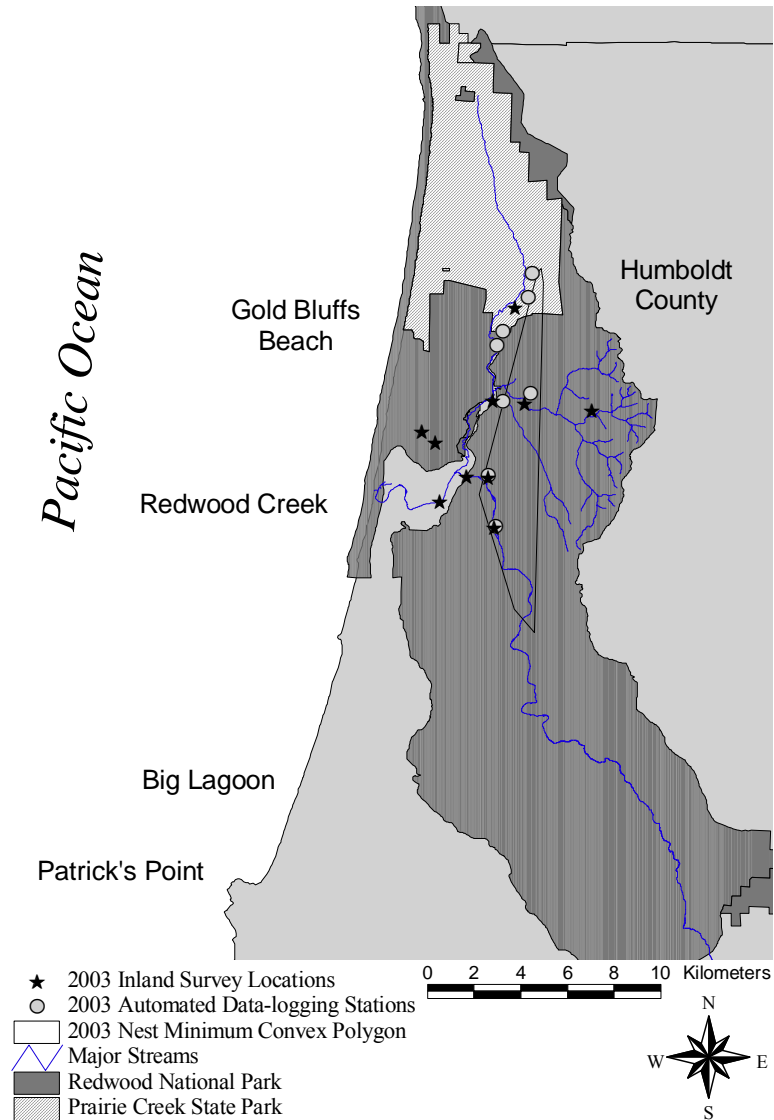


FIGURE 4-3. Location of ground based manual telemetry surveys and automated telemetry stations in 2003 in relation to nesting area (minimum convex polygon) in the Marbled Murrelet study area in northern California. Additional manual telemetry surveys were conducted further north near appropriate habitat along the Klamath and Smith Rivers, but no radio-marked murrelets were ever detected.

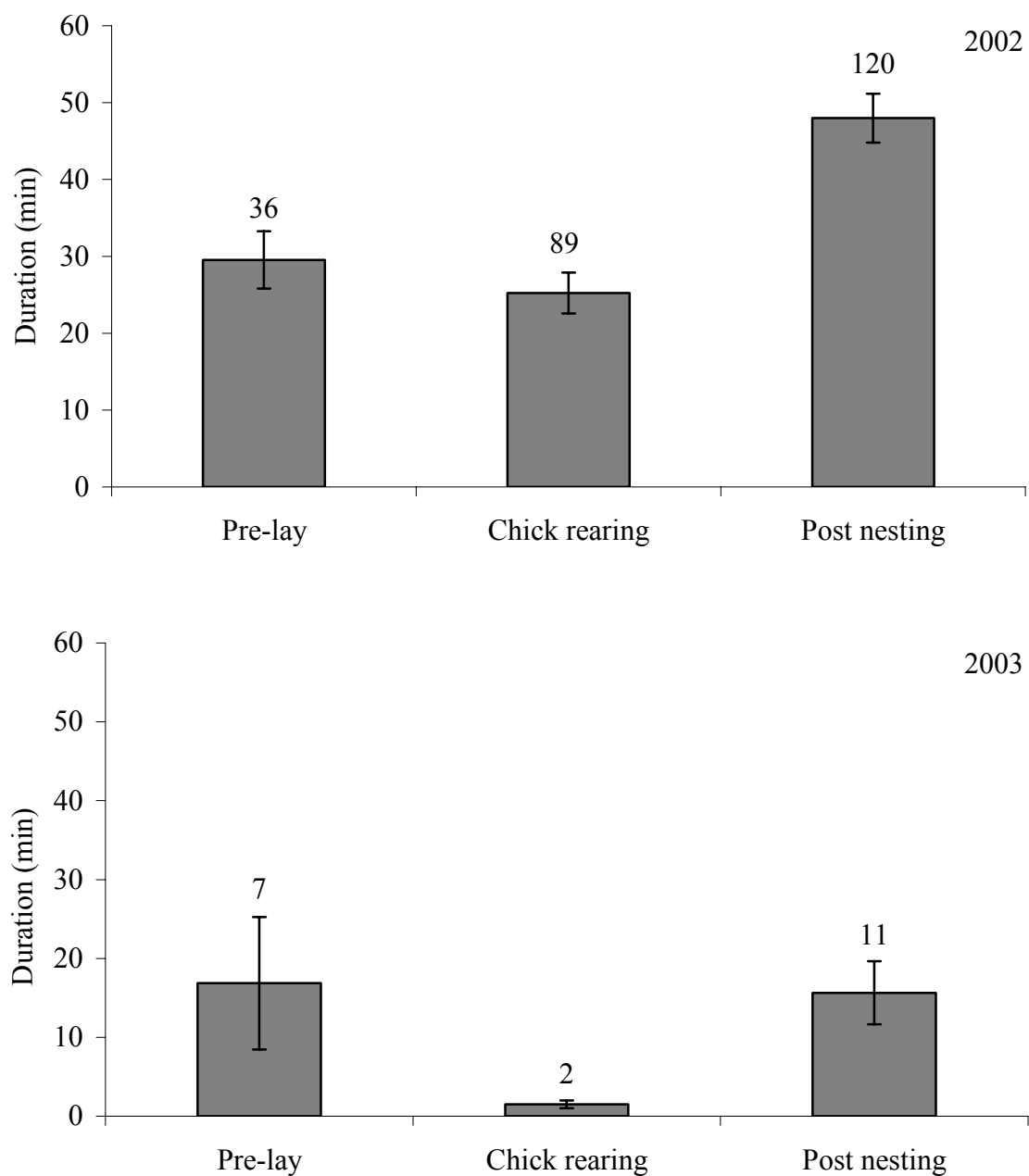


FIGURE 4-4. Duration of inland dawn flights of radio-marked nesting Marbled Murrelets during three temporal periods in northern California, 2002-2003. Error bars are ± 1 SE. Sample sizes above bars are number of inland flights.

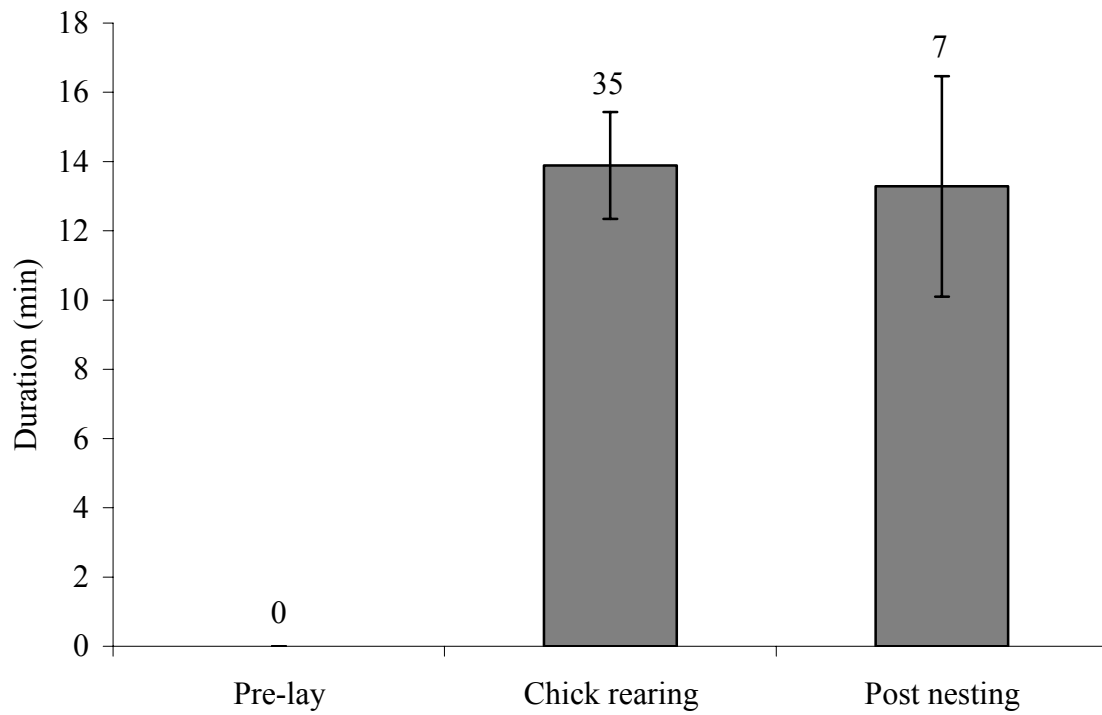


FIGURE 4-5. Evening inland flight duration of nesting birds in 2002 during three temporal periods in northern California. No inland flight durations were recorded for nesting birds in 2003. Error bars are ± 1 SE. Sample sizes above bars are number of inland flights.

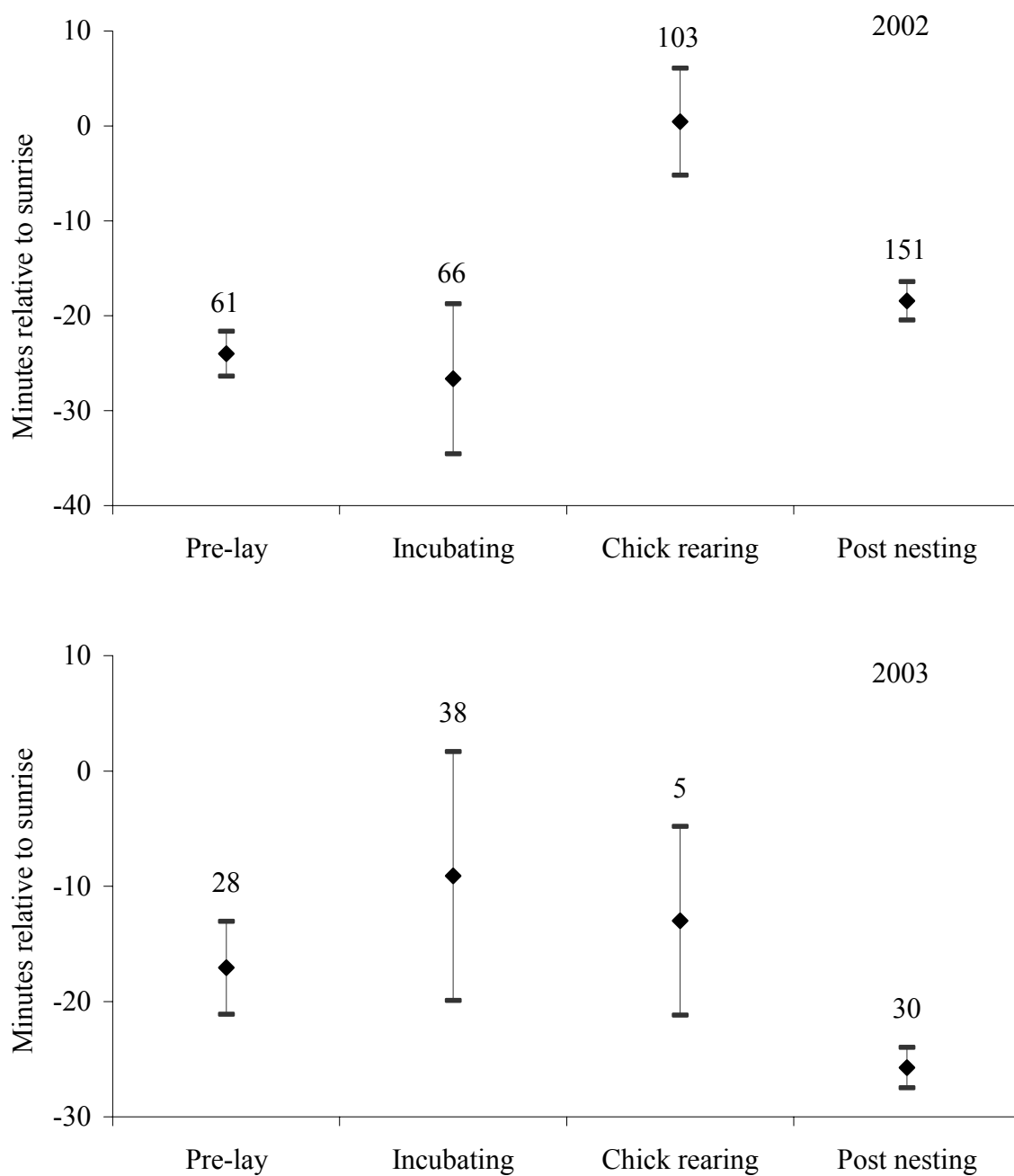


FIGURE 4-6. Initial times at dawn that nesting murrelets were detected flying inland grouped by four breeding periods in California, 2002-2003. Negative numbers are minutes before sunrise (= 0). Error bars are ± 1 SE and numbers of inland flights are above.

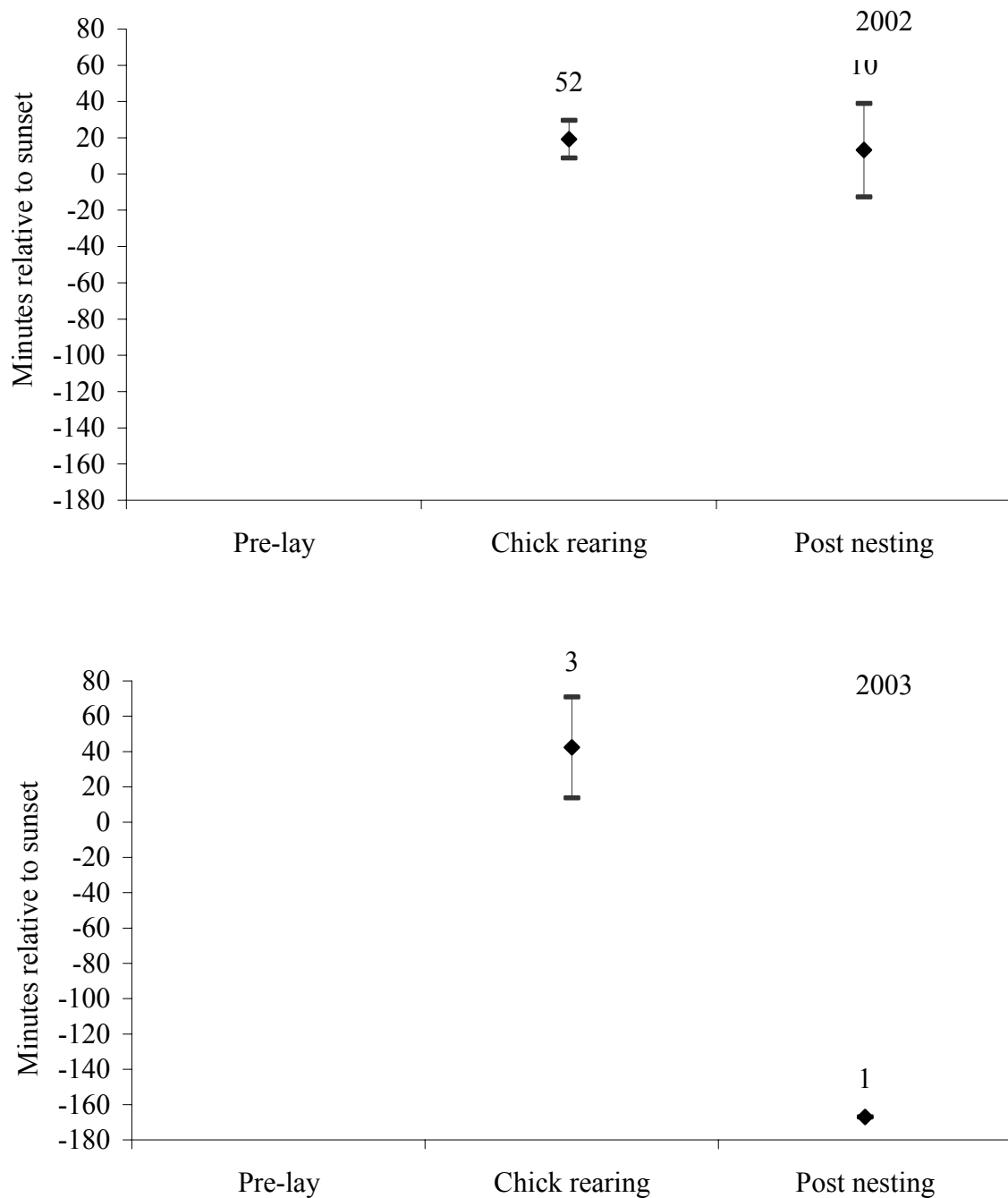


FIGURE 4-7. Initial evening times that nesting murrelets were detected flying inland grouped by four breeding periods in California, 2002-2003. Negative numbers are minutes after sunset (= 0). Error bars are ± 1 SE and numbers of inland flights are above.

TABLE 4-1. Mean brood patch score (Sealy 1974) of Marbled Murrelets at the time of capture compared between years in northern California.

	2002		2003	
	$\bar{x} \pm \text{SE}$	n	$\bar{x} \pm \text{SE}$	n
All radio-marked murrelets	1.9 ± 0.2	44	1.2 ± 0.2	35
Females	1.8 ± 0.3	20	1.3 ± 0.3	15
Males	1.9 ± 0.2	23	0.9 ± 0.3	18
Nesting murrelets	2.5 ± 0.2	21	1.5 ± 0.4	8
Non-nesting murrelets flying inland	1.5 ± 0.4	13	1.4 ± 0.3	16
Non-nesting murrelets never inland	1.1 ± 0.3	10	0.7 ± 0.3	11

TABLE 4-2. Duration (in minutes) of dawn inland flights of Marbled Murrelets in Redwood National and State Parks, California from 2002-2003. Samples size (n) is the number of flights used in analysis; repeated measures on individual birds were controlled for using repeated measures ANOVA.

	2002		2003	
	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n
All inland flights	36.4 ± 1.7	341	13.0 ± 1.9	50
Females	40.5 ± 2.9	145	12.5 ± 2.7	13
Males	33.3 ± 2.0	196	13.2 ± 2.4	37
Nesting murrelets	36.8 ± 2.0	245	13.5 ± 3.4	22
Non-nesting murrelets flying inland	35.2 ± 3.2	96	12.7 ± 2.1	28

TABLE 4-3. Duration (in minutes) of Marbled Murrelet inland flights compared between morning and evening in Redwood National and State Parks, California in 2002. Samples size (n) is the number of flights used in analysis; repeated measures on individual birds were controlled for using repeated measures ANOVA. Statistical analysis of non-nesting murrelets flying inland was excluded due to small evening sample size.

	Morning		Evening		F	df	P
	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n			
All inland flights	36.4 \pm 1.7	341	14.0 \pm 1.3	45	7.77	1	>0.01
Females	40.5 \pm 2.9	145	12.9 \pm 1.8	18	3.26	1	0.09
Males	33.3 \pm 2.4	196	14.7 \pm 1.8	27	4.58	1	>0.05
Nesting murrelets	36.8 \pm 2.0	245	13.9 \pm 1.4	43	6.65	1	0.02
Non-nesting murrelets flying inland	35.2 \pm 3.2	96	15.0 \pm 3.0	2			

TABLE 4-4. Initial time of inland flights in the morning (minutes before sunrise) and in the evening (minutes before sunset) of radio-marked Marbled Murrelets in Redwood National and State Parks, California in 2002 and 2003. Sample size (n) is the number of inland flights used in analysis; repeated measures on individual birds controlled for using repeated measures ANOVA.

	Morning						Evening			
	2002			2003			2002		2003	
	\bar{x}	\pm SE	n	\bar{x}	\pm SE	n	\bar{x}	\pm SE	n	
All inland flights	17.2	\pm 1.8	523	18.9	\pm 1.9	234	23.2	\pm 11.5	71	6.8 \pm 38.2 6
Females	18.5	\pm 2.6	232	16.2	\pm 3.4	59	8.6	\pm 8.5	26	40.5 \pm 35.5 2
Males	16.3	\pm 2.5	291	19.8	\pm 2.3	175	31.7	\pm 17.4	45	-10.0 \pm 56.1 4
Nesting murrelets	15.7	\pm 2.3	382	16.5	\pm 4.2	102	24.6	\pm 12.1	67	6.8 \pm 38.2 6
Non-nesting murrelets flying inland	21.5	\pm 2.4	141	20.7	\pm 1.0	132	0.3	\pm 7.4	4	0

TABLE 4-5. Duration (in minutes) of morning inland Marbled Murrelet flights when stratified by early, mid, and late season in Redwood National and State Parks, California, 2002-2003. Sample size (n) is the number of flights used in analysis. Repeated measures on individual birds were controlled for using repeated measures ANOVA.

	Early season ¹		Mid season ²		Late season ³		F	df	P
	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n			
2002									
All murrelets	25.7 ± 8.1	40	33.3 ± 4.4	13 7	41.5 ± 4	16 4	1.98	2	0.16
Nesting murrelets	25.0 ± 11.6	23	35.2 ± 6.1	82	39.8 ± 4.7	14 0	0.76	2	0.48
Non-nesting murrelets flying inland	26.6 ± 10.8	17	30.5 ± 6.0	55	52.0 ± 9.1	24	2.33	2	0.17
2003									
All murrelets	11.6 ± 2.4	17	15.1 ± 2.2	20	11.8 ± 2.8	13	0.70	2	0.51
Nesting murrelets	11.6 ± 4.8	8	22.5 ± 9.9	6	8.5 ± 2.9	8			
Non-nesting murrelets flying inland	11.6 ± 3.9	9	11.9 ± 3.1	14	17.0 ± 5.2	5			

¹ 7 May – 7 June in 2002 and 24 April – 21 May in 2003.

² 8 June – 8 July in 2002 and 22 May – 17 June in 2003.

³ 9 July – 9 August in 2002 and 18 June – 15 July in 2003.

TABLE 4-6. Initial time at dawn (minutes before sunrise) of inland Marbled Murrelet flights when stratified by early, mid, and late season in Redwood National and State Parks, California, 2002-2003. Sample size (n) is the number of flights used in analysis. Repeated measures on individual birds were controlled for using repeated measures ANOVA.

	Early season ¹			Mid season ²			Late season ³					
	\bar{x}	\pm SE	n	\bar{x}	\pm SE	n	\bar{x}	\pm SE	n	F	df	P
2002												
All murrelets	21.0	± 5.8	85	21.3	± 3.6	225	11.5	± 3.7	213	2.06	2	0.15
Nesting murrelets	23.6	± 7.7	49	20.0	± 4.5	146	10.2	± 4.0	187	1.94	2	0.17
Non-nesting murrelets flying inland	17.6	± 9.6	36	23.6	± 6.5	79	20.6	± 11.4	26	0.14	2	0.87
2003												
All murrelets	21.8	± 2.2	58	17.8	± 1.5	123	18.2	± 2.3	53	1.16	2	0.33
Nesting murrelets	19.5	± 5.2	22	14.4	± 3.5	47	17.5	± 4.2	33	0.37	2	0.71
Non-nesting murrelets flying inland	23.2	± 2.2	36	19.8	± 1.5	76	19.5	± 3	20	0.90	2	0.43

¹ 7 May – 7 June in 2002 and 24 April – 21 May in 2003.

² 8 June – 8 July in 2002 and 22 May – 17 June in 2003.

³ 9 July – 9 August in 2002 and 18 June – 15 July in 2003.

APPENDIX A

POTENTIAL EFFECTS OF ANESTHESIA ON THE POST-CAPTURE MOVEMENTS AND REPRODUCTIVE PERFORMANCE OF MARBLED MURRELETS

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Animal biologists have legal and ethical obligations to ensure the welfare of the animals they study, and are thus compelled to measure the value of their research against the welfare of the organisms they are studying (Association for the Study of Animal Behaviour 2002, U. S. Department of Agriculture 1994). Consideration must be given to the mitigation of pain and discomfort when animals are being handled, especially if the protocol requires invasive procedures (Association for the Study of Animal Behaviour 2002). For example, recent refinements of attachment methods for radio-transmitters used surgery (e.g. Mauser and Jarvis 1991), which was sometimes performed with the use of anesthetics (e.g. Golightly et al. 2002, 2005, McColl and Boonstra 1999, Blouin-Demers et al. 2000, Machin and Caulkett 2000) while not in other cases (see Loughheed 2000, Bradley et al. 2002, Hamilton 2005). In addition to alleviating the pain associated with transmitter attachment or implantation, the use of anesthesia while attaching radio-transmitters has potential to reduce stress associated with handling (Heatley et al. 2000), and facilitate the attachment of the radio-transmitters (Olsen et al. 1992).

The refinements of radio-telemetry techniques (Mauser and Jarvis 1991, Newman et al. 1999), in concert with improved capture techniques (Kaiser et al. 1995, Whitworth et al. 1997) have allowed more detailed studies of the biology of Marbled Murrelets (*Brachyramphus marmoratus*) (Hull et al. 2001, Bradley et al. 2002, Hébert et al. 2003, Peery et al. 2004). Efforts to study the nesting biology of Marbled Murrelets have been hampered by several attributes of their nesting behavior. Unlike typical ground nesting seabirds (e.g. Common Murre, *Uria aalge*, see Ainley et al. 2002) the Marbled Murrelet nests in coastal coniferous forests, primarily high in old-growth trees that are largely inaccessible to researchers without specialized monitoring techniques (Nelson 1997).

Marbled Murrelets are usually silent around the nest (Nelson and Hamer 1995), are difficult to observe because they have cryptic plumage, and are small (approximately 200g) in size (Carter and Stein 1995).

Due to habitat loss, and other anthropogenic pressures, Marbled Murrelets were listed as endangered in California in 1992 (Larsen 1991, California Fish and Game Commission 1992). Later, the population in Washington, Oregon, and California received protection as a threatened species (US Fish and Wildlife Service 1992) based on the federal Endangered Species Act. The status of the Marbled Murrelet further constrains the balance between the value of the research to the population and the welfare of the individual. Research on an endangered or threatened species must ensure that the research methodology and activities do not exacerbate the status of the species by impacting the reproductive contribution of individuals (Association for the Study of Animal Behaviour 2002).

In British Columbia, researchers have not used anesthesia on Marbled Murrelets during the radio attachment process (e.g. Loughheed 2000). The percentage of radio-marked birds initiating nesting ranged from 56 – 60% (Loughheed 2000, McFarlane-Tranquilla et al. 2003). By comparison, telemetry studies in central California have used anesthesia on Marbled Murrelets prior to attachment of radio-transmitters. In these studies fewer than 15% of radio-marked murrelets initiated nesting (Peery et al. 2004). It was unclear if the difference in nest initiation rates between the British Columbia and central California studies was due to underlying differences in habitat, predation, food availability or other biological difference between the two populations, or alternatively due to the use of anesthesia.

The effectiveness of various anesthetics and analgesics in alleviating pain and discomfort have been well studied (e.g. McColl and Boonstra 1999, Blouin-Demers et al.

2000, Machin and Caulkett 2000). For example, some inhalation anesthetics increased risk of mortality during anesthesia (Rotella and Ratti 1990, Blouin-Demers *et al.* 2000) or significantly altered physiological processes during and after anesthesia (Kreeger *et al.* 1998, Heatley *et al.* 2000). Biologists must consider the method of delivery of the anesthetic, the effectiveness of the anesthetic, the time required to induce sedation, the recovery time, including post-anesthetic effects (Flecknell 1987) and potential influences on reproductive function.

Isoflurane is an inhalation anesthetic that has several qualities that make it a practical choice as an anesthetic for immobilization and for alleviation of pain. These qualities include rapid induction and recovery times compared to injectable anesthetics (Flecknell 1987, McColl and Boonstra 1999). Rapid induction and rapid recovery times minimize the time an individual is influenced by the anesthesia and, for wildlife, the speed with which the animal can be returned to a free-ranging environment. For wildlife investigations, it is critical to minimize the time period that the animal is removed from its ecological and social environment. Consequently, isoflurane has been frequently chosen for anesthesia in birds (Ludders *et al.* 1995).

The purpose of this study was to determine if anesthesia of Marbled Murrelets prior to attachment of radio-transmitters: 1) affected the efficiency of radio-attachment and blood collection processes, 2) affected the reproductive performance of Marbled Murrelets, 3) affected post-capture movements. Different post-capture movements could subsequently influence pair bond formation or pair bond maintenance which in turn could influence breeding potential.

METHODS

CAPTURE AND HANDLING

We captured Marbled Murrelets in the coastal waters of northern California between Big Lagoon and Gold Bluffs Beach (N 41.186: W 124.135 and N 41.388: W 124.062, respectively; 2001 – 2003), and in Trinidad Bay (N 41.069: W 124.171; 2002). Capture occurred between 2100h and 0400h using a night-lighting and dip net technique (Whitworth et al. 1997). Capture crews, equipped with high intensity spotlights and a long-handled dip net, searched near-shore waters (within 5 km of shore) in two 4.5-m inflatable boats. A third 4.5-m inflatable boat provided animal transport and added safety. A Global Positioning System (GPS; Model GPSMap76, Garmin, Kansas City, Kansas) device was used to record capture locations. Captured Marbled Murrelets were transported inside plastic tubs with lids from the capture boat to a larger boat (or pier in Trinidad Bay) to measure morphology, attach radio-transmitters, and collect blood samples (hereafter this scenario is referenced to as handling process). Birds captured between Big Lagoon and Gold Bluffs Beach were processed on either the Humboldt State University research vessel Coral Sea (in 2001 - 2003), or a chartered 15-m fishing-trawler (in 2002 and 2003).

We first examined murrelets for the presence of a brood patch. When present, brood patches were scored using the scale developed by Sealy (1974). Murrelets with brood patches were examined using ultrasound to determine their sex and reproductive status. In addition, we measured body weight (g) using a 300-g Pesola spring scale, as well as bill length and depth (mm), and flattened wing chord length using dial calipers. Each murrelet was banded with a number-3 stainless steel U. S. Geological Survey leg band.

Radio Transmitter Attachment and Anesthesia.--To each Marbled Murrelet captured, we attached an approximately 2-g radio-transmitter with a unique frequency (Model BD-2G, Holohil Systems Ltd., Ontario Canada) using a subcutaneous anchor (Mauser and Jarvis 1991), following the procedure described by Newman et al. (1999). Birds were held in ventral recumbency by an assistant sitting directly opposite a veterinarian who attached the radio-transmitter. A small folded towel was placed over the bird's head, and the assistant held the murrelet's shoulders with thumbs and index fingers. The head was controlled using slight downward pressure by the base of the assistant's thumbs. The skin in the area of attachment was cleaned using 70% ethanol, which also helped to part the feathers between the scapulae. We incised the skin, using a 16 ga needle, at the dorsal mid-line between the scapulae, just cranial to the shoulders. The sterile stainless steel anchor was threaded through the incision into the subcutaneous space to a position directly cranial to the incision. A few drops of surgical tissue adhesive (Vetbond, 3M Animal Care Products, St. Paul, MN) were used to glue the transmitter to the underlying skin and feathers. Finally, a single suture (2-0 Prolene, Ethicon, Inc., Somerville, NJ) was placed through a pre-formed channel at the base of the transmitter, looped beneath the dermis, and tied. The surgical adhesive and the suture were used to keep the transmitter in place while the skin around the point of insertion healed (Newman et al. 1999).

We anesthetized a random sample of captured Marbled Murrelets with isoflurane (Newman et al. 1999) resulting in two groups for radio attachment; those managed with anesthesia and those managed without anesthesia. Murrelets were anesthetized by covering the beaks and nares with a mask connected to a non-rebreathing Bain circuit connected to an isoflurane vaporizer. Isoflurane was delivered at a rate of 3-5% in pure oxygen at a flow rate

of 1 L / min. Murrelets were supplied continuously with isoflurane until both struggling and the palpebral reflex ceased, at which point the mask was removed. Radio-transmitters were then attached. To assess the potential improvement to attachment caused by the anesthetic we recorded the time (in sec.) required for radio-attachment and for blood collection.

Blood Collection.--After attachment of radio-transmitters we attempted to obtain a 1.5 – 2.0 ml blood sample from each Marbled Murrelet for the purposes of sex determination following the method described by Griffiths et al. (1998), and steroid hormone assays. The blood sample was obtained from the metatarsal vein using a 3 ml syringe and a 25 gauge butterfly needle. Similar quantities of blood have been drawn from Marbled Murrelets with no harmful effects (Lougheed et al. 1998, Vanderkist et al. 2000).

After processing, Marbled Murrelets were held in the plastic transport tubs for approximately 20 minutes to allow sufficient time to recover from anesthesia. Total time in captivity was measured for both groups. Prior to release, murrelets processed with isoflurane were examined to ensure adequate muscle tone, palpebral reflexes and alertness. We hand released murrelets onto the water, and observed them for normal behavior for approximately 30 seconds, or as deemed appropriate based on the behavior of the bird. No abnormalities were noted.

POST-CAPTURE MOVEMENT

Aircraft telemetry (see Chapter 3), using GPS and telemetry procedures as outlined by Gilmer et al. (1981; see also Whitworth et al. 2000), was used to determine the at-sea (and inland) locations of Marbled Murrelets after capture. We determined at-sea locations of radio-marked birds from a fixed-wing aircraft (Cessna 182, 185) equipped with a receiver (model R4000, Advanced Telemetry Systems, Inc., Isanti, Minnesota) and either a 2 element

H-antenna or a single element omni-directional antenna. Aircraft telemetry began the morning after the first capture (13 April 2001, 13 April 2002, and 17 April 2003) and continued, weather conditions permitting, on a daily basis until the last radio-transmitter failed (19 August, 2001, 26 August, 2002, and 6 August 2003). Flights were usually conducted between 0800h and 2030h, the departure time and length of the flight depending on the weather, location of birds, and number of birds to be tracked.

We also used aircraft telemetry to determine nest initiation and nest success (Chapter 2). Telemetry flights began over the ocean and if a bird was not detected at sea, the plane then flew inland over areas with old-growth forest to determine the location of the missing bird(s). If a bird was not detected in the forest, then the search was expanded to the coastal waters and adjacent old growth south to Humboldt Redwoods State Park (40° 19'N, 123° 55'W) and north to Brookings, Oregon (42° 04'N, 124° 16'W). A bird detected inland after 0800h was considered to have initiated nesting (see Chapter 2).

To determine if the use of anesthesia affected post-capture movements in the two groups, we compared the distance traveled within the first day after capture (12 – 36 h after capture), and within 5 days after capture (108 – 132 hours). Distance traveled was calculated by plotting each location in geographical information system (Arcview 3.3, ESRI, Redlands, CA) and using the Animal Movement extension (Hooge and Eichenlaub 2000).

NEST INITIATION

We compared the number of radio-marked Marbled Murrelets that initiated nesting and that were managed without anesthesia to the number of murrelets that were managed with anesthesia. We also compared the time elapsed between capture and nesting for murrelets in the two groups.

STATISTICAL ANALYSES

There were slight differences in procedure between years: the amount of blood collected from each bird was increased from 1.5 ml in 2001 to 2.0 in 2002 and 2003. We also detected differences in morphometric characteristics of captured Marbled Murrelets between years. Because processing and morphometric measurements differed between years, we minimized inter-year differences by standardizing morphometric data using the method described by Perrins and McCleery (1985). For each characteristic, the yearly mean was subtracted from each observation, and the result was divided by the yearly standard deviation. We used Fisher's exact probability test to compare the number of Marbled Murrelets that initiated nesting in both groups. We compared date of nest initiation between treatment groups using standardized data to minimize interyear differences. We used two-factor (year, treatment) analysis of variance to determine the affect of anesthesia on 1) the number of days elapsed between capture and nesting and 2) the post-capture movements within the 24 and 72 h after capture. Analyses for date of nest initiation were performed on standardized data.

RESULTS

CAPTURE AND HANDLING PROCESS

Radios were attached to 102 murrelets over 3 breeding seasons (Table A-1). The amount of blood collected differed between years, and this difference approached significance (MANOVA, $F_{2, 89} = 3.06$, $P = 0.052$). More blood was collected in 2002 and 2003 than 2001 (Table A-2). Brood patch scores, mass, and wing chord length were similar between years, however, culmen length and bill depth varied significantly between years (Table A-3). Time a murrelet spent in captivity was similar between years (2-way ANOVA,

with year and treatment as class variables; $P > 0.5$). The time required to attach the radio-transmitters ($P > 0.8$) and to collect blood samples ($P > 0.2$), were also similar between years (Table A-1). The mass of transmitters used was significantly different between years (MANOVA, $F_{2,89} = 225.2$, $P < 0.001$).

There was no difference in mass or morphometric measurements between birds that received anesthesia and those that did not (Table A-3). Mean induction time for murrelets treated with isoflurane was 75.3 ± 5.8 sec ($n = 12$). Time in captivity, transmitter mass, time to attach the radio, amount of blood obtained, and time to obtain blood were similar for birds with anesthesia and without anesthesia (Table A-4; A-5).

POST-CAPTURE BIOLOGY

Nest initiation.--Within each year, 26% of captured birds received anesthesia while 33, 18 and 22% of these initiated nests in 2001, 2002, and 2003, respectively (Table 6). Mean date of nest initiation was similar ($P > 0.6$) for murrelets that did and did not receive anesthesia for attachment of radio-transmitters (Table A-7). The time elapsed between capture and nesting was similar between years (ANOVA; $P > 0.70$) (Table A-8). When time elapsed between capture and nesting was combined across years, number of days between capture and nesting was similar ($P > 0.2$) for murrelets managed with and without anesthesia for attachment of radio-transmitters (Table A-7).

Distances traveled within 24h of release were similar between years (Table A-9) ($P > 0.25$). However, distance traveled in the 72h after capture was significantly different between years (MANOVA, $F_{2,24} = 7.72$, $P = 0.003$). When the data were standardized and combined across years, the distances traveled 24h and 72h after release were similar for murrelets managed with and without anesthesia (Table A-10).

DISCUSSION

The anesthesia used to immobilize Marbled Murrelets in our study did not affect the time required to attach radios and collect blood. Further, the overall time Marbled Murrelets were in captivity was similar for murrelets processed with and without anesthesia. Thus, anesthesia did not improve handling times in our application of the handling process.

Differences between years for radio-transmitter mass and amount of blood collected were due to prescribed changes in the handling process. In 2002 and 2003 the radio-transmitters were altered and mass increased slightly. We also increased the maximum amount of blood that was attempted to be collected from approximately 1.5 ml in 2001 to approximately 2.0 ml in 2002 and 2003.

The use of anesthesia could have reduced the amount of pain and discomfort experienced by the birds during radio-attachment. The level of serum corticosterone has been used as an indirect measure of stress experienced by an individual birds (Ludders 2002). Heatley et al. (2000) compared serum corticosterone levels in Hispaniolan Amazon parrots (*Amazona ventralis*) that were restrained manually or restrained with anesthesia (isoflurane). Parrots that were treated with anesthesia exhibited significantly lower serum corticosterone levels compared to parrots that were restrained manually (Heatley et al. 2000). This suggests that the use of anesthesia had potential to reduce the amount of stress and pain associated with the handling process. Unfortunately, it is very difficult to directly assess the potential stress or pain caused by the handling process.

There appeared to be few effects of anesthesia on the post-capture movements or nesting of Marbled Murrelets. There were no differences in flight movements. There did not appear to be an effect on the date of nest initiation. In 2002 we did detect fewer Marbled

Murrelets that were exposed to anesthesia and initiated nesting than expected. A greater proportion of Marbled Murrelets that did not receive anesthesia initiated nesting compared to murrelets that did receive anesthesia (Table A-6). However, the proportion nesting was similar between the two groups in both 2001 and 2003. No differences in the handling process were obvious in 2002. Differences were probably not due to differences in the morphometric characteristics of the birds processed without and with anesthesia. The mass and size of Marbled Murrelets were similar between groups and years.

If fewer nesting attempts among birds exposed to anesthesia was due to an anesthesia effect, the pathology of this effect was unclear. Isoflurane is rapidly metabolized (Ludders et al. 1995) and long-term effects would not be expected. In fact, most birds recovered from the anesthesia prior to completion of the radio-attachment process. In the central California study where all murrelets were anesthetized, only 15% nested after capture and was coincidental with poor ocean condition (E. Burkett, personal comment). In 2002, ocean condition in our study appeared good and more nesting occurred (Chapter 2).

Although we did not observe many differences in the post-capture ecology of Marbled Murrelets treated with anesthesia, we caution that sample sizes were relatively small, and the causal relationships were unknown. Because anesthesia did not improve handling times, but may be related to subtle effects on nesting in some years, we do not recommend the use of anesthesia for field studies at this time.

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TABLE A-1. Between year comparisons of time in captivity, to attach radio-transmitters, and to collect blood sampled from Marbled Murrelets from 2001 – 2003.

	2001		2002		2003	
	$\bar{x} \pm \text{SE}$	n	$\bar{x} \pm \text{SE}$	n	$\bar{x} \pm \text{SE}$	n
Time in captivity (min)	73.6 ± 3.3	23	69.0 ± 3.1	43	69.7 ± 4.0	34
Time for radio attachment (min)	8.4 ± 0.5	23	8.1 ± 0.4	44	7.8 ± 0.5	36
Time to obtain blood (min)	5.7 ± 1.0	23	8.7 ± 0.9	44	7.5 ± 0.7	36

TABLE A-2. Transmitter mass and volume of blood obtained in 3-years of study of Marbled Murrelets in Redwood National and State Parks from 2001 – 2003.

	2001		2002		2003	
	$\bar{x} \pm \text{SE}$	n	$\bar{x} \pm \text{SE}$	n	$\bar{x} \pm \text{SE}$	n
Transmitter mass (g)	2.2 ± 0.0	23	2.5 ± 0.1	44	2.0 ± 0.0	36
Amount blood obtained (ml)	1.3 ± 0.1	19	1.8 ± 0.1	44	1.6 ± 0.1	36

TABLE A-3. Morphometric measurements and brood patch scores (Sealy 1974) for Marbled Murrelets treated with and without anesthesia during attachment of radio-transmitters. Data are combined across years (2001 – 2003).

	Did Not Recieve Anesthesia		Received Anesthesia		P ¹
	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n	
Brood Patch Score	1.5 ± 0.1	76	1.7 ± 0.2	26	ns
Mass (g)	216.0 ± 2.0	75	220.0 ± 4.0	26	ns
Culmen (mm)	18.2 ± 0.1	76	17.9 ± 0.2	26	ns
Bill Depth (mm)	6.2 ± 0.1	76	6.3 ± 0.1	26	ns
Wing chord Left (mm)	123.3 ± 0.5	76	123.4 ± 0.4	26	ns

¹ P-values based on multivariate analysis of variance (main effects = year and treatment). ns = not significant ($P > 0.05$).

TABLE A-4. Time to accomplish radio attachment, to obtain blood, and period of confinement for Marbled Murrelets treated with and without anesthesia.

Data are combined across years (2001 – 2003).

	Did Not Receive Anesthesia		Received Anesthesia		p ¹
	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n	
Time in captivity (min)	70.5 \pm 2.5	73	70.7 \pm 3.5	26	ns
Time for radio attachment (min)	8.1 \pm 0.3	76	8.0 \pm 0.5	26	ns
Time to obtain blood (min)	7.2 \pm 0.6	75	9.0 \pm 1.0	26	ns

¹Based on multivariate analysis of variance (year and treatment as main effects). ns = not significant ($P > 0.05$).

TABLE A-5. Transmitter mass and volume of blood obtained from Marbled Murrelets managed with and without anesthesia. Data are combined across all years (2001 – 2003).

	Did Not Recieve Anesthesia		Received Anesthesia		P ¹
	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n	
Transmitter Mass (g)	2.2 ± 0.03	76	2.2 ± 0.04	26	ns
Amount blood obtained (ml)	1.6 ± 0.1	74	1.6 ± 0.1	24	ns

¹Based on multivariate analysis of variance (year and treatment as main effects). ns = not significant ($P > 0.05$).

TABLE A-6. Number of Marbled Murrelets that initiated nests after treatment with anesthesia and number of murrelets that initiated nests that did not receive anesthesia.

	2001	2002	2003
Number of birds that received radio-transmitters	23	44	35
Number of birds that received anesthesia	6	11	9
Number of birds that did not receive anesthesia	17	33	26
Birds that initiated nests and received anesthesia	2	2	2
Birds that initiated nests and did not receive anesthesia	3	19	6

Table A-7. Proportion of Marbled Murrelets that nested and date of nest initiation by murrelets that received anesthesia (n = 26) during radio attachment and murrelets that did not receive anesthesia (n = 76). Data are combined across all years (2001 – 2003).

	Did Not Receive Anesthesia		Received Anesthesia		p ¹
	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n	
Proportion nesting after capture (%)	36.8	28	23.1	6	ns
Date of nest Initiation (julian) ¹	153 \pm 4	26	157 \pm 7	6	ns
Days Between Capture and Nesting	24 \pm 3	26	31 \pm 6	6	ns

¹ Comparison was made using standardized data.

TABLE A-8. Mean number of days after capture that nesting was initiated by Marbled Murrelets that received and did not receive anesthesia in Redwood National and State Parks from 2001 – 2003.

	2001		2002		2003	
	$\bar{x} \pm \text{SE}$	n	$\bar{x} \pm \text{SE}$	n	$\bar{x} \pm \text{SE}$	n
All murrelets	26 ± 9	5	27 ± 3	21	22 ± 6	8
Murrelets with anesthesia	42 ± 11	2	28 ± 2	2	23 ± 16	2
Murrelets without anesthesia	15 ± 10	3	27 ± 3	19	21 ± 8	6

TABLE A-9. Mean distance traveled from the capture and release site by Marbled Murrelets in the 24h and 72h after capture from 2001 – 2003.

	2001		2002		2003		P ¹
	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n	$\bar{x} \pm SE$	n	
Distance 24h after capture (km)	2.2 \pm 2.0	3	7.0 \pm 0.7	37	10.0 \pm 3.6	24	ns
Distance 72h after capture (km)	8.0 \pm 4.1	10	8.1 \pm 1.3	13	27.2 \pm 5.2	15	0.003

¹Based on multivariate analysis of variance (year and treatment as main effects). ns = not significant (P > 0.05).

TABLE A-10. Mean distance traveled by Marbled Murrelets that did receive anesthesia and that did not receive anesthesia within 24h and 72h after capture. Data are combined across years.

	Did Not Receive Anesthesia		Received Anesthesia		P ¹
	$\bar{x} \pm \text{SE}$	n	$\bar{x} \pm \text{SE}$	n	
Distance traveled 24h after capture (km)	8.9 ± 1.9	47	5.2 ± 0.8	17	ns
Distance traveled 72h after capture	15.1 ± 3.1	25	16.6 ± 5.6	13	ns

¹Based on multivariate analysis of variance (year and treatment as main effects). ns = not significant ($P > 0.05$).

APPENDIX B

NEST-SITE FIDELITY IN MARBLED MURRELETS NESTING IN NORTHERN CALIFORNIA

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Fidelity to a specific nest-site (Morse 1980) in successive years has been documented in several avian taxa, including hole-nesting birds (Newton 1994, Ingold 1991), raptors (Jenkins and Jackman 1993) and seabirds (Williams and Rodwell 1992, Aebischer et al. 1995) including most alcids (e.g. Sealy 1968, Harris et al. 1996). Nest-site fidelity would be favored in species that exploit nesting habitats with a stable structure (McNicholl 1975, Harvey et al. 1979) that may be limiting (Manuwal 1974, Dobkin et al. 1986, Newton 1994). A stable nesting habitat, such as the rocky substrate of offshore islands and rocks used by nesting seabirds (Birkhead 1977), increases the likelihood that a previous nest site will be available for subsequent nesting attempts. If habitat was limiting, nest-site fidelity would be favored because of reduced costs associated with nest-site selection and territory establishment (Bried and Jouventin 2002).

The Marbled Murrelet (*Brachyrmphus marmoratus*), unlike most other alcids, has been reported to be a solitary nester that usually nests on large moss-covered branches in the upper canopy of coastal old-growth coniferous forests of the Pacific northwest (e.g. Naslund et al. 1995, Manley and Kelson 1995, Jordan and Hughes 1995; but see Johnston and Carter 1985, Bradley and Cooke 2001). Such old forests could probably be considered stable habitats, and hence favor the evolution of nest-site fidelity in Marbled Murrelets. Marbled Murrelets have been reported to exhibit fidelity to the same nest stand (Divoky and Horton 1995) and to a lesser extent the nest tree (Nelson and Peck 1995, Naslund et al. 1995). However, there is only one documented case of a Marbled Murrelet nest-site being reused in subsequent (Singer et al. 1995) (but not consecutive) years. In fact, Nelson (1997) speculated that nest-site fidelity in Marbled Murrelets would be rare because they likely change nest-sites between years in response to high nest predation by corvids (e.g. Nelson

and Hamer 1995, see also Appendix D). Nest predation has also been cited as the reason that nest-site reuse would not be common in open-nesting forest dwelling passerines (e.g. Hendricks 1991).

However, given that nest-site fidelity is a common feature of alcid biology, it would be expected that Marbled Murrelets could exhibit nest-site fidelity. Here we present observations of Marbled Murrelet nests in northern California which indicate that at least some Marbled Murrelets exhibit nest-site fidelity, and that such fidelity is apparently not influenced by predation, but may be favored by limited habitat availability.

METHODS

We captured Marbled Murrelets in the coastal waters of northern California between Big Lagoon and Gold Bluffs Beach (N 41.186: W 124.135 and N 41.388: W 124.062, respectively; 2001 – 2003), and in Trinidad Bay (N 41.069: W 124.171; 2002). Capture occurred between 2100h and 0400h, using the night-lighting and dip net technique (Whitworth et al. 1997). Capture crews, equipped with high intensity spotlights and a long-handled dip net, searched near-shore waters (within 5 km of shore) in two 4.5-m inflatable boats. A third 4.5-m inflatable boat served as a transport boat, and a safety/backup boat. Captured Marbled Murrelets were transported, inside plastic tubs with lids, from the capture boat to a larger boat (or pier in Trinidad Bay) to collect data on morphology, attach radio-transmitters, and collect blood samples. Radio transmitters (Model BD-2G, Holohil Systems Ltd, Ontario, Canada) were attached with a subcutaneous anchor to the back of each bird, in the manner described by Newman et al. (1999). Birds captured between Big Lagoon and Gold Bluffs Beach were processed on either the Humboldt State University research vessel *Coral Sea* (in 2001 – 2003), or a chartered 15-m fishing-trawler (in 2002 and 2003). All birds

were released near the capture site within 2h of capture (see Appendix A for additional details).

Locations of radio-marked birds in forests (and at sea; Chapter 3) were determined from fixed-wing aircraft (Cessna 182 or 185). Aircraft were equipped with a receiver (model R4000, Advanced Telemetry Systems, Inc., Isanti, Minnesota) and either a 2-element H-antenna or a single-element omni-directional antenna. Locations of radio-marked Marbled Murrelets were established using a global positioning system (GPS) and aerial telemetry procedures (Gilmer et al., 1981, Whitworth et al. 2000a, b). Flights were conducted beginning the day after the first capture along the coast and over adjacent forested areas between Eureka, California (40° 47'N, 124° 09'W) and Crescent City, California (41° 58'N, 124° 15'W).

A bird detected inland after 0800h was considered to have initiated nesting. Once a potential nest initiation had been indicated by aircraft telemetry, we began a ground search for the nest tree using an ATS receiver (Model R4000, Advanced Telemetry Systems, Inc., Minnesota) and a 2-element H-antenna (Model RA-2A, Telonics, Mesa, Arizona). When a tree or trees had been identified as a potential nest site we subsequently conducted early morning surveys between 0500 and 0630h (PDT) to identify the nest tree used by the radio-marked Marbled Murrelet. If a murrelet was observed landing in the tree, an investigator ascended an adjacent tree to confirm the presence of an egg, chick or incubating adult.

To determine if Marbled Murrelets retained nest-sites between years, we conducted early morning surveys at nest trees used by radio-marked birds in previous years. We conducted between 2-10 early morning surveys at each previously used nest tree between April and July. If we observed a murrelet landing in a nest tree, an investigator ascended an

adjacent tree to determine if nesting had begun. At three nests, originally used in 2001 ($n = 1$), and 2003 ($n = 2$) we placed a persistent video camera (PC106C Weatherproof C-Mount Monochrome Video Camera, Supercircuits, Liberty Hill, TX) attached to a time-lapse video recorder (ST-960N, Supercircuits, Liberty Hill, TX) and a battery 25m from the nest-site. Video tapes and batteries were replaced every 2 – 4 days. In 2002 and 2003 the video recorder ran continuously. In 2004 and 2005 the video recorder was programmed to begin recording at 0400h and to stop recording at 2300h. Video tapes were later reviewed to identify the location of the new nest compared to the first, and to follow the fate of that nest.

RESULTS

In 2001 we captured 23 Marbled Murrelets, of which five initiated nesting. The mean date of nest initiation (excluding re-nest attempts) was 23 May \pm 14 days ($\bar{x} \pm 1$ SE). We precisely located one of the nest trees used in 2001 (Nest 1). This nest was tended by a female that was captured on 24 April.

In 2002 we captured 44 Marbled Murrelets, of which 21 initiated 19 nests (two pairs had both members radio-marked). The mean date of nest initiation was 11 June \pm 4 days. We precisely located six of these nest trees (Nests 2 – 7). Nest 2 was tended by a male Marbled Murrelet that was captured on 18 May. An adjacent tree was climbed on 11 June, and a chick estimated to be 8 – 10 days of age was observed on the platform. This chick died of unknown causes at approximately 26 days of age, following the prejuvenal molt. The skeletal remains of the radio-marked male tending this nest were found on a local beach on 9 July approximately one week after the chick died.

Nest 3 was tended by a male Marbled Murrelet that was captured on 1 May with a brood patch score of 2. Nest 4, initiated on 9 June, was tended by a female Marbled Murrelet

that was captured on 1 May. Nest 5, initiated on 13 June, was tended by a female murrelet that was captured on 17 May. This nest failed of an undetermined cause during the incubation period. A re-nesting attempt initiated on 21 July failed when the chick died of unknown causes at about 15 days of age. Nest 6, initiated on 20 June, was tended by a pair of radio-marked Marbled Murrelets captured on 21 May. Both the male and female had a brood patch score of 2. This nesting attempt failed of an unknown cause early into the chick period. Nest 7, initiated on 30 June, was also tended by a pair of radio-marked Marbled Murrelets. Both birds were captured on 22 May. The female had a brood patch score of 3, and the male had a brood patch score of 2. This nest failed of unknown causes soon after hatching.

In 2003 we captured 38 Marbled Murrelets in April and May, of which 8 initiated nesting. The mean date of nest initiation was 25 May \pm 5 days. Three of these nests (Nests 8 – 10) were precisely located. Nest 8, initiated on 10 May, was tended by a male captured on 1 May. This nest failed soon after hatching from an unknown cause. A re-nesting attempt was initiated on 10 June. This nest also failed after hatching from an unknown cause. Nest 9, initiated on 11 May, was tended by a male captured on 1 May. The chick at this nest died after 18 days of age, but before the juvenal molt had been initiated. Nest 10, initiated on 10 June, was tended by a male captured on 12 May. This nest failed from an unknown cause late in the incubation period.

NEST REUSE

Nest 1.--During early morning surveys conducted on 15 and 20 May 2002, we observed a single Marbled Murrelet land three times and once, respectively, on the same platform used in 2001. The nest-site was subsequently monitored intermittently with a video

camera between 29 May and 3 July. On 5 July, an adult was observed sitting at the nest site used in 2001 (Figure D-1). This nest was initiated 26 days after the mean date of initiation for 2002 and 69 days after the date of nest initiation recorded at this nest site in 2001. This nest failed on 10 July when the unattended egg was depredated by a Steller's Jay (*Cyanocitta stelleri*; see Appendix D for further details). No re-nesting attempt was detected at this site in 2002.

On 14 April 2003, we observed a pair of murrelets circling in the area of the nest tree. At 0618h the pair flew below the canopy towards the nest tree. One member of the pair veered off approximately 25 m from the nest tree, and the other bird flew to the nest tree, and landed on the platform used in 2001 and 2002 (see Figure D-1). Approximately 2 minutes later, the murrelet in the nest tree left the platform. At 0630h, a pair of murrelets (presumably the same pair) was again observed circling in the area, and at 0632h both birds landed on the same platform used in 2001 and 2002. Both birds remained on the platform for approximately 10 min, after which they left the nest platform. At least one murrelet gave partial "keer" (see Nelson 1997) vocalizations when leaving the nest platform. A persistent video camera was placed next to the nest site on 19 April. Video recordings indicate that an egg was laid on 26 April, one day earlier than the nest initiation recorded in 2001, and 70 days earlier than the nest initiation date recorded in 2002 (5 July). This nest was also initiated 29 days before the mean date of nest initiation for 2003 (25 May). The egg hatched between 25 May and 3 June, and the chick fledged during the morning of 4 July. An aluminum leg-band was detected on the left leg of a murrelet feeding the chick at this nest. The female that tended this nest in 2001 was banded on the left leg.

In 2004, video recordings at Nest 1 indicate that an egg was laid at the nest-site on 3 June at 0544h. This nest failed one hour later when the egg was carried away by a Common Raven (*Corvus corax*, see Appendix D).

In 2005, video recordings indicate that an egg was laid on 4 May at 0615h at Nest 1, marking the fifth consecutive year that this nest site has been used. This nest failed 32 days later, probably due to predation (see Appendix D).

Nest 2.--We conducted nine morning surveys between 7 April and 21 July 2003. We did not observe any Marbled Murrelets landing on the platform used in 2002. In 2004, early morning visits (2-3) at the nest tree did not detect evidence of nesting or visits to the nest site.

Nest 3.--We conducted morning surveys on 10 June and 15 July 2003. We did not observe any Marbled Murrelets landing in the nest tree. In 2004, early morning visits (2-3) at the nest tree did not detect evidence of nesting or visits to the nest site.

Nest 4.--We conducted four morning surveys between 28 May and 10 July 2003. No Marbled Murrelets were observed landing in the nest tree. In 2004, early morning visits (2-3) at the nest tree did not detect evidence of nesting or visits to the nest site.

Nest 5.--We conducted four morning surveys at this nest tree between 20 May and 23 June 2003. On 20 May a single Marbled Murrelet was observed landing on the nesting platform used in 2002. On 21 May two Marbled Murrelets were observed landing on the same nest platform at 0530h. Both birds left at approximately 0540h. An adjacent tree was climbed on 22 May, and an adult was observed incubating at the same nest site used in 2002 (Figure D-2). Assuming the nest was initiated on 22 May, this nest initiation was 22 days earlier than the nest initiation date observed at this nest site in 2002 (13 June), and 2 days earlier than the average nest initiation date for 2003 (25 May). During morning surveys on

21 and 23 June we observed a single Marbled Murrelet leaving the nest. An adjacent nest tree was climbed on 12 July and no egg or chick was detected. This nest is presumed to have failed of unknown causes during the incubation period. In 2004, early morning visits (2-3) at the nest tree did not detect evidence of nesting or visits to the nest site.

Nest 6.--Although this nest was initially found in 2002, we did find evidence in the same year that the nest platform had been used previously. Both members of this pair were radio-marked. The nest was initiated on 20 June, 11 days after the mean date of initiation for 2002 (9 June). An investigator climbed an adjacent tree on 6 July and an adult was observed incubating. Both members of the pair continued to alternate 24h at the nest and 24h at sea until 21 July, approximately three days after the egg is presumed to have hatched. The nest tree was climbed on 2 August after it was confirmed by an early morning survey that the nest had failed. On the nest platform the climber observed two nest sites (Figure D-3). The first, and most proximal to the tree boll (Figure D-3), was from the 2002 nest that we believe failed early during the chick period. The second nest site, a moss-free depression (Figure D-3) was approximately 10 cm further out on the tree limb from the 2002 nest site. Because both members of the pair nesting on this platform were radio-marked, and neither of the radio-marked birds was detected inland during the day prior to the date of nest initiation (20 June), we are confident that the second nest site (the moss-free depression) was created by a chick in the previous year.

We conducted 4 surveys between 11 June and 10 July 2003. On 11 June we observed two Marbled Murrelets landing on the same platform as in 2002. Moments later (< 30 seconds), two murrelets were observed leaving the platform. This behavior was repeated four times between 0525 h and 0535 h. On 13 June, an investigator ascended an adjacent

tree and did not observe an egg, incubating adult or a chick. During three additional morning surveys at this nest tree we did not observe Marbled Murrelets landing in or circling the nest tree. In 2004, early morning visits (2-3) at the nest tree did not detect evidence of nesting or visits to the nest site.

Nest 7.--We conducted morning surveys on 12 June and 16 July 2003. We did not observe Marbled Murrelets landing in the nest tree. In 2004, early morning visits (2-3) at the nest tree did not detect evidence of nesting or visits to the nest site.

Nest 8.--In 2004, early morning visits (2-3) at the nest tree did not detect evidence of nesting or visits to the nest site.

Nest 9.--In 2004, early morning visits (2-3) and video observations at the nest tree did not detect evidence of nesting or visits to the nest site.

Nest 10.--In 2004, early morning visits (2-3) and video observations at the nest tree did not detect evidence of nesting or visits to the nest-site.

DISCUSSION

Video-observations made at Marbled Murrelet nest sites and observations made during visits to nest sites during this study indicate that at least some Marbled Murrelets nesting in Redwood National and State Parks, California exhibit nest-site fidelity in consecutive years. At one of these nests the nest-site was used in at least five consecutive years (2001 – 2005). At two other nest sites, the same site was used in at least two consecutive years.

Nest-site fidelity is common among colonial ground nesting seabirds (e.g. *Eudiptes chrysolophus*; Williams and Rodwell 1992) including ground nesting alcids (e.g. *Uria aalge*; Birkhead 1977) and crevice/burrow nesting alcids (e.g. *Alca torda*; Harris and Wanless 1995;

Cepphus grille, Ewins 1989). Rates of nest-site fidelity among alcids, for marked individuals often exceeded 70% (e.g. *C. grille*, Birkhead and Harris 1985; *Synthliboramphus hypoleucus*, Drost and Lewis 1995), and can exceed 90% (*Fratercula arctica*, Ashcroft 1979). By comparison, the extent of nest-site fidelity among supposedly solitary-nesting alcids such as the *Brachyramphus* murrelets is poorly known. For example, there has been only a single observation of nest-site fidelity occurring in the Kittlitz's Murrelet (*B. brevirostris*; Piatt *et al.* 1999).

The evolution of nest-site fidelity in alcids may have been selected for by several factors. First, reuse of a nest-site could be due to limited availability of nest-sites. Alcids compete for available and appropriate space, burrows and crevices on offshore rocks and islands (Manuwal 1974). If space was limiting, individuals that retained their nest-site would be more likely to have nested successfully compared to individuals that established a new nest site (e.g. Manuwal 1974, Fairweather and Coulson 1995, Harris *et al.* 1996, St. Clair *et al.* 1999).

Regardless of the amount of overall old-growth forest available, nest-sites could be limiting for Marbled Murrelets. Although there could be an abundance of large branches within a given stand of old-growth trees, the majority of the large branches might not be useful to Marbled Murrelets. Access is likely a key element in determining platform availability. Marbled Murrelet access to a platform could be obstructed by smaller branches on the platform and adjacent trees, and epiphytes on the nesting platform. A platform could also be rendered unusable if the nest-site was blocked by a fallen branch, or if the debris forming the previous nest-site was removed following a wind storm or a rain storm. These

factors are likely more important in determining nesting potential of a site than the physical characters of the nesting platform.

Nest-site fidelity would also be favored because it facilitated the re-uniting of pairs and thus promote mate-fidelity (Birkhead and Harris 1985), which could lead to greater reproductive success (Bried and Jouventin 2002). Mate fidelity could reduce costs associated with courtship and formation of a pair-bond. For Marbled Murrelets, retention of a nest platform between years would thus provide a site for the reuniting of the pair, facilitate pair formation and mate fidelity in subsequent years, and reduce the amount of time and the costs associated with pair formation. In our study, the re-sighting of a leg band in a subsequent year would strongly suggest that the nest was being used by the same bird.

Another benefit of nest-site fidelity would be reduction in the costs associated with nest-site selection. In alcids nest-site selection occurs during the pre-breeding and breeding period. Nest-site selection is often part of courtship, and pairs may spend considerable energy day and night visiting nest-sites, and eventually establishing a nest-site (Ainley and Boekelheide 1990, Gaston 1994, Ainley et al. 2002). By contrast, nest-site selection in Marbled Murrelets is limited to a few hours a day, typically under lowlight conditions (Naslund 1993, Nelson 1997; see also Chapter 4). Consequently, nest-site selection could take much longer in Marbled Murrelets compared to other alcids. This might explain why some non-nesting murrelets make regular morning flights into nesting areas (Chapter 4, see also Naslund 1993). Finding an appropriate nest-site would be energy and time consuming, and entail a relatively high risk of predation. Consequently, nest-site fidelity would reduce the energy and time costs associated with nest-site selection in Marbled Murrelets.

One of our nest-sites (Nest 1) has been used in at least five consecutive years. Of the five nesting attempts, two failed as a result of egg predation by corvids (2002, 2004), and a third (2005) was suspected of failing due to predation by corvids (Appendix D). Also, during the third nesting attempt (2003), which was successful, video recordings detected additional visits by a Steller's Jay during the chick period (Appendix D). If nest-site selection or nest-site fidelity in Marbled Murrelets were influenced in part by corvid predation, we would not expect this nest site (Nest 1) to have been retained between 2002 and 2003, or between 2004 and 2005. Fidelity to the nest-site in this case suggests that nest-site selection or fidelity in Marbled Murrelets is less influenced by predation than by the availability of appropriate and accessible nest-sites. Furthermore, at Nest 5, an initial nesting attempt in 2002 failed 8 days after the egg was laid (13 June), presumably due to egg predation. A second nesting attempt at the same site also failed when the chick was approximately 20 days old due to unknown causes (Hébert et al. 2003). Consequently, if predation influenced site selection, it would be expected that this nest-site would be abandoned. However, the nest-site was again retained in 2003. These observations also suggest that nest-sites may be limiting, and consequently, regardless of predation risk, favored the evolution of nest-site fidelity.

The prevalence of nest-site fidelity in Marbled Murrelets (3/10 nests sites) was less than that reported in other alcids. However, we may have failed to detect some reuse due to predation occurring early in incubation (see Chapter 2). Because some of these nests were visited infrequently (especially in 2004), we could have missed a failed nesting attempt. Nest failure early in incubation was common (see Chapter 2).

Additionally, nest-site fidelity was more common when both members of a pair survive to the next breeding attempt (Aebischer et al. 1995). Beissinger and Nur (1997)

estimated annual survivorship for adult Marbled Murrelets to be 85%. Thus, of the 10 nests we followed, two would likely not be re-used simply as an outcome of the death of one member of the pair. Where nest-site fidelity (in other alcids) has been related to nest-success, nest-site fidelity was more common among successful pairs than unsuccessful pairs (Aebischer et al. 1995, Harris et al. 1996). During our study, overall reproductive success was as low as 6.9% (see Chapter 2). Thus, if failed nesting influenced fidelity, only 30% of nest-sites would be retained between years. However, nest failure did not deter the birds at nest 1 and 6 from nesting again at their respective sites. Another source of change in reuse would be the characteristics of the platforms; if they changed between seasons the site could be rendered less appropriate or accessible. For example epiphytes may reduce or eliminate access to the platform or the nest-site specifically. Also, nest-sites supported by duff or debris could be damaged by rain and/or wind that reduce the quality or stability of the debris, rendering it unusable. Considering these factors, opportunities for nest-site fidelity would be fewer than reported for other species, and would be consistent with the hypothesis that nest sites could be limiting.

The occurrence of nest-site fidelity in Marbled Murrelet nesting in Redwood National and State Parks suggests a need to protect current sites in old-growth forests (see also Divoky and Horton 1995). Removing a nest tree could affect the reproductive potential of a pair of murrelets in two ways. First, removing a nest tree would eliminate an important component of pair formation. This would serve to delay breeding if both members of the affected pair sought out new mates. Second, these new pairs would then have to find new nest platforms, which could take a year or more. For every nest removed, there would be the potential for a non-proportional increase in the number of non-nesting pairs in a population.

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FIGURE B-1. Picture of Nest 1 in 2002 and 2003. Pictures were taken from opposite directions.



FIGURE B-2. Picture of Nest 5 in 2002 and 2003.



FIGURE B-3. Picture of confirmed Nest 6 in 2001 (A)

and presumed nest site in 2002 (B).

Eggshell fragments are present at A.

TABLE B-1. Ten Marbled Murrelet nests monitored for reuse and their respective initiation date, hatching success and fledging success in Redwood National and State Parks from 2001 – 2003. Brood patch scoring followed methods of Sealy (1974).

Nest	Year											
	2001				2002				2003			
	Date Initiated	Hatch	Fledge	Brood Patch	Date Initiated	Hatch	Fledge	Brood Patch	Date Initiated	Hatch	Fledge	Brood Patch
1	27-Apr	Yes	Yes	3	5-Jul	No			26-Apr	Yes	Yes	
2					6-May	Yes	No	3				
3					30-May	Yes	Yes	2				
4					9-Jun	Yes	Yes	3				
5					13-Jun	No		2	22-May	No		
6	____ ¹	____ ¹	____ ¹		20-Jun	Yes	No	2				
7					30-Jun	Yes	No	2-Mar				
8									10-May	Yes	No	2
9									11-May	Yes	No	2
10									10-Jun	No		3

¹ Nest 6 was used in 2001 but no data was obtained.

APPENDIX C

EXTRA-PAIR VISITATIONS TO A MARBLED MURRELET NEST IN NORTHERN CALIFORNIA

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Unlike most colonial alcids, Marbled Murrelets (*Brachyramphus marmoratus*) nest solitarily on moss-covered branches of old-growth coniferous trees throughout most of their breeding range in the northeastern Pacific Ocean (Nelson 1997, USFWS 1997, McShane et al. 2004). Marbled Murrelets also are observed on the ocean and flying mainly as single individuals and as pairs throughout the year, although larger groups are occasionally observed. Larger groupings at sea occur when murrelets participate in feeding flocks, aggregate in feeding areas, or when molting and juvenile birds co-occur in flocks. Solitary nests, cryptic breeding plumage, and crepuscular nest visitations reflect adaptations to reduce predation in inland forests and to feed solitarily in nearshore feeding areas (Carter and Sealy 1990, Strachan et al. 1995, Nelson 1997). Here, we describe two observations of extra-pair visitations of Marbled Murrelets at an active old-growth tree nest in northern California and discuss possible explanations for this previously undescribed behavior.

METHODS

As part of a radio-telemetry study on Marbled Murrelets in 2001-2003, we captured murrelets in April and May using the night-lighting and dip net technique (Whitworth et al. 1997) in near-shore waters of northern California between Trinidad (41° 03'N; 124° 09'W) and Gold Bluffs Beach (41° 17'N; 124° 07'W) in Humboldt County (Chapter 1-4). To each Marbled Murrelet captured, we attached an approximately 2-g radio-transmitter with a unique frequency (Model BD-2G, Holohil Systems Ltd., Ontario Canada) using a subcutaneous anchor (Mauser and Jarvis 1991), following the procedure described by Newman et al. (1999). All birds were released near the capture site within 2 h of capture. Radio-marked murrelets were then located at sea and in adjacent coastal forests using aircraft telemetry. A potential nesting attempt was identified through the presence of a radio-marked

Marbled Murrelet in a forested area after 0800h. Once a potential nest initiation had been indicated by aircraft telemetry, we began a ground search for the nest tree using an ATS receiver (Model R4000) and a 24-element H-antenna (Model RA-2A, Telonics, Mesa, Arizona). When a tree or trees had been identified as a potential nest site we subsequently conducted early morning observational surveys (see Paton et al. 1990) to identify the specific nest tree used by the radio-marked Marbled Murrelet. A nest tree was identified when a murrelet was observed landing in a suspected nest tree, and the strength of the radio signal coincided with the arrival of the bird at that tree. An investigator then ascended an adjacent tree to confirm the location of the nest site. On 19 April 2003 we placed a persistent video camera attached to a time-lapse video recorder at a nest site that had been active in 2001 and 2002 (the same nest described in Appendix B). Sound was not available on the video. Based on video recordings an egg was laid on 26 April, hatched between 25 May and 3 June, and the chick fledged during the morning of 4 July. At this nest site, we recorded on video the presence and behavior of extra-pair murrelets. Postures and displays of the birds were relatively simple, and we briefly describe these observations. Birds described herein were identified for purposes of this description by letters of the alphabet, assigned in order of their appearance on the video.

RESULTS

OBSERVATION #1

Extra-pair birds were first observed at this nest on 11 May, 22 days after egg laying. An incubation exchange occurred at 0522h. The murrelet being relieved of incubation duties (Bird Z) departed immediately after arrival of another bird (Bird A). Bird A did not immediately incubate the egg, but rather stood next to the egg facing east, which was the

direction in which Bird Z had departed. At 0524h two murrelets (Birds B and bird C) landed on the platform together, arriving from the east. Bird B was closest to Bird A (< 20 cm) and Bird C was further away (approximately 30 cm). Upon landing, Bird B and Bird C stood upright with their necks extended and the bill pointing up (“Bill Up” posture; see Strachan et al. 1995, Nelson 1997). Bird A turned to face birds B and C, and also performed the Bill Up posture, although the neck was not fully extended. Bird C (furthest from Bird A) maintained the Bill Up posture intermittently while Bird B lowered its bill, but continued to keep the neck extended. All three birds then assumed resting postures, with neck retracted and bill lowered, for approximately 3 seconds. Bird A sat next to the egg facing Birds B and C, while Birds B and C faced each other. Then, all three birds stood and performed the Bill Up posture in unison, appearing to rock up and down on their tarsi. During this time, Bird C opened its bill slightly on two separate instances, Bird B faced away from Bird A and opened its bill, and Bird C extended its neck with bill up posture and also opened its beak before immediately retracting its neck. Then, Bird A performed a “Head Pump” display, where the head was rapidly pumped forward and backward without fully extending the neck or pointing the bill straight up.

At about 4 seconds after the extra-pair had arrived, Bird C turned its head to face Birds A and B, then lowered its head and bill, then quickly raised its bill. Bird B then raised its bill without neck extension. Immediately, Bird B and C, facing each other, quickly lowered their heads, then quickly extended their necks in Bill Up posture (Bird C with an open bill). Bird B then pulled its head back over its shoulders, then again extended the neck straight up with bill open in Bill Up posture. Bird B then performed the same sequence of

behaviors. Again, Bird A performed the Head Pump display in response to Bill Up postures of Birds B and C. After a brief pause, both birds lowered their bills and retracted their necks.

At about 6 seconds after the extra-pair arrival, Bird B momentarily turned to face Bird A, quickly followed by Birds B and C again performing the Bill Up posture, and Bird A performing the Head Pump display. Birds B and C then retracted their necks, performed a Bill Wiping display (where the back and sides of the head and the bill are wiped across the upper back similar to a head and bill cleaning motion), and Bird A again performed the Head Pump display. Birds B and C then perform the Bill Up posture, followed by Bird A. This sequence of behaviors was quickly followed by another “Bill Wiping” display by Birds B and C, while Bird A again Head Pumped. Finally, approximately 8 seconds after landing on the platform, birds B and C left the nest platform. Bird A then moved to begin incubating the egg that had been exposed during the entire episode.

OBSERVATION #2

The second instance of extra-pair birds at this nest occurred on 20 June, when the chick was about 15 days old. An adult (Bird D) carrying a small fish crosswise in its bill landed on the nest platform at 0523h, and moved towards the chick. At 0530h the chick had not yet taken the fish from bird D, when a pair of murrelets (Birds E and F) landed together on the platform. Upon landing, both additional murrelets stood with necks extended and bills pointing forward but not up. Bird E landed closest to the chick, and also carried a fish crosswise in its bill, whereas Bird F landed furthest from the chick and was not carrying a fish. Just prior to the extra-pair arrival, Bird D had shifted its position on the branch to a point further from the tree-trunk, which provided more landing space on the platform. Bird D did not direct any overt behavior towards Birds E and F upon their arrival. Bird D then

proceeded to pass its fish to the chick (which immediately swallowed it), and then Bird D departed from the platform about 15 sec after extra-pair arrival. At 0534h Bird F, without a fish, approached the chick (< 10 cm) momentarily. While approaching the chick, Bird F retracted its neck and lowered its head. At this point, Bird E, still holding its fish, lowered its head briefly, and Bird F then turned around and walked away from the chick. The chick did not react to this approach. Bird F then departed from the platform at 0535h. Bird E sat quietly at the site before passing its fish to the chick (which immediately swallowed it) at 0552h, and then departed from the nest platform. As with the first extra-pair observation, we did not detect any overt signs of aggression between the three adult Marbled Murrelets on the platform.

DISCUSSION

Extra-pair visitations have not been previously recorded or described at solitary Marbled Murrelet nest sites. However, nest sites are not readily visible from the ground and few nest sites have been monitored with video cameras, as were used in our study. Video cameras allow for detection of brief visits to nests, which are difficult or impossible to study from ground-level vantage points (e.g. Singer et al. 1991). With only two extra-pair observations in the 1216 hours of video prior to fledging at this nest in 2003, and no observation in 2001 or 2002 (although video was incomplete in these years), we suspect that extra-pair visitations are infrequent and may reflect special circumstances.

In Observation #1 during the incubation period, the extra-pair may have reflected prospecting adults searching for an appropriate platform for nesting. Apparent prospecting is a common behavior in Marbled Murrelets, with many reports of birds landing on platforms without apparent egg laying beforehand or afterwards (Nelson 1997; see Chapter 4). Given

arrival shortly after departure of the adult that was relieved of incubation duties, the extra-pair may have observed its departure, which may have provided a behavioral clue for the presence of a suitable platform for landing or breeding. However, it was also possible that the extra-pair involved the relieved adult which had just left the nest-site and one member of the extra-pair was in fact a mate (see Observation #2 below). The behavior of the extra-pair in Observation #1 was characterized by frequent Bill Up postures which are typically considered to be courtship and nest-greeting behavior in Marbled Murrelets (Strachan et al. 1995; P. Hébert and R. Golightly, unpublished data). However, Bill Up postures by all three birds at the nest site, including one or possibly both mates, suggested familiarity between all individuals. The Bill Wiping display between the extra-pair has not been previously described in Marbled Murrelets but also suggested familiarity and comfort between extra-pair and the active mate. We suspect that the extra-pair birds probably did not include a member of the active pair, but instead that one or both extra-pair birds had previously nested at this site as a previous mate of one of the active pair. Alternatively, one of the extra-pair birds may have been an offspring of one or both of the active pair. Nest re-use was recorded at this nest site in 2001-05 (Appendix B). Divorce, which is known in alcids (e.g., Ashcroft 1979) but not yet described in Marbled Murrelets, and natal philopatry, which is also well known in alcids (Gaston and Jones 1998) but not yet described in Marbled Murrelets, could occasionally lead to interactions between familiar individuals. However, most of these types of interactions typically occur before egg laying at a nest site. The Head Pump display also has not been previously described in Marbled Murrelets but may have suggested a form of low-level aggression between the attending adult and the extra-pair. Low-level aggression may be favored to encourage non-mates to depart from cryptic nests without incident,

avoiding accidental dislodging of the egg from the branch, and avoiding potential attraction of predators to the nest or adults.

In Observation #2 during the chick period, the third murrelet that landed on the platform during a chick feeding sequence could have been an offspring from a previous year or a previous mate. Non-aggressive interactions characterized by few postures or displays again suggested familiarity between individuals. This nest site had been successful in 2001, but not in 2002. Thus, the third murrelet could have been prior offspring two years of age or older. Younger subadult alcids often arrive later in the season at nesting areas than breeding birds (Hudson 1985).

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APPENDIX D

VIDEO OBSERVATIONS OF CORVIDS AT A MARBLED MURRELET NEST: IMPLICATIONS FOR ESTIMATES OF NEST SUCCESS AND CORVID MANAGEMENT

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Predation is an important evolutionary force that has shaped the life-history patterns of most bird species (Ricklefs 1969). Alcids, for example, exhibit several characteristics that probably evolved in response to predation. Surface nesting alcids such as Common Murres (*Uria aalge*; Ainley et al. 2002), and most crevice and burrow nesting alcids such as Crested Auklets (*Aethia cristatella*; Jones 1993) and Ancient Murrelets (*Synthliboramphus antiquus*; Sealy 1976), nest colonially on islands that are usually devoid of mammalian predators. Burrow or crevice-nesting probably evolved in response to predation (Gaston and Jones 1998). Several alcid species exhibit nocturnal (e.g., Cassin's Auklet, *Ptychoramphus aleuticus*; Manuwal and Thoresen 1993) activity around the colony or nesting site, thus reducing the risk of predation by diurnal avian predators.

Marbled Murrelets (*Brachyramphus marmoratus*), unlike other alcid species, do not nest colonially, but rather in the upper canopy of old-growth coniferous trees (Singer et al. 1991, Manley and Kelson 1995); seemingly these nests are solitary. Nonetheless, predation is believed to be an important factor affecting their reproductive success (Nelson and Hamer 1995). Marbled Murrelets have evolved several characteristics that serve to minimize the risk of predation: 1) breeding adults fly inland before or at sunrise to attend nest sites (Nelson and Peck 1995), 2) adults are usually silent around the nest (Nelson and Hamer 1995), 3) Marbled Murrelets have cryptic plumage and are small in size (Carter and Stein 1995), and 4) both incubating adults and chicks tend to remain motionless on the nest branch (Nelson and Hamer 1995, Chapter 1).

The Marbled Murrelet, like other bird species (Fahrig 2001, see also George and Brand 2002), has been affected negatively by habitat fragmentation (Raphael et al. 2002). Over the last 30-50 years Marbled Murrelet populations have declined as a result of habitat

loss (see Perry 1995) resulting from the harvest of old growth coniferous forests (Carter and Erickson 1992, Kelson et al. 1995). In addition to the loss of nesting habitat, the fragmentation of old growth forests may have compounded the risk of predation for Marbled Murrelets (Nelson and Hamer 1995) through its influences on the distribution and foraging behavior of corvids, especially Steller's Jays (*Cyanocitta stelleri*; Masselink 2001, George and Brand 2002, Raphael et al. 2002).

The importance of relating Marbled Murrelet reproductive success to corvid predation as a possible constraining factor on populations was recognized in the Marbled Murrelet Recovery Plan (U. S. Fish and Wildlife Service 1997). However, Marbled Murrelet nests are difficult to locate (Chapter 1), and previously the determination of nesting success occurred after the breeding season, based on the presence or absence of a fecal ring, down, and egg shell fragments (Nelson 1997). Here we present records from video observations of corvid activity at Marbled Murrelet nests in northern California, and discuss how estimates of reproductive success and productivity based solely on the presence of fecal rings may likely overestimate nesting success and hence, productivity.

METHODS

As part of a larger study of the nesting biology of Marbled Murrelets (Chapter 1, 2, 3, 4), we captured Marbled Murrelets in the coastal waters of northern California between Big Lagoon and Gold Bluffs Beach (N 41.186: W 124.135 and N 41.388: W 124.062, respectively; 2001 – 2003), and in Trinidad Bay (N 41.069: W 124.171; 2002). Capture occurred between 2100h and 0400h, using the night-lighting and dip net technique (Whitworth et al. 1997). Each murrelet was banded with a U. S. Geological Survey stainless steel leg band. To each Marbled Murrelet captured, we attached a 2-g radio-transmitter, with

a unique frequency (Model BD-2G, Holohil Systems Ltd., Ontario Canada), attached with a subcutaneous anchor (Mauser and Jarvis 1991), following the procedure described by Newman et al. (1999). All birds were released 1 - 2 h after capture.

Locations of radio-marked birds in forests (and at sea; Chapter 3) were determined from fixed-wing aircraft (Cessna 182 or 185). Aircraft were equipped with a receiver (model R4000, Advanced Telemetry Systems, Inc., Isanti, Minnesota) and either a 2-element H-antenna or a single-element omni-directional antenna. Locations of radio-marked Marbled Murrelets were established using a global positioning system (GPS) and aerial telemetry procedures (Gilmer et al. 1981, Whiworth et al. 2000a, b).

Flights were conducted between 0800h and 2030h along the coast and over adjacent forested areas between Eureka, California (N 40.47: W 124.09) and Crescent City, California (N 41.58: W 124.10). If a bird was not found in this area, the search was extended south to Cape Mendocino and Humboldt Redwoods State Park (N 40.19: W 123.55) and north to Brookings, Oregon (N 42.04: W 124.16). A bird detected inland after 0800h was considered to have initiated nesting. Once a potential nest initiation had been indicated by aircraft telemetry, we began a ground search for the nest tree using an ATS receiver (Model R4000) and a 2-element H-antenna (Model RA-2A, Telonics, Mesa, Arizona). When a tree or trees had been identified as a potential nest site we subsequently conducted early morning observational surveys (see Paton et al. 1990) to identify the specific nest tree used by the radio-marked Marbled Murrelet. A nest tree was identified when a murrelet was observed landing in a suspected nest tree, and the strength of the radio signal coincided with the arrival of a bird at that tree. An investigator then ascended an adjacent tree to confirm the location of the nest site.

Beginning in 2002, we installed a persistent video camera (PC106C Weatherproof C-Mount Monochrome Video Camera, Supercircuits, Liberty Hill, TX) to monitor potential effects of trail users on Marbled Murrelet behavior and nest success at one nest initially located in 2001. The video camera was connected via a 100-m cable to a time-lapse video recorder (ST-960N, Supercircuits, Liberty Hill, TX), and to a 12 v deep cycle battery enclosed within a secure metal box located 25 m from the nest-tree. Video tapes and batteries were replaced every 2 – 4 days. We let the video recorder run continuously in 2002 and 2003. In 2004 and 2005 we programmed the video recorders to begin recording at 0400h and to stop recording at 2300h. Video tapes were later reviewed to determine if potential nesting activity had occurred at the nest platform.

RESULTS

We first located the nest that had the persistent video in 2001. We captured the female of the pair on 24 April, 2001. Incubation was initiated on 27 April. A chick fledged from this nest on 26 June.

In 2002 we conducted an early morning survey on 13 May, between 0500h and 0630h. During this time we observed a Marbled Murrelet flying into the suspected nest tree and land on the nest platform used in 2001. A persistent video camera was placed in the nest tree on 29 May. The video operated from 29 May to 3 July, during which time one or two adults visited the nest site in the early morning, but no egg was seen. On 5 July, an adult was observed sitting at the nest site.

An experimental disturbance trial (see Chapter 1) was conducted at the nest on 9 July, between 1600h and 1930h. We returned to the nest tree the following day (10 July) to conduct a disturbance trial on the other member of the pair. Using a portable video monitor

we observed that there was no adult present and the egg had disappeared. An investigator ascended the nest tree and detected only 2 – 3 small drops of albumen that were partially dry. Video recordings from the persistent camera showed that during the latter part of the trial on 9 July, a Steller's Jay appeared in the branches < 2 m from the nest. When the jay appeared in the branches adjacent to the nest, the incubating murrelet extended its neck, gaped in the direction of the jay and kept the jay in view by turning its head. The jay left the field of view within 30 sec. Approximately 1 hour after this interaction (at about 2030h) the incubating Marbled Murrelet departed and left the egg unattended. No murrelets were detected returning to the nest platform before darkness.

The following morning (10 July), both members of the pair arrived at the nest site at approximately 0500 h and left minutes later. Over the next 30 min both birds visited the nest site several times for a few minutes and then departed. At approximately 0530h one of the birds settled on the egg and the other bird left the nest platform. At 1000h the incubating adult left the nest site and did not return. Approximately 90 min after the incubating murrelet left the nest site a Steller's Jay landed at the nest site and pecked at the egg several times, broke a hole into the egg, each time consuming some of the egg contents. After 3 min the jay grasped the egg by inserting its lower mandible through the hole it had created and flew off with the egg.

In 2003, video recordings at the same nest site indicated that an egg was laid on 26 April. The egg hatched on or about 24 May. On 6 June, when the chick was approximately two weeks old, a Steller's Jay approached within < 1 m of the nest. Just prior to the arrival of the jay at 0627h, the chick was resting, and then lifted its head and gaped. In the next video frame (12 sec later) the Steller's Jay was observed standing on the nest platform within 2 m

of the murrelet chick. The jay then moved out of sight. However, the murrelet chick continued to gape (see also Simons 1980) and appeared to flap its wings and change position, apparently following the jay around the nest site. At 0629h the murrelet chick returned to the resting position it had exhibited prior to the arrival of the jay.

Minutes later (0635h) the video tape required exchange and recording temporarily stopped. At 0710h a Steller's Jay again landed on the nest platform within 2 m of the chick. When the jay appeared, the chick began to gape and flap its wings as the jay approached. The chick approached to within 1m of the jay. In the next frame the jay was out view, although the chick was still gaping with its neck outstretched, presumably in the direction of the jay. The jay came into view another six times over the next 4 minutes. During this time the jay did not approach within 1 m of the chick and the chick adjusted its position (presumably to follow the jay in the branches) and continued to gape and/or flap its wings. The jay was last detected at 0715h. The chick returned to the nest site at 0718h and appeared to be resting normally.

Later, at 0736h an adult arrived carrying a sandlance (*Ammodytes hexapterus*) crosswise in its beak to feed the chick. A few minutes later, a jay appeared on a branch within 1.0 m of the nest cup. The adult immediately dropped the fish and flew away. Two minutes later the chick picked up and swallowed the fish head-first. The jay was not seen again at this nest and the chick fledged during the morning of 4 July, 2003.

In 2004, during the morning of 3 June a male Marbled Murrelet was observed incubating an egg that had been laid at approximately 0544h that morning. At approximately 0636h the incubating murrelet raised its head and looked around. Approximately 10 min later the adult murrelet left the nest platform. At 0647h a Common Raven appeared in the

branches adjacent to the murrelet nest site. Over the next five min the raven hopped from branch to branch around the nest platform (< 2 m), appearing to inspect the nest site. Then at 0653h the raven grasped the egg in its beak and flew away, leaving no evidence indicating that an egg had been laid.

In 2005 the same pair of murrelets initiated a nest on 4 May. On 5 June at the usual time for an incubation exchange (0530h), an adult Marbled Murrelet situated itself on the nest cup for 2 min and then flew away, revealing an empty nest cup where a 32-day old egg had been the previous day. The camera did not operate at night and the egg was possibly predated on during the night or very early dawn.

Though we could not confirm how the egg disappeared, we did observe a Steller's Jay 11 days before the disappearance. The jay moved about the nest area for 1 min and within 2 m, but received no detectable reaction from the incubating adult. After disappearance of the egg, a jay was observed examining the nest cup for less than 1 min, 2, 4 and 6 days after the egg disappearance. We also recorded some irregularity in the incubation pattern of this murrelet pair. The egg was left alone for < 1 min three times prior to the disappearance and one adult abandoned the egg for at least six hours just three days prior to the disappearance.

DISCUSSION

We confirmed that the Steller's Jay and Common Raven are predators of Marbled Murrelet eggs, which had previously been suspected (see Singer et al. 1991, Naslund et al. 1995, Nelson and Hamer 1995). Without video-recordings obtained from the camera at the nest, the exact cause of failure would not have been known in either of these cases. Little to no evidence of predation was left at the nest site. Further, we would have missed the 2004

nesting attempt altogether if the video had not already been operating in anticipation of nesting (based on 2001, 2002 and 2003 attempts). The egg was only present for about one hour. Our aircraft that searched for nesting, would not have left the ground until after 0800h. The defensive interactions between the jay and the chick suggest that, given the opportunity, Steller's Jays may also take murrelet chicks (see Singer et al. 1991), although here the jay was unsuccessful.

The video observations presented here raise at least two important implications for the study and management of Marbled Murrelets and corvids. First, the video recordings clearly demonstrate that jays and ravens are capable of carrying a Marbled Murrelet egg from the nest site. Similarly, Singer et al. (1991) observed a Steller's Jay carrying a young murrelet chick away from the nest. With the removal of the murrelet egg there was little to no evidence of nesting activity. In the one case, the few drops of albumen would likely have been overlooked had we not known there had been an egg on the nest platform. Consequently, estimating murrelet nesting activity based on the presence of a fecal ring or egg shell fragments (Nelson and Hamer 1995) likely underestimates the number of nesting attempts and the number of nest failures during the incubation period. Even using radio-telemetry, nesting attempts may be underestimated if the predation occurs prior to detection by investigators. The degree to which the number of nesting attempts and nest failures are under-estimated depends on the rate of predation. For Marbled Murrelets hatching success was relatively low (this study, 43%; see Chapter 2; 67% reported in Nelson 1997) compared to other alcids, where hatching success is usually over 90% (e.g, Gaston 1994, Ainley et al. 2002, Piatt and Kitaysky 2002). If this lower hatching success in Marbled Murrelets is a result of egg predation, the extent of this problem may be compounded by the fact that

murrelets in northern California occupy a fragmented habitat (Nelson and Hamer 1995, see also George and Brand 2002) that exacerbates the risk of predation.

Second, it is also important to point out that neither the incubating Marbled Murrelet or the 14 -day old chick flushed when approached by the Steller's Jay. Rather, both the murrelet adult and chick responded by gaping and facing the jay. The jay was apparently dissuaded from attempting to displace the incubating adult murrelet to gain access to the egg. The average mass of a Marbled Murrelet in our study was 220 g (Chapter 2) and is greater than that of an adult Steller's Jay (140 g, Greene et al. 1998). Perhaps there is sufficient risk of injury for a Steller's Jay that approaches an incubating Marbled Murrelet too closely. The positive outcome of these encounters raises a question: why have so many Marbled Murrelet nests been suspected of failing during incubation as a result of corvid predation, especially by Steller's Jays (Nelson and Hamer 1995)? We believe the answer to this question, can be determined from analyzing usual alcid behavior. Several studies have observed irregular incubation patterns (see Chapter 2). Sealy (1984) first described the phenomenon in the Crested and Least Auklet (*Aethia pusilla*), and the Ancient Murrelet. Others (Chapter 4) have reported murrelets to occasionally miss a day during incubation. Radio-telemetry evidence obtained during this study suggests that at least some Marbled Murrelets interrupt the normal incubation with short periods of neglect early in the incubation period (Chapter 2). Therefore, we suggest that instances of interrupted incubation render murrelet eggs vulnerable to predation (see also Naslund et al. 1995), not only by corvids but other potential egg predators such as Douglas squirrels (*Tamiasciurus douglasi*).

We cannot explain why the incubating adult left the egg unattended in 2002 after the initial encounter with the jay. It is possible that our experimental disturbance (exposing the

adult to the sound of an operating chainsaw; see Chapter 1) may have caused the adult murrelet to abandon the egg. However, none of the remaining 12 adults tested in a similar fashion had previously flushed during or after our experimental disturbance trials. It was also possible that the jay was able to consistently and persistently harass the murrelet for a period of time, but outside the view of our camera (our cameras were tightly focused on the nest). Another possible explanation is that one of the murrelets at this nest may have been an inexperienced breeder (see below) and thus more likely to exhibit inconsistent incubation tendencies (which ultimately exposed the egg to predation).

Even more puzzling is the fact that the adult murrelet that incubated the day after the disturbance trial also abandoned the egg. We could not differentiate between the adult murrelets at the nest, and it is possible that the murrelet that incubated the second day was the same bird that had abandoned the egg the previous evening. Interestingly, both members of the pair arrived together at the nest on the morning of the predation event. Both adults departed within seconds of arriving and repeated this behavior several times before one murrelet finally settled on the egg. To our knowledge this is the first report of such behavior during the incubation period and may indicate that one of the members of the pair could have been an inexperienced breeder. It was the second year for a nest at the site. Given that this nest was initiated in July, compared to April the previous year, the late onset to nesting may also indicate that at least one of the members of the pair was an inexperienced breeder. Alternately, the late nesting date could have been because it was a renesting attempt (see Hébert et al. 2003), and a first nest already was lost to predation. Regardless, the failure of the videoed nest appears to be attributable to predation.

In 2004, the male Marbled Murrelet tending the egg flushed approximately two min before the raven was seen near the nest site. It is possible that the raven was in a branch near the nest site out of view of the camera at the time the murrelet abandoned the egg. Previous studies have reported murrelets flushing when approached by ravens (Singer et al. 1991). Given the size disparity between the smaller Marbled Murrelet relative to the Common Raven, it is not surprising that the murrelet would flush from the nest site.

Finally, it is important to note that the murrelet chick that was approached by a Steller's Jay in 2003 managed to successfully fend off the jay. The murrelet chick was approximately two weeks old and based on the video observations it was about half the size of an adult murrelet. The murrelet chick was active during the interaction with the jay, including gaping, wing flapping and moving on the nest platform. The favorable outcome of this encounter was likely due to the combined behaviors exhibited by the murrelet chick.

In conclusion, the observations obtained from video-recordings at this Marbled Murrelet nest confirm Steller's Jays and Common Ravens as predators of murrelet eggs. Of interest is the fact that both the jay and raven carried the egg away and left little evidence of the event. Without the video recordings, the exact cause of failure at this nest would have been unknown. We caution biologists and managers to be conservative in their estimates of nesting attempts and nesting success based solely on presence or absence of egg shell fragments and fecal rings. Also, our observations show that not all predation attempts by jays are successful and this is likely due to behaviors exhibited by murrelet adults and chicks during encounters with jays. Such observations suggest that Marbled Murrelets are more susceptible to predation by jays early in the incubation period when adult murrelets may miss a day of incubation or when the chicks are less than 14 days old. Based on these

observations, we encourage management and conservations efforts which protect against anthropogenic activities that increase predation risk, especially during vulnerable early periods of incubation.

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APPENDIX E

**SUMMARY OF MARBLED MURRELET MORTALITIES
DOCUMENTED IN 2001-2003, AND NECROPSIES
CONDUCTED IN 2003**

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The following is a narrative of each documented or suspected case of mortality during the radio-telemetry portion of the study described in Chapters 1 and 4. Additionally, we here describe some of the egg or chick loss that we could confirm via the video system between 2001 and 2003.

2001

In 2001, one Marbled Murrelet died with an active radio-transmitter. On 4 May 2001, the telemetry pilot advised us that a Marbled Murrelet was located on the beach just north of the Eureka/Arcata Airport, approximately 6 km south of Trinidad, California. The remains of the Marbled Murrelet were located 80 – 100 m from the water's edge. There were 3 distinct piles of feathers, each approximately 2 – 5 m apart. In addition to the feathers, we found the humerus, ulna and radius of what is believed to be the right wing. We also found the synsacrum including thoracic, and possibly cervical vertebrae, as well as 2 ribs (Humboldt State University Museum #8548).

The cause of death of this Marbled Murrelet was unknown. The bird was captured on 24 April, 2001. The bird was in captivity for a total of 60 minutes. The bird had a mass of 252 g. This mass was well above the average of birds we captured. After capture this male murrelet was located, by aerial telemetry and shore-based telemetry, at the mouth of Redwood Creek or offshore at Big Lagoon. For two days prior to mortality the bird was observed (via telemetry from shore) to be feeding north of Trinidad, and southwest of Patrick's Point.

2002

In 2002, four birds with radio-marks were either found dead or there were indications that they had died. In addition, one chick of a radio-marked bird died and one egg of a nest that was discovered in 2001 was taken by a predator.

The first presumed adult-mortality occurred between 2 - 4 June. The telemetry pilot advised us that a Marbled Murrelet was located close to shore approximately 7 km north of the Klamath River. On 5 June an attempt was made to locate the bird, but the rising tide restricted our access to the shoreline. We returned the following day and found the radio-transmitter at 1930 h. The transmitter was approximately 500 m north of the mouth of Wilson Creek, buried under rocks on the shore. No remains were found. This bird had been observed alive but close to shore three days prior to the pilot's notification.

The second presumed adult-mortality occurred between 2 and 6 June. We were advised by the telemetry pilot that a Marbled Murrelet was located on shore, south of the Smith River. An initial attempt to find the radio-transmitter was made on 6 June, but the transmitter was not found. The transmitter was found on 8 June, approximately 75 m from the shoreline, and 2 km south of the Smith River. No remains were found.

The third presumed adult-mortality occurred between 23 and 26 June. We were advised by the telemetry pilot that a Marbled Murrelet was located on the shore adjacent to Dry Lagoon. On 27 June we found the radio-transmitter under a tree, approximately 300 m from the shoreline. A 10 m x 10 m area was searched around the site where the transmitter was found, but no remains were found.

The fourth confirmed adult-mortality occurred on or about 9 July. We were advised by the telemetry pilot that a Marbled Murrelet was located on shore, south of Trinidad. The

radio transmitter was located at approximately 1000 h, approximately 50 m south of the Little River, and approximately 200 m from the ocean. Two wings were located as well as many down feathers and a few contour feathers. The humeral part of each wing was bare. The remaining parts of the wings were essentially intact. Automobile tire tracks, bicycle tire tracks, dog tracks, and various bird tracks were observed in the area. This murrelet raised a chick that fledged around 1 July.

We also detected the mortality of a chick that was approximately 20 days old. This chick had previously been exposed to the sound of an operating chainsaw approximately 10 days earlier (see Chapter 1). The chick did not flush during the disturbance trial. Video recordings made with the aid of a persistent video camera adjacent to the nest site indicated that the parents came to feed the chick at least once a day. Logistical difficulties prevented recordings when the chick was 17 – 20 days old, the time when the chick apparently died. A general necropsy did not detect any obvious signs for the cause of death.

The final mortality from 2002 was an egg at a nest that was first found in 2001. In 2002, we conducted an early morning survey on 13 May, between 0500h and 0700h. During this time at least one bird was seen flying into the suspected nest tree. A persistent video camera was placed in the nest tree on 29 May. The nest was monitored, via the video camera, intermittently between 29 May and 3 July, during which time one or two adults visited the nest site in the early morning, but no egg was detected. On 5 July, an adult was observed sitting at the nest site. An experimental disturbance trial (see Chapter 1) was conducted at the nest on 9 July, between 1600 h and 1930 h. At approximately 1925 h, a Steller's Jay (*Cyanocitta stelleri*) flew into the nest tree within approximately 1 m of the Marbled Murrelet nest. The jay hopped around in the branches for less than 20 sec. During this time

the incubating murrelet gaped, and followed the jay by turning its head. Video recordings from the persistent video camera indicated that later in the evening (approx. 2030 h) this adult left the nest site, and did not return before dark. On the morning of 10 July, both members of the pair arrived at the nest site at approximately 0500 h. Both birds left the nest site minutes later. Over the next 30 min both birds visited the nest site for a few minutes and then left. At approximately 0530 h one of the birds settled on the egg, and the other bird left the nest site. At approximately 1100 h the incubating adult left the nest site, and did not return. Approximately 90 min after the incubating murrelet left the nest site a Stellar's Jay came into view of the camera and pecked at the egg. After consuming some of the egg contents, the jay then flew off with the egg in its bill. No egg remains were observed at the site after the jay left.

2003

In 2003 we experienced three mortalities during capture. We also observed one confirmed mortality and two possible mortalities of radio-marked birds post-capture. The three mortalities that occurred during capture included two adult females that died during blood sampling, and an egg that broke after the female laid the egg in a transport box while she was being returned to the site of capture. We present here, for the purpose of improving our knowledge of Marbled Murrelet biology, the summaries of the necropsies for the two adults that died during the handling process. Necropsies were performed by Dr. L. J. Lowenstine, Veterinary Medical Teaching Hospital, University of California, Davis, California. Necropsies of the two adults were performed during the evening of 5 May, approximately 51 and 37 h post-mortem.

The first adult died at 0320 h on 1 May, during venipuncture to draw a blood sample. The bird weighed 204 g at capture, and had a brood patch score of 0 (see Sealy 1974), although a slight defeathering had occurred. There were no overt signs that the bird was in trouble prior to venipuncture. Gross inspection indicated that the bird was in excellent nutritional condition, and had excellent muscling. The coelomic cavity contained a small amount of fat. The pancreas was abundant, and spleen weighed 0.074 g, and measured 1.7 x 0.3 x 0.2 cm. The digestive tract was empty. Ureters for both kidneys contained thick white urates. The airsacs were intact and transparent, and no gross lesions were detected in the respiratory tract. The heart weighed 3.69 g. The atria, jugular veins, and abdominal veins were congested. Remnants of the bursa or thymus could not be detected. The femur and tibia did not contain marrow, were relatively small in diameter and dense. Sections of the tibiotarsus contained cortex and medullary trabeculae comprised of dense compact bone. There was abundant medullary bone with amphophilic to basophilic tide marks that are typical for hens during egg production.

In addition this bird had mild parasitism, with focally severe proventriculitis. Several regions of the digestive tract had mild to acute signs of either lymphocytic, heterophilic and/or granulocytic serositis. Coccidiosis and transmural inflammatory lesions, both of which are common in seabirds, and may have resulted from the penetration of foreign bodies (such as fish bones) or parasite migration, or both. The oviduct of this bird was well developed, and a well yolked pre-ovulatory follicle was present in the ovary.

The exact cause of death for this bird could not be ascertained from gross examination, or histologic examination. The acute hemorrhage in the trachea and atelectasis in the lungs suggest these may have been associated with the death of this bird. The lack of

reaction, however, and the acute nature of these lesions, suggest they could also have been caused by agonal breathing resulting from another cause. The congestion of blood vessels is indicative of pooling of blood associated with terminal shock. However, such congestion is also associated with hyperthermia, which may have occurred during the handling process.

The second murrelet died during processing on 2 May 2003 at 0010 h, again during venipuncture to draw a blood sample. The bird weighed 260 g at capture, and had a brood patch score of 3. There were no overt signs that the bird was in trouble prior to venipuncture. Gross inspection indicated that the bird was in excellent nutritional condition, with a moderate amount of dermal and subcutaneous fat, and had excellent muscling. The digestive tract was empty except for a small amount of tan-cream mucoid material. The liver weighed 1.9 g. The spleen weighed 0.137 g, and was slightly larger than expected ($2.0 \times 0.4 \times 0.3$ cm). The kidneys had a combined weight of 4.158 g, and no lesions were observed. The airsacs were intact and transparent, and no gross lesions were detected in the respiratory tract. The heart weighed 4.01 g. The atria and jugular veins were congested. Remnants of the bursa or thymus could not be detected. The brain weighed 2.05 g and vessels were congested. Inflammatory changes in the digestive tract were noted. The oviduct was well developed, and contained a partially-shelled egg with a mass of 27.5 g. The ovary contained a few small pre-hierarchical follicles. Fertility of the egg could not be confirmed.

In addition, a female murrelet captured at 0205 h on 13 May, laid an egg in the transport boat during transport back to the capture site. This female weighed 240 g at capture, and had a brood patch score of 3. The egg broke in the plastic tub during transport.

The first presumed mortality of a radio-marked adult murrelet occurred between 4 - 5 May. The telemetry pilot advised us on 4 May that a Marbled Murrelet (female) was located

close to shore approximately 8 km south of Crescent City, and 5 km north of Wilson's Creek. As the location was inaccessible we could not determine whether the murrelet had been depredated or that the radio-transmitter fell off the bird. The radio-transmitter was never recovered.

The second presumed adult mortality of a radio-marked adult occurred between 25 and 27 May. We were advised by the telemetry pilot on 27 May that a Marbled Murrelet (female) was located on the shore 0.5 km north of the Arcata Airport. We located the radio-transmitter on 27 May, approximately 100 m from shore. We did not find any Marbled Murrelet remains.

The third adult mortality occurred between 25 and 26 May. On 27 May, we were advised by the telemetry pilot that a Marbled Murrelet was likely located on shore. The transmitter and presumably the head of the male murrelet that carried the transmitter were recovered on 28 May.